Annual Report

Phase 3B Yr2

June 1, 2024 | DE–EE0007080 | University of Utah

UTAHFORGE

Phase 3B Year 2 Annual Report

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

Utah FORGE

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EXECUTIVE SUMMARY

This report describes Phase 3B Year 2 activities conducted by Utah FORGE. In previous phases, three deep wells 56-32, 58-32 and 78B-32, and the injection well, 16A(78)-32 were drilled. A permanent seismic monitoring network consisting of two rings of borehole geophones, a 1000 ft well (FORK), and a DAS cable in 78B-32 was installed. Three stages near the toe of the injection well were stimulated and the resulting seismic cloud was monitored. The network was augmented with temporary geophone strings in the three deep wells and nodal arrays during drilling and stimulation activities.

Major accomplishments of the Utah FORGE team during Phase 3B include:

1. Drilling and successfully completing the production well 16B(78)-32
2. Successfully stimulating wells 16A(78)-32 and 16B(78)-32
3. Achieving commercial production rates as a result of the stimulation
4. Deploying three fiber optic cables in the annulus of the production casing and successfully monitoring seismicity, strain, temperature and pressure
5. Effectively monitored seismicity during stimulation activities using surface nodals and deep geophone strings
6. Deployment of R&D experiments by Battelle, University of Texas-Austin, Rice University, Clemson University and PetroQuip at the Utah FORGE site
7. Drilling a highly productive water supply well on the 58-32 pad
8. Selection of thirteen new R&D projects for funding. Ten projects were successfully negotiated and ready to start in April 2024
9. Expansion of Outreach and Communication activities
10. Placing more than 277 GB of data to the Geothermal Data Repository (GDR)

Utah FORGE remains the most thoroughly documented geothermal site in the world and the only site dedicated to testing tools and technologies for EGS development.

A. OVERVIEW OF 3B YEAR 2 ANNUAL ACTIVITIES

During Phase 3B, activity at the Utah FORGE site centered on the drilling of production well 16B(78)-32 and reservoir creation. Well 16B(78)-32 was drilled parallel and 300 ft above the injection well 16A(78)-32. The production well penetrated the seismic cloud generated during the three-stage stimulation of the injection well. Well 16B(78)-32 was drilled to a measured depth of 10,947 ft and a true vertical depth of 8,391 ft. The temperature at total depth is estimated to be ~ 430^{o}F. Approximately 700 ft of the well was left uncased. A complete suite of logs was collected and made available through GDR. Improved rates of penetration, compared to previous wells, were achieved through the use of PDC bits and optimizing drilling parameters based on real-time monitoring of Mechanical Specific Energy. ROPs exceeding 100-120 ft/hr were achieved.

Tests of rotary steerable systems, particle drilling and insulated drill pipe were conducted. The insulted drill pipe proved effective in reducing temperatures. Neither the rotary steerable systems or the particle drilling performed as well as expected.

Utah FORGE assisted several of the R&D projects with permitting and tool deployment. Three fiber optic cables were successfully deployed in the annulus of the 7-inch casing cemented in well 16B(78)-32. Two of the cables, a Shell flat pack and a pressure-temperature gauge were installed as part of University of Texas-Austin's R&D program. The third cable was provided by Silixa under Rice University's R&D program. The cables allowed monitoring of temperature, seismicity, strain and pressure. Data were obtained during the stimulation of 16A/B(78)-32 in April 2024 at Utah FORGE (Fig. 1) and during Fervo Energy's stimulation program conducted in March 2024. In addition, Rice University deployed four Stationary Orbital Vibrators (SOVs). Clemson University deployed two high resolution strainmeters. Battelle conducted a series of minifrac tests in the vertical section of 16B(78)-32. PetroQuip's locking bridge plug was successfully installed. LBNL will test their VEMP tool in 78B-32 in May 2024. Stanford University is scheduled to deploy its chemical detection tool in 16B(78)-32 during the long-term circulation test in 2024, and Rice University will deploy its intervention fiber optic cable in 16B(78)-32 to assess contributions to the production fluid from the open hole section of the well. Core was made available to all of the R&D projects requesting samples and to several non-funded projects.

A successful commercial scale stimulation was conducted. Both the injection (16A(78)-32) and production (16B(78)-32) wells were stimulated. The stimulation of 16A(78)-32 included a refrac of the three stages stimulated in April 2022, in addition to seven additional stages. Four stages were stimulated in 16B(78)-32. The stimulation program was designed to test the application and mobility of silica sand and lightweight proppant, frac plug designs, slickwater vs viscosified fluid, the number and spacing of clusters within each stage, novel tracers, and the application of fiber optic cables for monitoring. Stages consisting of one, four, and eight clusters were stimulated. All of the clusters were propped. The maximum injection rate was 80 bpm.

The Utah FORGE stimulation was monitored using downhole geophones in wells 56-32, 58-32, FORK and 78B-32, augmented by fiber optic cables in wells 16B(78)-32, and 78B-32, and surface nodal arrays. A fiber optic cable was installed in the casing of 58B-32. The cable will be integrated with 3-component geophones once geophone testing is complete. The maximum magnitude detected was 1.9. The data suggest the fracs grew symmetrically, forming a circular cloud of events with approximately equal dimensions above and below the injection well.

Strain measurements recorded on the fiber optic cable in 16B(78)-32 throughout the stimulation and circulation tests proved extremely useful. The data were of exceptional quality. The measurements provided information on the location and migration of the strain fronts during the stimulation; information that was critical for locating the perforation depths in 16B(78)-32. Strain data collected during the circulation portion of the test suggest the lower perforations in 16A(78)-32 were contributing to fluid production from 16B(78)-32. This information could not be obtained from spinner data due to logistical issues.

A nine-hour circulation test was conducted following the stimulation. At the end of the test, the production well was producing ~8.2 bpm at a temperature of 282°F while ~13 bpm was being injected, despite the limited number of stimulated stages. Overall, ~70% of the injected fluid was recovered, demonstrating commercial success of the stimulation program.

The conceptual geologic model has been updated. Characterization of core and cuttings has shown that soluble phases, including halite in fractures, and anhydrite as fracture and pore space fillings occur in the reservoir. Dissolution of these phases likely contributed to the pronounced increase in dissolved solids in the flowback waters from the April 2022 stimulation of well 16A(78)-32. Four types of fractures are observed in the core from 16B(78)-32 collected from depths expected to contain fractures stimulated in April 2022, including: 1) planar, 2) mineralized natural; 3) irregular; and 4) curviplanar. Comparison of core samples with FMI logs suggests the FMI logs overinterpret the abundance of fractures.

Major improvements were made to the infrastructure. Electric power was brought to the fiber optic data acquisition trailers and the 16B(78)-32 wellhead on the 16A/B(78)-32 pad, and to the groundwater well on the 58-32 pad. Fiber optic lines were trenched between the well pads to allow for high data throughputs and real time seismic monitoring across the site. A highly productive water well (58B-32) was drilled on the 58-32 pad. The well produces ~260 gpm of water from an aquifer located at a depth of ~700 to 920 ft. Storage facilities capable of holding 200,000 barrels of water were located on the east side of the 16A/B(78)-32 pad and filled with water from the well for the stimulation. No external source of water was required.

Thirteen R&D projects in five topic areas were selected for negotiation: Adaptive induced seismicity monitoring protocols; Alternative stimulation schemes; Field-scale experiments to measure heat-sweep efficiency; High temperature proppants and; Multiset straddle packers for open hole operations. At the time of this report, ten of the thirteen projects have been negotiated.

InSAR, gravity, water levels and GPS monitoring continued on approximately a quarterly basis. No changes due to the stimulation were identified.

We continued to share technical information on Utah FORGE with the scientific community through the Utah FORGE website, conferences and publications, field trips, wiki pages and the DOE Geothermal Data Repository (GDR). More than 277 GBytes of data have been uploaded to the GDR since the project was initiated.

Public outreach continues to be a priority for Utah FORGE. 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 (X, Facebook, LinkedIn, Instagram and, YouTube), subscription-based email distribution, webinars. Information about the project is also offered at public events and during scientific forums. Wiki pages developed for Utah FORGE and each of the R&D projects have been populated with new information. Scientific data are available through numerous publications, conference proceedings (refer to the Utah FORGE website), the wiki pages, and the Geothermal Data Repository (GDR).

Figure A-1. *Drone shot looking south taken during the stimulation of wells 16A/B(78)-32. The rigs are set up on the injection and production wells. The two large pits adjacent to the well pad hold a total of 200,000 barrels. They will provide water storage during future drilling, and stimulation and circulation testing. The pit in the upper left belongs to Fervo Energy.*

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 drill pad

- Earthwork
    - A 50 by 50 ft gravel pad was installed and compacted below the rig footprint.
    - Construction of the cellar, mouse hole and rat hole before rig move in.
    - The 16A/B pad was regraded prior to rig move in.
- Power was trenched to the north side of the sump for the Rice/Silixa and UT Austin/Shell fiber optic data acquisition trailers and conduit was installed between the trailers and the 16B(78)-32 well head to safely route the fiber optic cables.
- A fiber junction box and 120V power feed were installed at the 16B(78)-32 wellhead.
- Windsocks were installed on the 16A/B pad prior to spudding 16B(78)-32.
- Temporary housing was placed on the 16A/B pad to support drilling operations and tied into the electrical grid and temporary water/sewer systems.
- Signage was replaced that had been destroyed by weather and livestock.
- 16B(78)-32 wellhead repair (probably covered elsewhere, I think this is the restacking of the wellhead to reroute the fiber optic cables, I don't have many details).
- Upon completion of well 16B(78)-32 the command center trailer was repositioned to its long-term location on the north side of the 16A/B(78)-32 drill pad, near the entrance. New electric service was run to the trailer and water/sewer tanks were installed.
- Cleaned up site after rig move off.

Well 58-32 drill pad

- Power was routed from the meter base at the NE corner of the 58-32 drill pad to where the mud cleaning system for the USGS's drill rig was located for the drilling of the water well (Figure B.1-1). The mud cleaning system will be powered by the grid rather than a diesel generator. Upon completion of well 58B-32 power was trenched to the wellhead to power the downhole pump.

- Re-located casing and surplus materials on 58-32 to prepare for water well drilling.
- A 14.75-inch diameter water supply well was drilled in December 2023 and tested in February 2024. The stratigraphy penetrated alluvial silt, sand and gravel, with a highly productive interval between 700 and 920 ft depth (Figure B.1-2); the static water level is 484 ft below surface. A submersible pump was installed at 684 ft depth, pump rates of 260-280 gpm were attained, and the estimated transmissivity is 42,840-88,290 ft^2/day. The water permit annual allowance is 49.55 Acre feet which is equivalent to 384,400 bbl (16.14 million gallons).

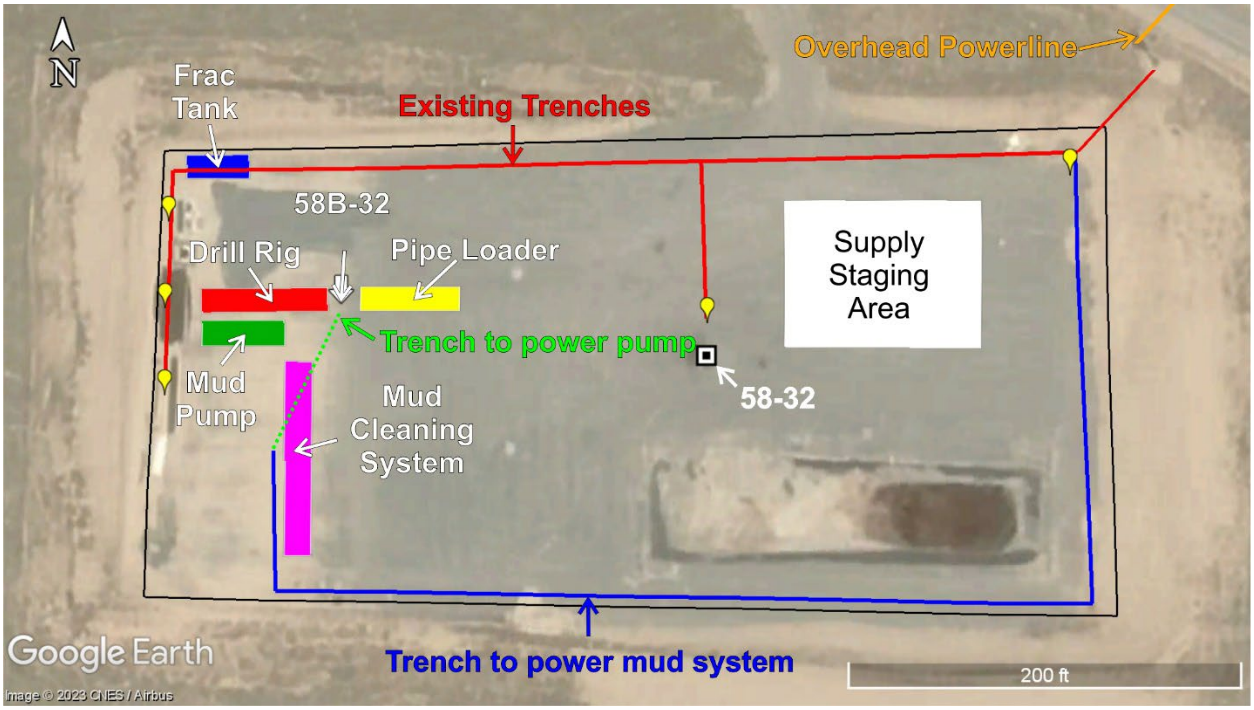


Figure B.1-1. *Map of the 58-32/58B-32 drill pad showing existing (orange and red), and new (blue & green) electric infrastructure and the layout for the USGS's water well drilling operations.*

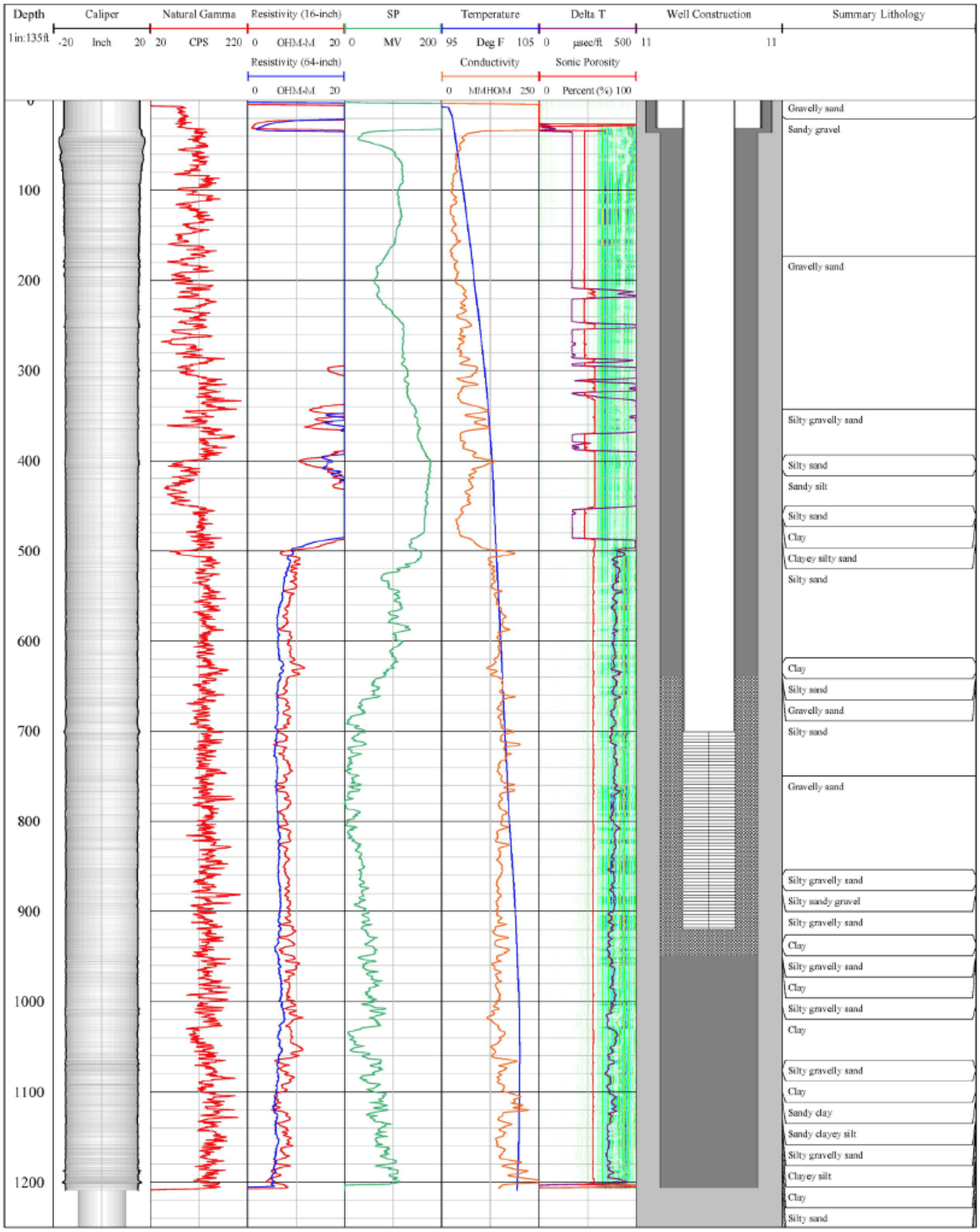


Figure B.1-2. *Construction diagram, geophysical logs, and stratigraphy for water supply well 58B-32, drilled, completed, and tested by the US Geological Survey. The well was drilled to 1200 ft depth, with 8.625 inch casing to 700 ft depth, and stainless-steel screen from 700 to 920 ft depth.*

Stimulation and Circulation Testing

- Two lined lakes were constructed to facilitate stimulation and circulation activities. The lined lakes have capacities of 75,000 and 125,000 bbl. To construct the lakes the total volume of cut was 25,735 yd^3 and the total fill was 19,540 yd^3. Diagrams of the lakes are shown in Figure B.1-3.
- An 8 ft fence was erected around the perimeter of the two lined lakes to keep out cattle and wildlife.
- The southern edge of the 16A/B(78)-32 drill pad was expanded and a road was constructed between the drill pad and the lined lakes.
- Four large harpoon tanks were erected for water storage on the 58-32 and 16A/B(78)-32 drill pads.
- A 6” water line was installed to transfer water from well 58B-32 to the lined lakes and harpoon tanks.
- In order to facilitate high data throughputs for real time seismic monitoring across the site, fiber optic cables were trenched between the 78B-32, 58-32, 56-32 and 16A/B(78)-32 drill pads (Figure B.1-4). In addition, a conduit was trenched between the fiber optic data acquisition trailers and the command center trailer. Seismic data from across the site can be monitored from the command center trailer.
- Power has been run to SOVs 2 and 3 adjacent to the 16A/B(78)-32 and 56-32 drill pads, negating the need for generators (Figure B.1-5).
- Nine cameras have been installed across the drill pads at the Utah FORGE site to enable remote monitoring and documentation of visitation.
- The sumps on the 58-32 and 16A/B(78)-32 drill pads were cleaned out.
- Temporary housing and office trailers were placed on the 16A/B(78)-32 and 78B-32 drill pads. These were connected to the power grid and temporary water/sewer tanks.

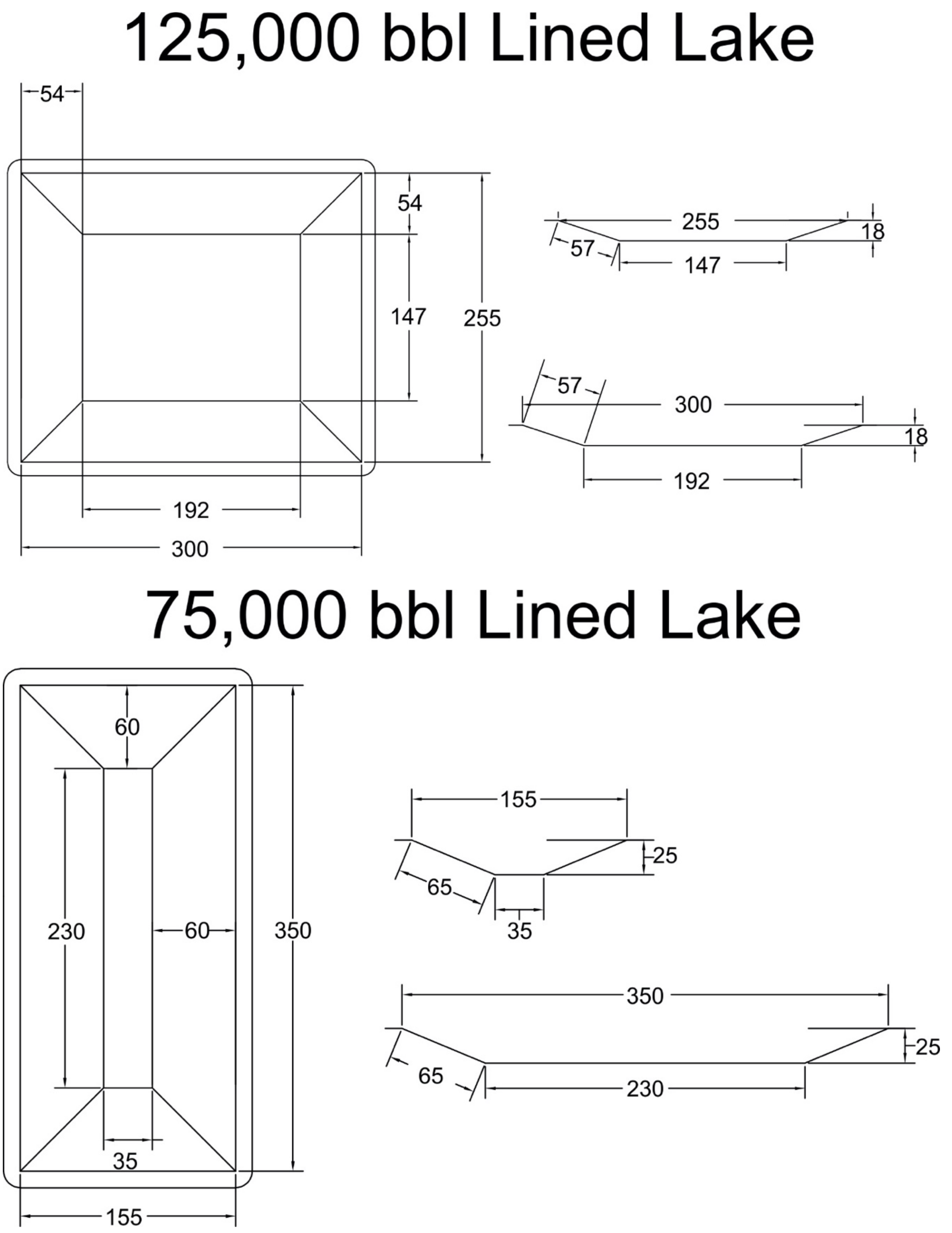


Figure B.1-3. *Dimensions of the lined lakes in plan and cross-section.*

__Figure B.1-4.__ Trenches by fiber optic cable run. Approximate lengths in legend.

__Figure B.1-5.__ Map showing the locations of SOVs 2 and 3 adjacent to the 16A/B(78)-32 and 56-32 drill pads, which have been connected to grid power.

B.2 CIRCULATION PROGRAM: JULY 4/5, 2023, AND JULY 18/19, 2023

Background

The aim was to implement low-rate injection to interrogate the reservoir between the injection and the production wells, 16A(78)-32 and 16B(78)-32, respectively. In addition, it was desirable to assess if interconnection had resulted from the first fracturing campaign (April 2022) and to determine the partitioning of flow between the three frac stages previously pumped. Consequently, the circulation testing was designed to use low enough injection rates so that limited new hydraulic fracturing would be created and to pump volumes less than each stage of the April 2022 fracture stages – for the same reason.

July 4, 2023 – Circulation 1, Day 1

SLB was rigged up with one MPF-331 CT Pump Truck to well 16A(78)-32. Tracer injection was set up for addition into the suction manifold of the CT Pump Truck at a constant concentration using 2,7-nds. The treating pressure at the 16A(78)-32 wellhead is shown for July 4, 2023, in Figures B.2-1 and B.2-2. As can be seen, injection started at 0.5 bpm, was later increased to 2.5 bpm, and finally was increased to a maximum rate of 5 bpm. The single pumping unit could not achieve 5 bpm at the wellhead pressure encountered and the second (standby) unit was rigged up and brought on line. Subsequently, the first pumping unit was shut down due to mechanical issues and the last part of the first day was carried out with a single pumping unit. Notice several features:

1) Wellhead pressure did not build rapidly at 0.5 bpm. This is unlike the initial openhole DFIT and shear stimulation treatments which built and opened rapidly. This is not unexpected because additional frac stages have been pumped since those treatments were pumped.
2) There could have been some limited fill-up of casing fluid volume at the start of pumping. The cause of the rapid pressure decline for the slug tests performed several days prior is uncertain since the well has held pressure since pumping terminated – indicating almost no reservoir permeability – as expected from lack of drilling mud losses while drilling both wells.
3) When the injection rate is increased to 5 bpm, the wellhead pressure builds more rapidly and rolls over at about 4,486 psi, well above the previously determined fracture gradient considering a wellbore filled with water.

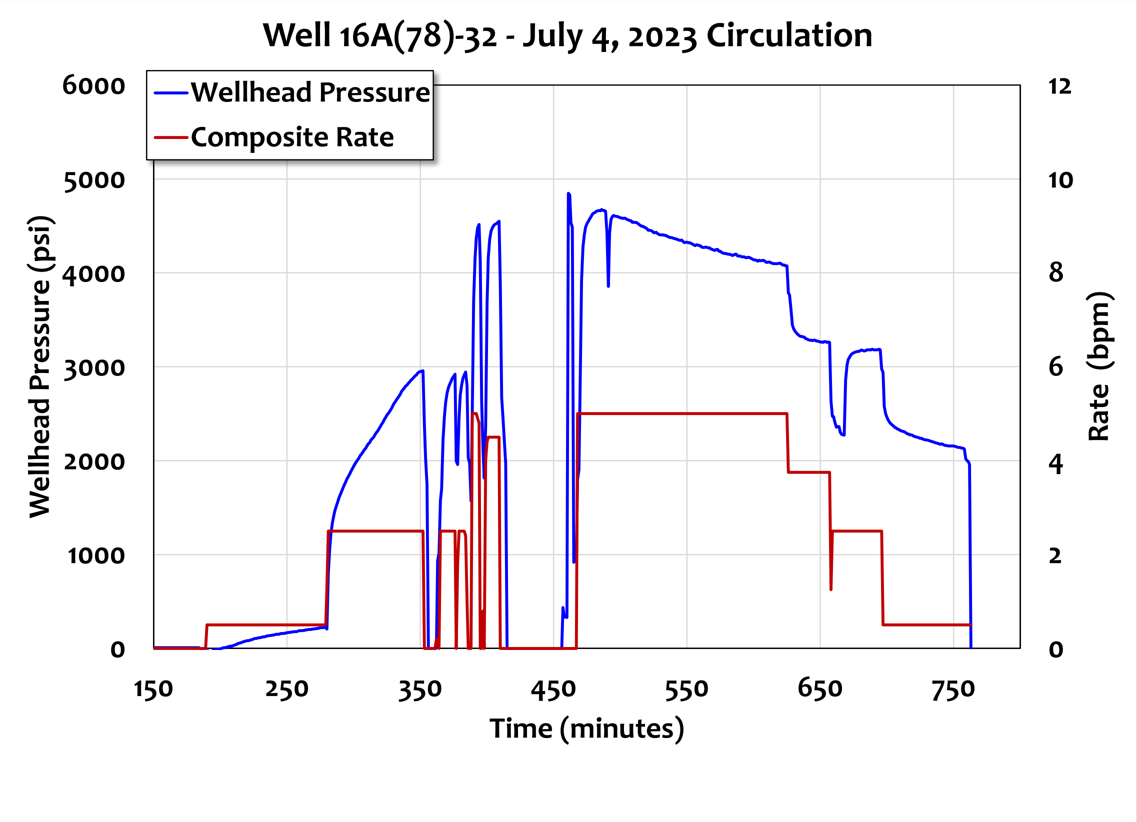


Figure B.2-1. *Treating pressure and total wellhead injection rate for pumping into Well 16A(78)-32 on July 4, 2023 supplied by SLB.*

The wellhead pressure on Well 16B(78)-32 built slowly while the flow line was closed. When the wellhead pressure reached 200 psi a throttling valve in the flow line was opened to maintain 200 psi as back-pressure by flowing to the pit. Late in the pumping, the back pressure was reduced to 100 psi. The wellhead pressure in Well 16B(78)-32 is shown in Figure B.2-3.

Note that the raw SLB data is on Pacific time.

Also, note the reduction in treating pressure with time. Some of this may be due to an increase in the hydrostatic head as cold fluid enters the wellbore, to thermoelastic aperture increase, to possible precipitate removal, or a reduction in tortuosity.

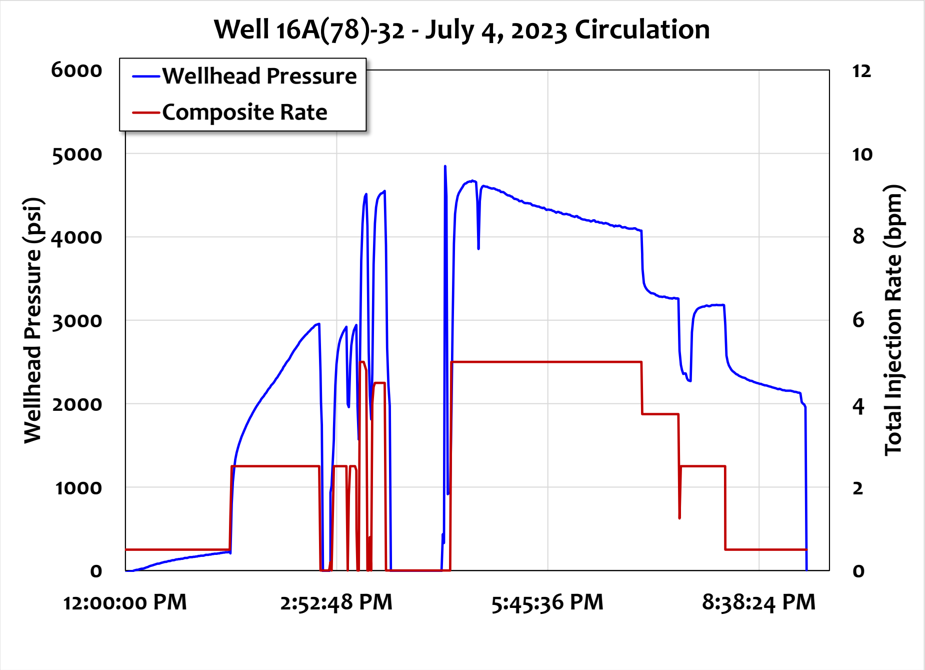


Figure B.2-2. *Treating pressure and total wellhead injection rate for pumping into Well 16A(78)-32 on July 4, 2023. The original SLB data were on Pacific time. They have been converted to Mountain Time here.*

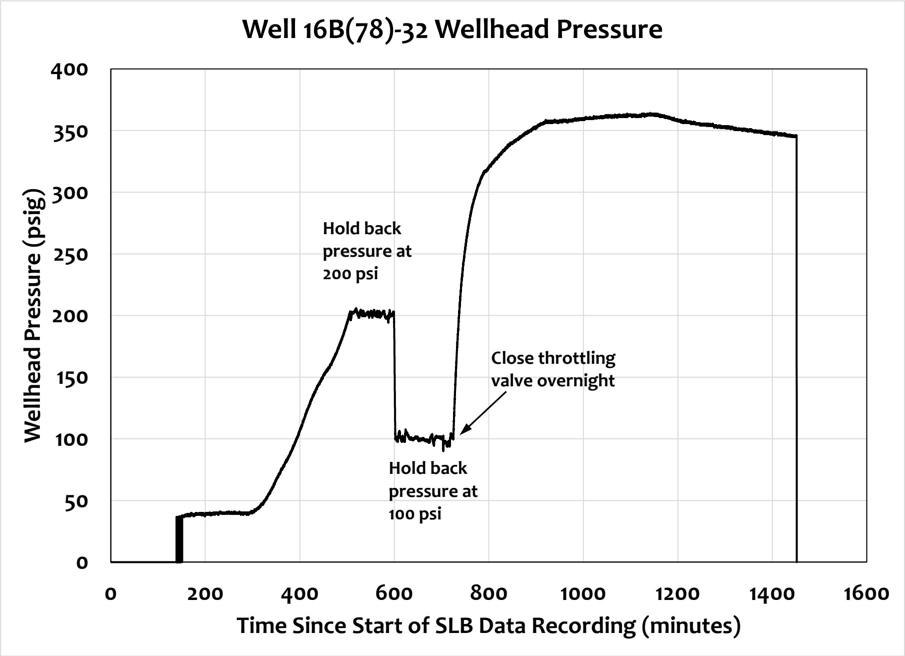


Figure B.2-3. *Pressure response at the throttling valve in Well 16B(78)-32. Per plan, pressure built to 200 psi and was maintained at this level for approximately 100 minutes. Then the pressure was reduced to 100 psi.*

During the injection, there was flow from the well to the pit, but it was below the lower threshold for the flow meters placed in the flow line from well 16B(78)-32 – per manufacturer, this is 1 bpm.

July 5, 2023 – Circulation 1, Day 2

The injection program on July 5 was to pump for 6 hours at a constant injection rate of 5 bpm. This program was extended by 20 minutes to perform extra flow measurements. The pressure and rate chronology for the injection well (16A(78)-32) is shown in Figure B.2-4.

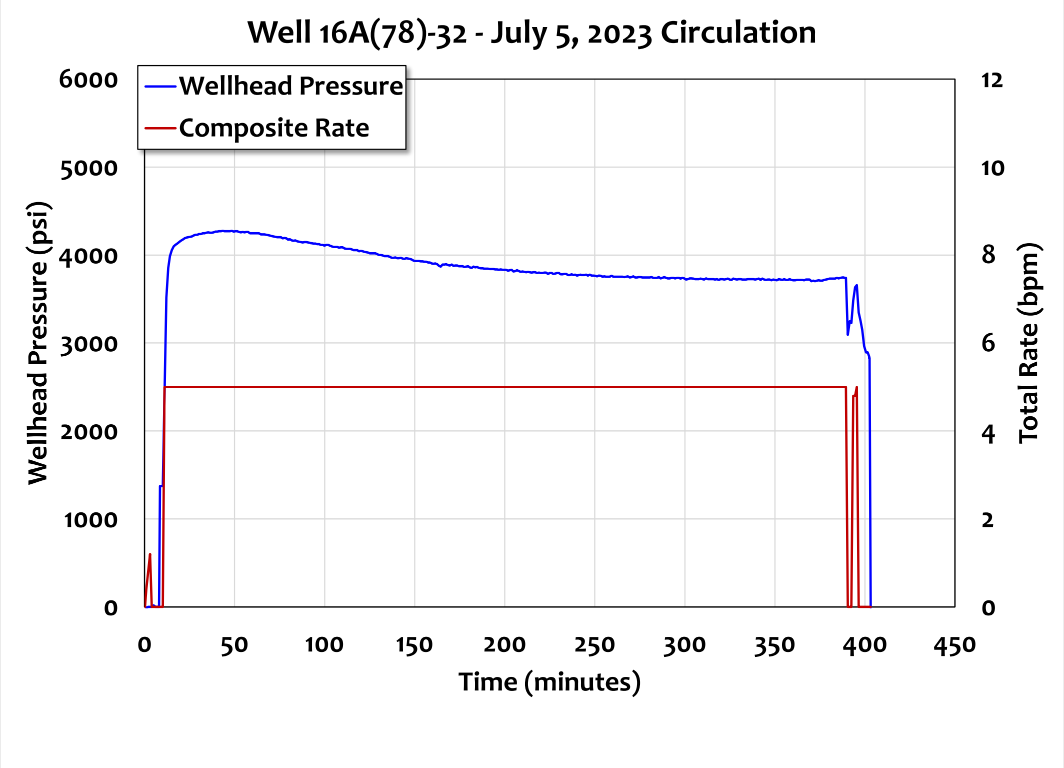


Figure B.2-4. *Wellhead pressure in Well 16A(78)-32, as pumped on July 5, 2023. The ISIP is about 2,900 psi, suggesting a frac gradient of somewhat less than 0.77 psi/ft which is consistent with earlier measurements (Jan 2021) on this well for the original openhole DFIT.*

Figure B.2-5 shows the wellhead pressure response on the production well (16B(78)-32). Figure B.2-6 shows flow measurements. These were made by timing flow into a five-gallon bucket. Flow was below the detection threshold of the flow meters except during surge cycles. The measured flows are also tabulated in Table B.2-1.

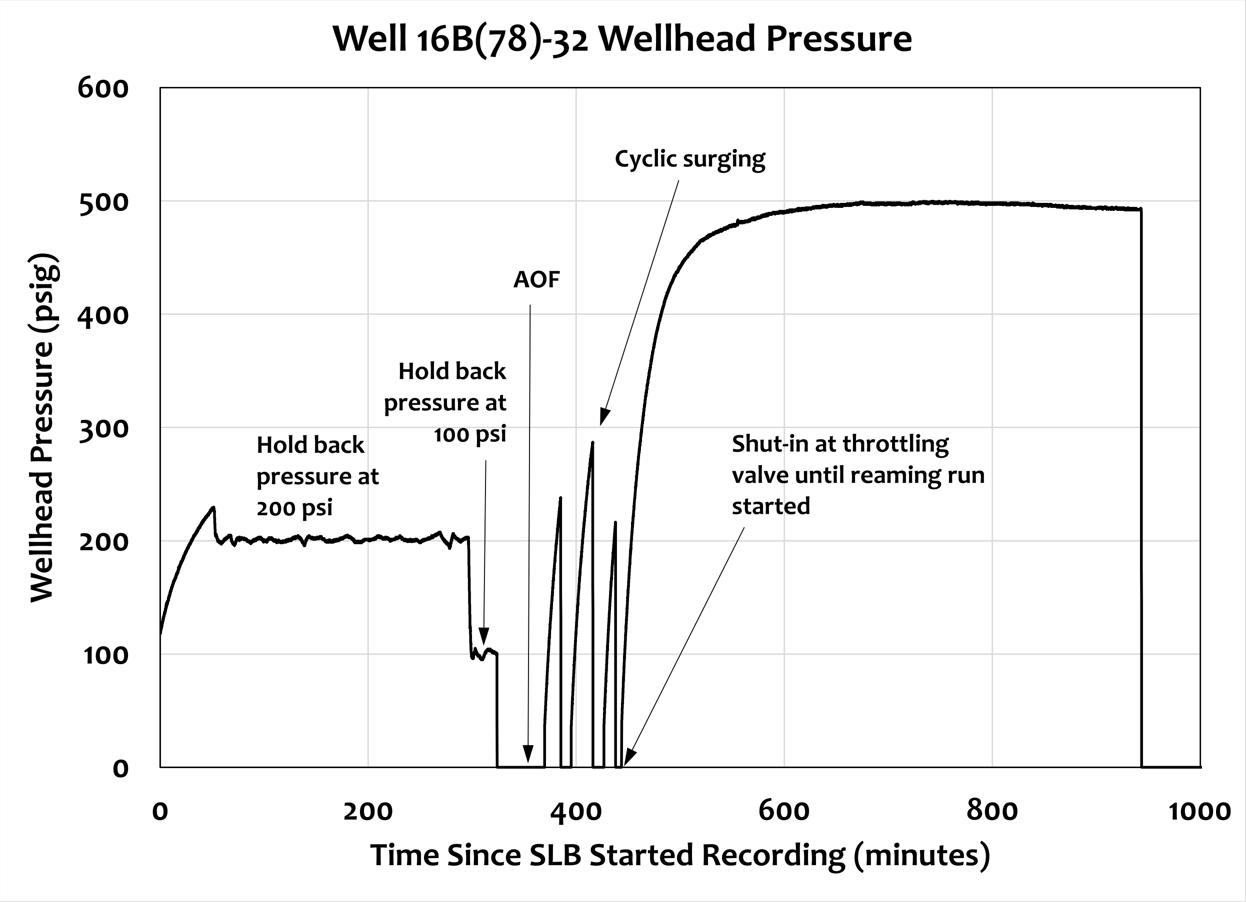


Figure B.2-5. *Pressure response upstream of the throttling valve on Well 16B(78)-32. Of note, the back pressure was systematically reduced and there were some buildup-surge cycles (although it is unlikely that this was felt substantially downhole).*

Table B.2-1. *July 5 Flow Measurements (16B(78)-32).*

Date	Time (hr: min)	Time (minutes since midnight. July 3)	Rate (bph)
July 5, 2023	10:45 a.m.	3,525	2.38
July 5, 2023	11:45 a.m.	3,595	4.20
July 5, 2023	01:40 p.m.	3,700	4.76
July 5, 2023	02:17 p.m.	3,737	5.95
July 5, 2023	02:44 p.m.	3,764	8.92
July 5, 2023	02:50 p.m.	3,770	10.28
July 5, 2023	03:20 p.m.	3,800	9.12

July 5, 2023	03:54 p.m.	3,834	10.45
July 5, 2023	04:25 p.m.	3,865	12.38
July 5, 2023	04:45 p.m.	3,885	14.77
July 6, 2023	01:50 a.m.	4,431	7.93

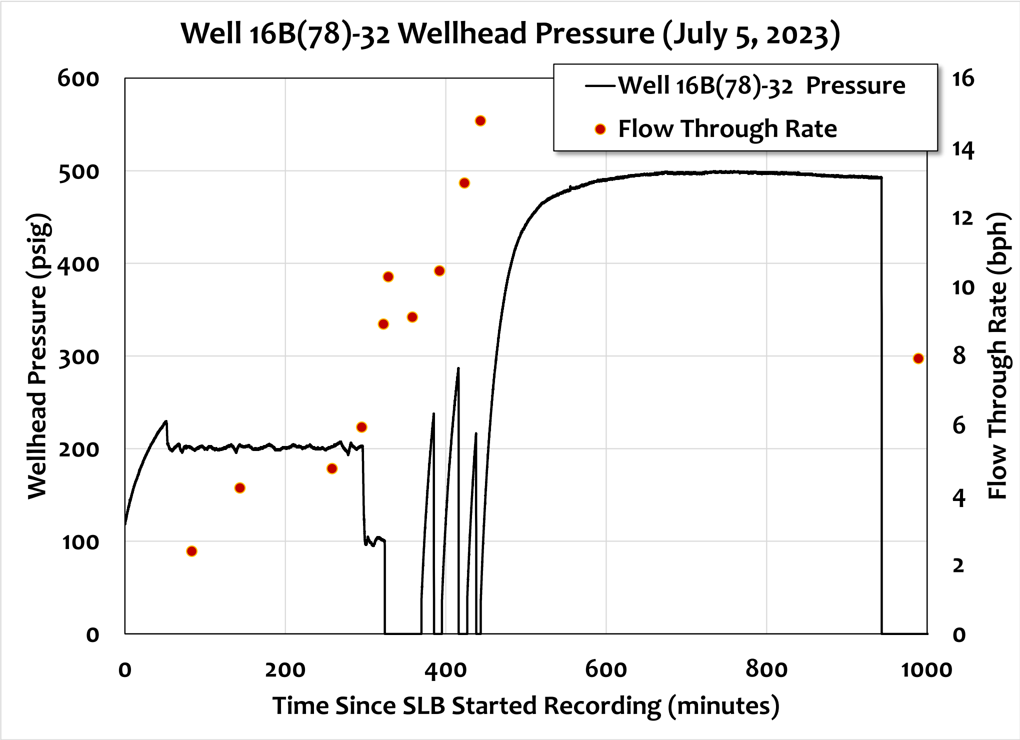


Figure B.2-6. *The July 5, 2023, pressure response is shown as well as measured rates of flow through going to the pit from Well 16B(78)-32.*

Composite Plots and Sampling

Composite plots for both wells are shown in Figures B.2-7 and B.2-8. In addition, bottoms-up samples from Well 16B(78)-32, collected after the circulation testing showed elevated levels of chlorides. These samples are summarized in Table B.2-2. The following is extracted and slightly modified from an email from A.T. Kuhns with ExLog.

A dummy casing run was carried out where wellbore circulation was done at 10,215 ft MD and annular outflow samples were caught. Subsequently, additional samples were caught while reaming at depths from 10,000 to 10,300 ft MD. During preparation for catching the fluid samples from the deep circulation while reaming (10,000 – 10,300 ft MD) the drill fluids representative (Sean Hart, with Sinclair Drilling Fluids) completed the scheduled mud check and found the chloride content had increased from approximately 500 - 550 ppm established content to approximately 800 ppm. Two full sets (1 – 60 ml, 1 – 250 ml sample bottles) of fluid samples were taken from the suction tank and inventoried as circulation from the deep section was at the shakers.

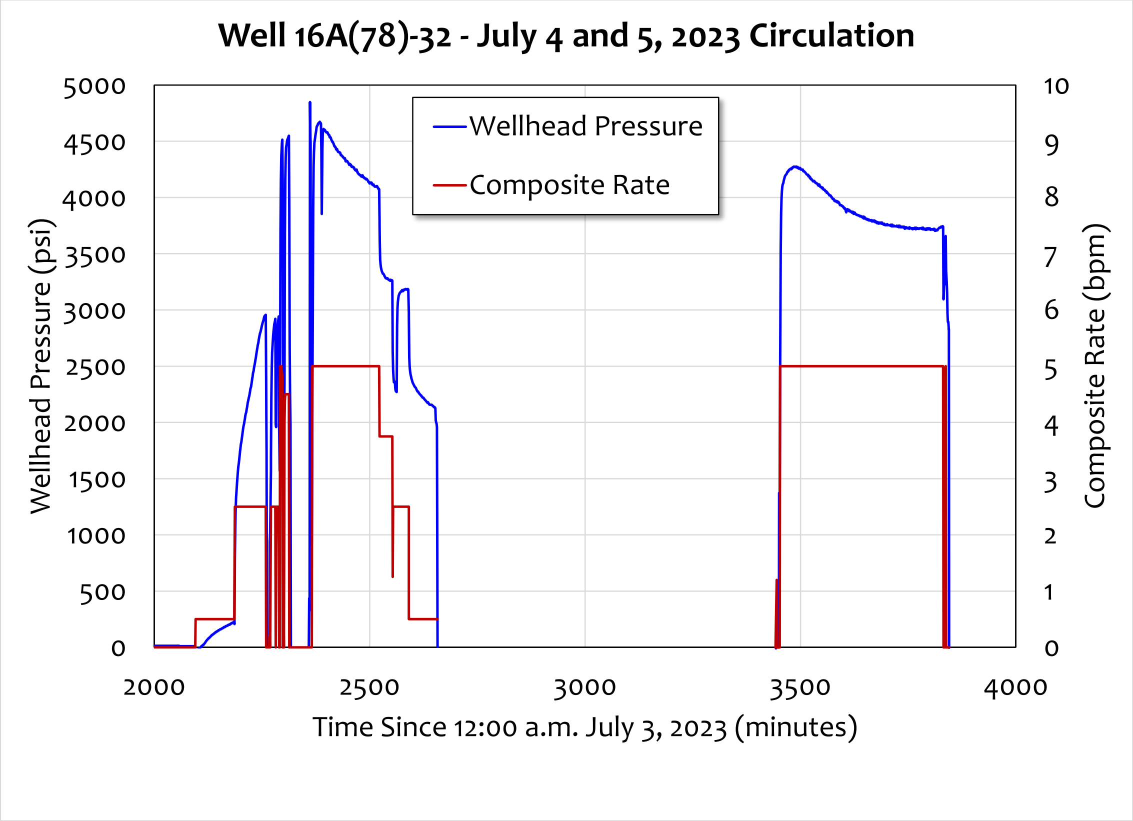


Figure B.2-7. *Wellhead pressure and pumping rate for Well 16A(78)-32.*

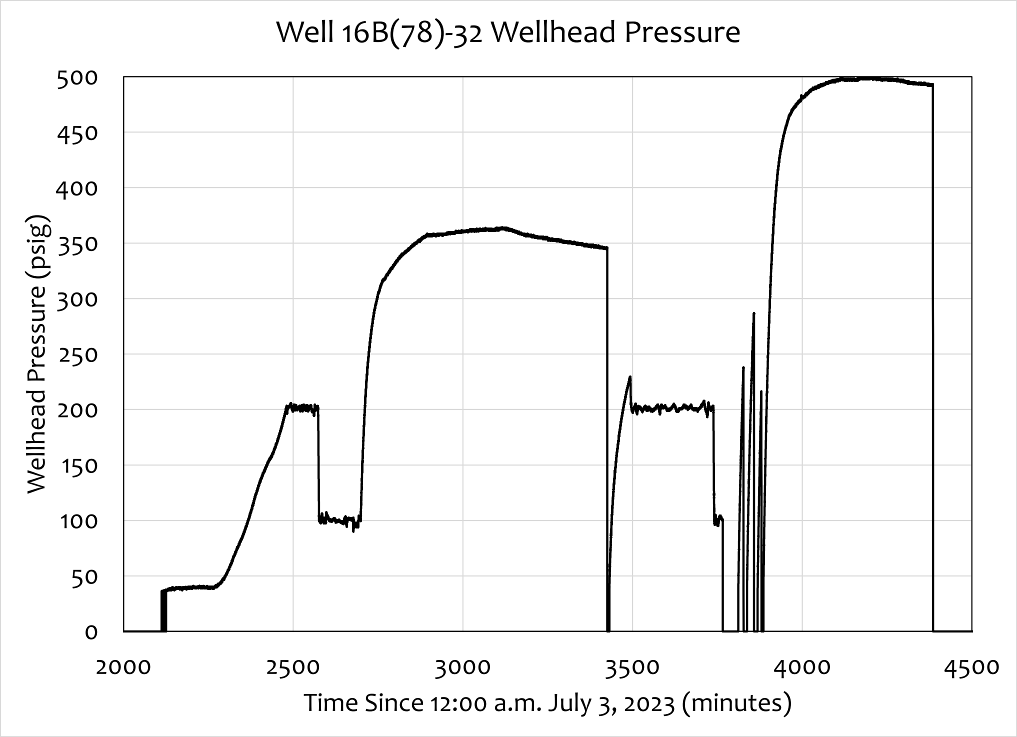


Figure B.2-8. *Wellhead Pressure chronology at Well 16B(78)-32 for injections on July 4 - July 5, 2023.*

The first samples of the deep reaming were taken at 13:00 hr. Then two 15-minute interval samples followed. After the two 15-minute intervals were complete as a correlation to the deep casing set samples interval, 10-minute samples were taken for a total of two bottoms-up volumes after the 13:30 hr catch. After completion of the sample catch, all samples from the casing circulation and the deep interval reaming were tested for chloride content.

The purpose of the chloride testing was based on the reported increase in chlorides on flowback of the Well 16A(78)-32 stimulations and by analogy that elevated chlorides in a sample from Well 16B(78)-32 may be an indicator of flow-through fluid from the intervals stimulated and pumped under pressure with tracer-bearing water. This would be diagnostic of a hydraulically induced connection between the wells.

The chloride test results for both circulation events are shown in Tables B.2-3 through 5. Testing parameters were improved with new titration chemicals. A new background of chloride values was established with the new chemicals at a baseline of 500 ppm. The samples were all tested with the same chemical from the same bottle. Of the total samples below, the two that tested highest in chloride content dropped out suspended solids within hours of acquisition.

Table B.2-6 includes chloride concentration data acquired while circulating for cooldown before cementing (July 12 and 13, 2023).

Table B.2-3. *Field-measured chloride Content for circulation at the intended 7" casing setting depth of 10,215 ft MD*

Time	Chloride Concentration (ppm)
15:15	500
15:30	4,500
15:45	600
16:00	500
16:15	600
16:30	550
16:43	500

Table B.2-4. *Field-Measured Chloride Content for circulation while reaming from 10,000 to 10,300 ft MD*

Time	Chloride Concentration (ppm)	Time	Chloride Concentration (ppm)
13:00	1,050	14:30	950
13:15	900	14:40	950
13:30	850	14:50	1,150
13:40	1,100	15:00	1,200
13:50	2,850	15:10	1,200
14:00	1,000	15:20	1,200
14:10	950	15:30	1,150
14:20	900	15:40	1,050

Table B.2-5. *Field-measured chloride Content for circulation before spotting bentonite on 7/8/23 between 17:30 hr and 18:55 hr*

Time	Depth (ft MD)	Chloride Concentration (ppm)	Time	Depth (ft MD)	Chloride Concentration (ppm)
17:30	10,910	1,200	18:20	10,920	1,100
17:45	10,866	1,450	18:25	10,931	1,100

17:50	10,900	4,000	18:30	10,862	1,100
17:55	10,926	1,800	18:35	10,873	1,100
18:00	10,859	1,600	18:40	10,893	1,150
18:05	10,873	1,150	18:45	10,910	1,150
18:10	10,890	1,200	18:50	10,930	1,250
18:15	10,906	1,150	18:55	10,847	1,400

Table B.2-6. *Field-measured chloride Content for circulation below casing shoe (approximately 10,213 ft MD) before cementing – July 12 and 13, 2023.*

Time	Depth (ft MD)	Chloride Concentration (ppm)	Time	Depth (ft MD)	Chloride Concentration (ppm)
22:14	shoe	3,100	23:39	shoe	1,450
22:19	shoe	2,150	23:44	shoe	1,450
22:24	shoe	1,850	23:49	shoe	1,450
22:29	shoe	4,650	23:54	shoe	1,450
22:34	shoe	5,300	23:59	shoe	1,450
22:39	shoe	1,700	00:04	shoe	1,450
22:44	shoe	1,700	00:19	shoe	1,550
22:49	shoe	5,650	00:34	shoe	1,950
22:50	shoe	6,000	00:49	shoe	2,150
22:54	shoe	6,000	01:04	shoe	2,600
22:59	shoe	3,200	01:19	shoe	2,750
23:04	shoe	1,600	01:34	shoe	2,450
23:09	shoe	1,450	01:49	shoe	2,100
23:14	shoe	1,450	02:04	shoe	1,850
23:19	shoe	1,450	02:19	shoe	1,800
23:24	shoe	1,450	02:34	shoe	1,900
23:29	shoe	1,500	02:49	shoe	1,850
23:34	shoe	1,450	03:04	shoe	2,000

July 18, 2023 – Circulation 2, Day 1

SLB was rigged up with one MPF-331 CT Pump Truck and one cementing unit to Well 16A(78)-32. Tracer injection was set up for addition into the suction manifold of the CT Pump Truck at a constant concentration using 2,6-nds. The treating pressure at the 16A(78)-32 wellhead is shown for July 18, 2023, in Figures B.2-9 and B.2-10. As can be seen, injection started at 2.5 bpm, was later increased to 5 bpm, and finally was increased to a maximum rate of 7.4 bpm. Injection rate fluctuations were experienced while going to 5 bpm while the second unit was brought online. Going to 10 bpm, there were some equipment issues but it was lined out at 7.4 bpm.

Zoomed-in views of the data during pumping are provided in Figure B.2-11.

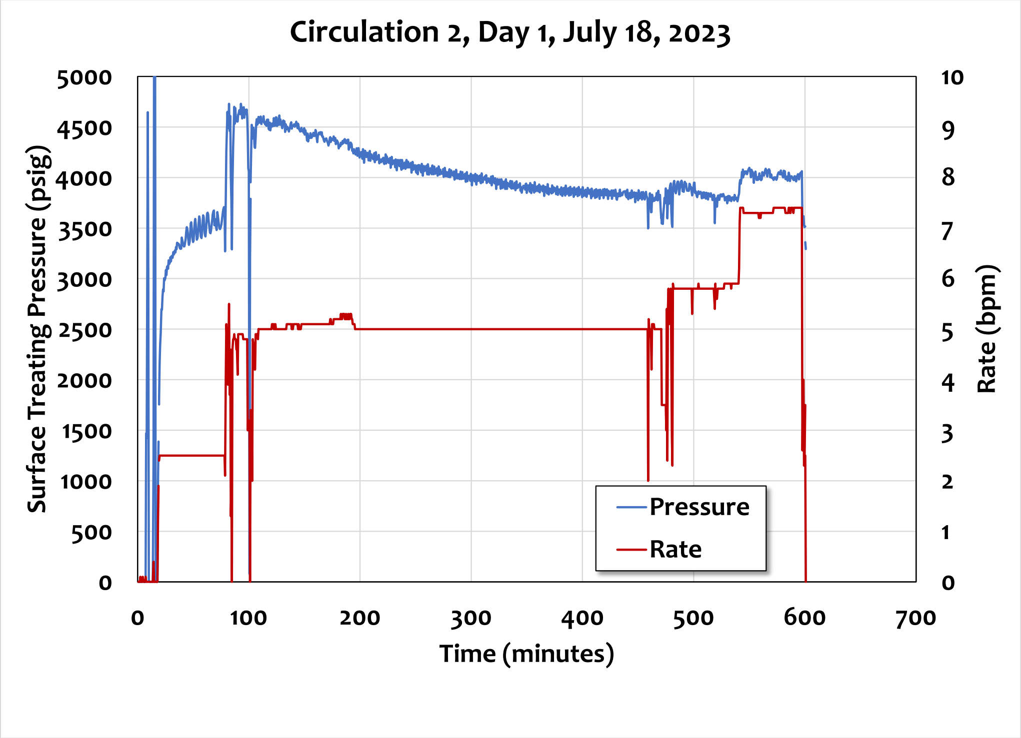


Figure B.2-9. *SLB record of surface pressure and rate at Well 16B(78)-32. Notice the declining pressure during the 5 bpm segments and only limited change in surface pressure as the rate was increased. Shut-in data were recorded with Pason equipment (as seen in Figure B.2-10).*

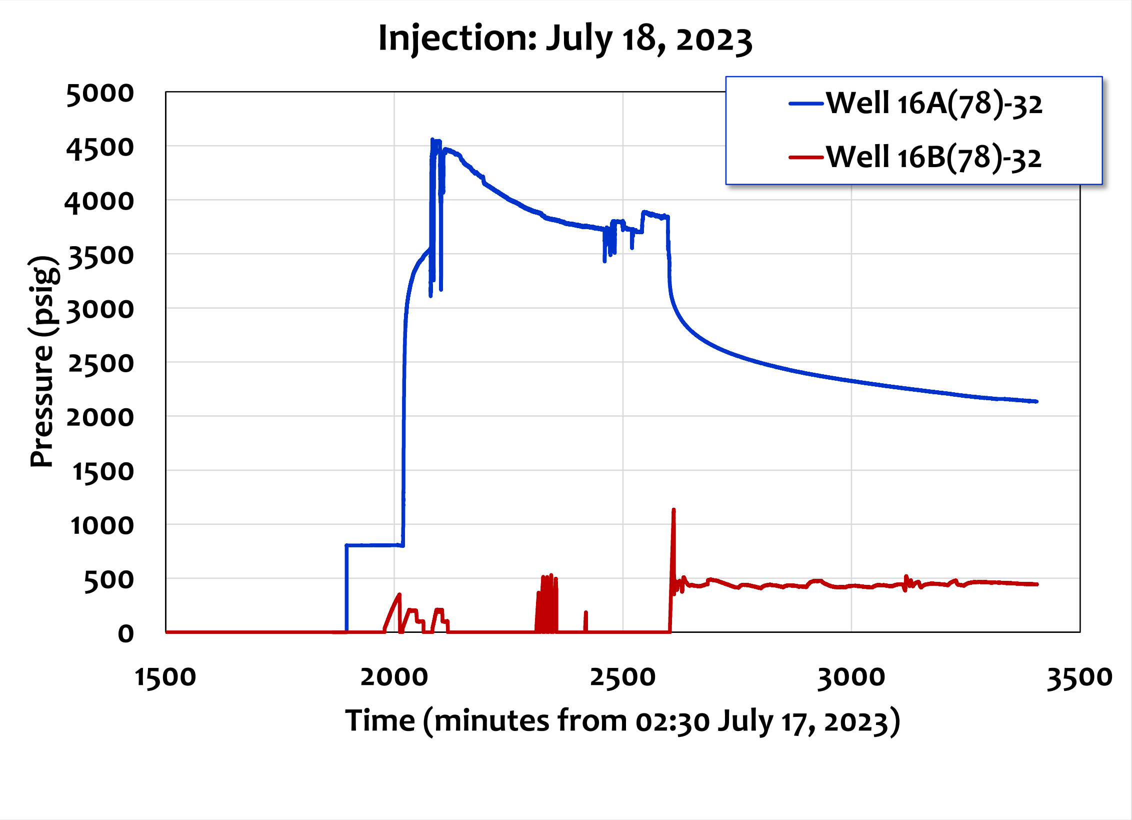


Figure B.2-10. *Pason data for both the injection and the production wells for the first day of the second circulation test. Notice that the back-pressure in the production well (16B(78)-32) was kept low to promote flow paths to the production well. Some shut-in/flowback pressure cycling was used part way through the 5 bpm segment. On shut-down, the back pressure was maintained at 500 psi by adjusting the throttling valve.*

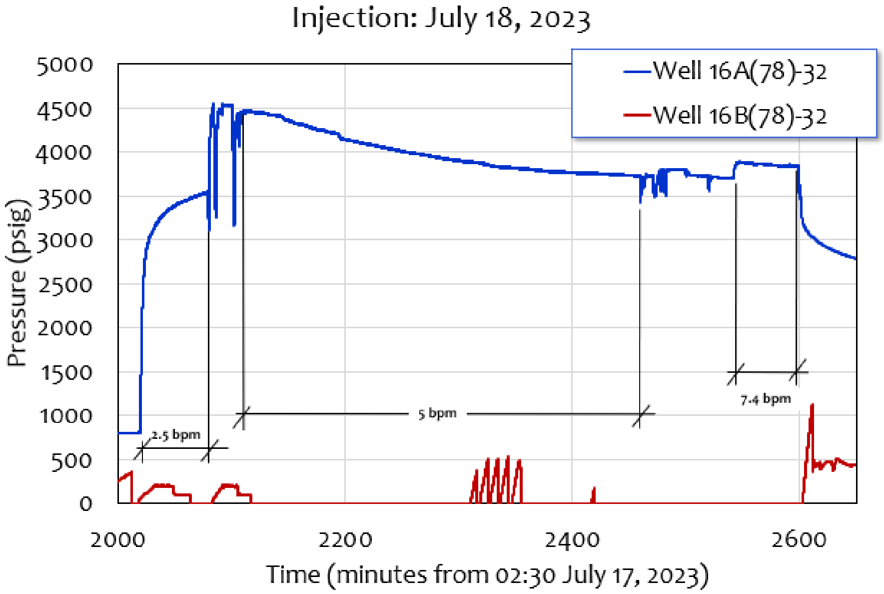


Figure B.2-11. *Notice the cycles in Well 16B(78)-32. During the 2.5 bpm stage, the back pressure was allowed to build to 200 psi, held, reduced to 100 psi, and reduced to AOF. While trying to establish and line out the 5 bpm stage, the same protocol was followed. Several surge cycles were implemented part-way through the 5 bpm stage. After the 7.4 bpm stage, the pressure rose rapidly and then it was maintained at under 500 psi.*

Before the treatment, the fluid level in Well 16B(78)-32 was reduced by running in and out of the hole with 10 stands of 4-3/4-inch drill collars without fill-up. Pressure recovery was monitored using the Baker Hughes downhole pressure-temperature gauge that is ported into the 7” casing string with the fiber-optic installation. Those data are shown in Figures B.2-12 and B.2-13. Data recording with that device continued during the subsequent injection. An extended (through injection) version of Figure B.2-12 is shown in Figure B.2-14 and data are reported in Table B.2-7.

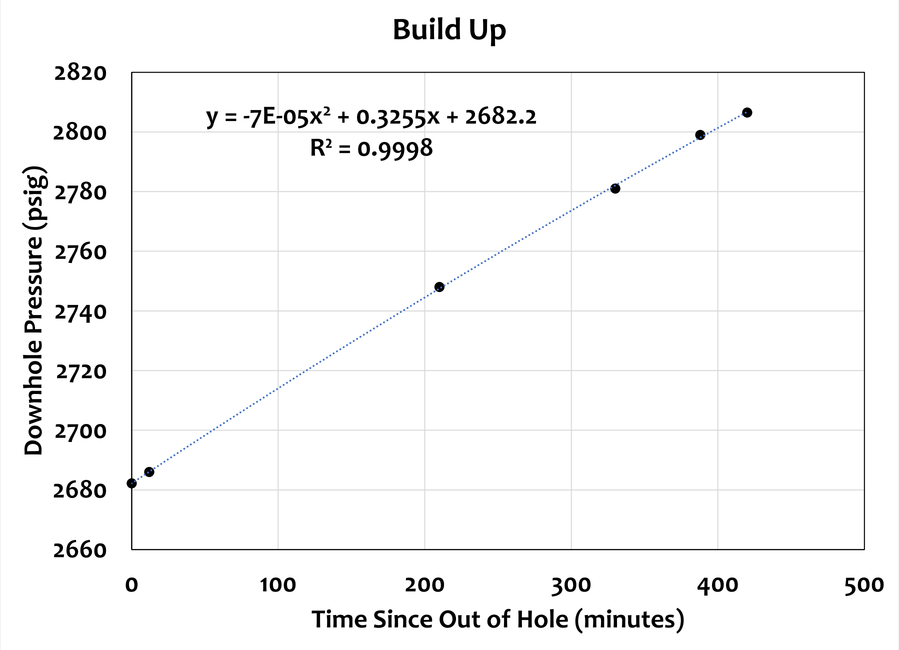


Figure B.2-12. *Downhole pressure was recorded (at the Baker Hughes pressure gauge) after reducing the hydrostatic head in Well 16B(78)-32. These data were fitted with a second-order curve and the zero pressure was estimated by extrapolation.*

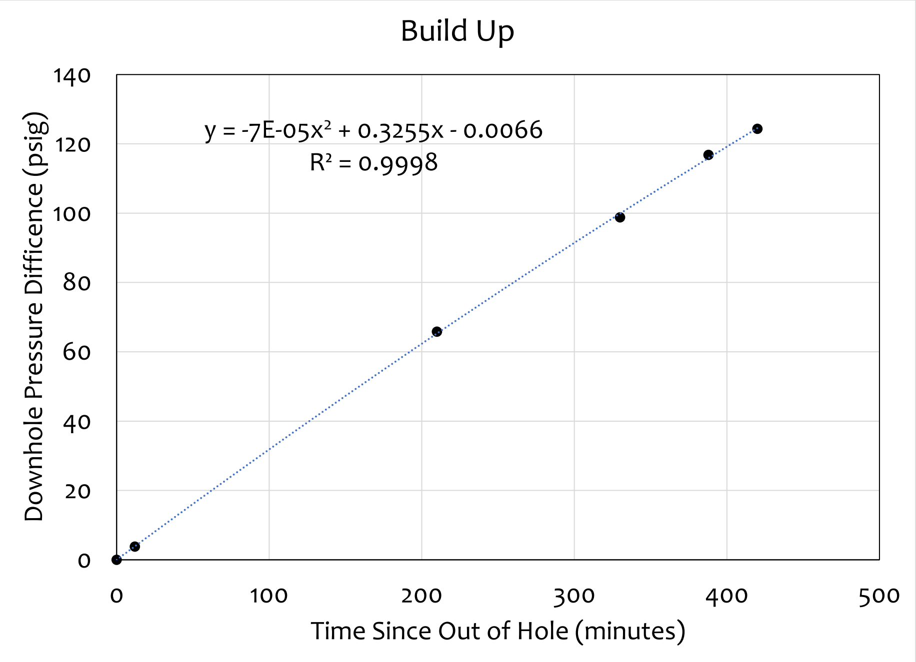


Figure B.2-13. *Differential pressure was recorded after reducing the hydrostatic head in Well 16B(78)-32. Pressure is different with respect to pressure from a second-order extrapolation to the start time. The response is near linear with time (minor curvature). Time zero is 01:00 a.m. on July 18, 2023.*

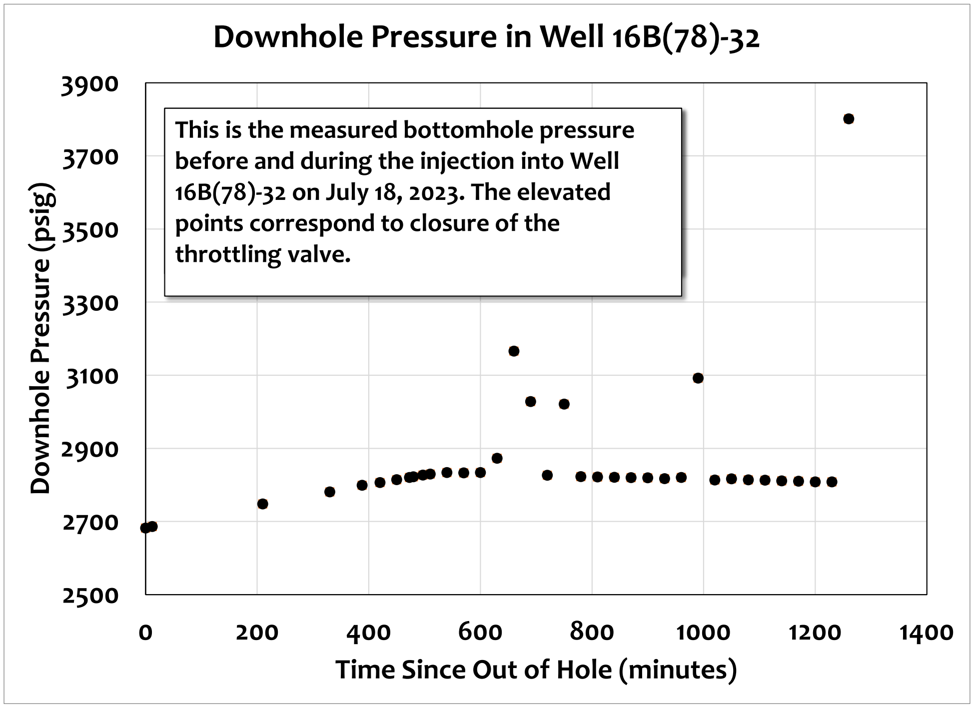


Figure B.2-14. *Downhole pressure was recorded after reducing the hydrostatic head in well 16B(78)-32 and through the injection on July 18, 2023. Time zero is 01:00 a.m. on July 18, 2023. The treatment (Circulation 2, Day 1) started at 12:09 p.m. on July 18, 2023.*

July 19 and 20, 2023, Circulation 2, Day “2”

On July 19, 2023, a grease head was rigged up for pressure control while running the SLB HT PLT tool. There was a lubricator on location but the available crane could not lift it. Consequently, it was necessary to flow Well 16A(78)-32 to the pit to relieve pressure. Flowback started at about 4:15 p.m. on July 19 (16:15 July 19, 2023). Rig up continued and the injection started about 09:09 p.m. on July 19 (21:09 July 19, 2023). The spinner data are summarized in Tables 7 and 8 as well as Figures 15 and 16.

Table B.2-7. *Stage Partitioning (Kevin England, from SLB field print, Figure B.2-15).*

	2.5 bpm	**5.0 bpm**	**7.5 bpm**
Stage 3 Frac	**25%**	**33.5%**	**30.7%**
Stage 2 Frac	**8%**	**16%**	**8.3%**
Stage 1 (OH) Frac	**67%**	**67%**	**61%**

Table B.2-8. *Stage Partitioning (fraction of total rate entering stage wellbore domain) (John McLennan, from field notes, Figure B.2-16).*

Rate (bpm)	Stage 1	Stage 2	Stage 3
2.5	0.58	0.18	0.24
5	0.49	0.14	0.37
7.5	0.61	0.08	0.31

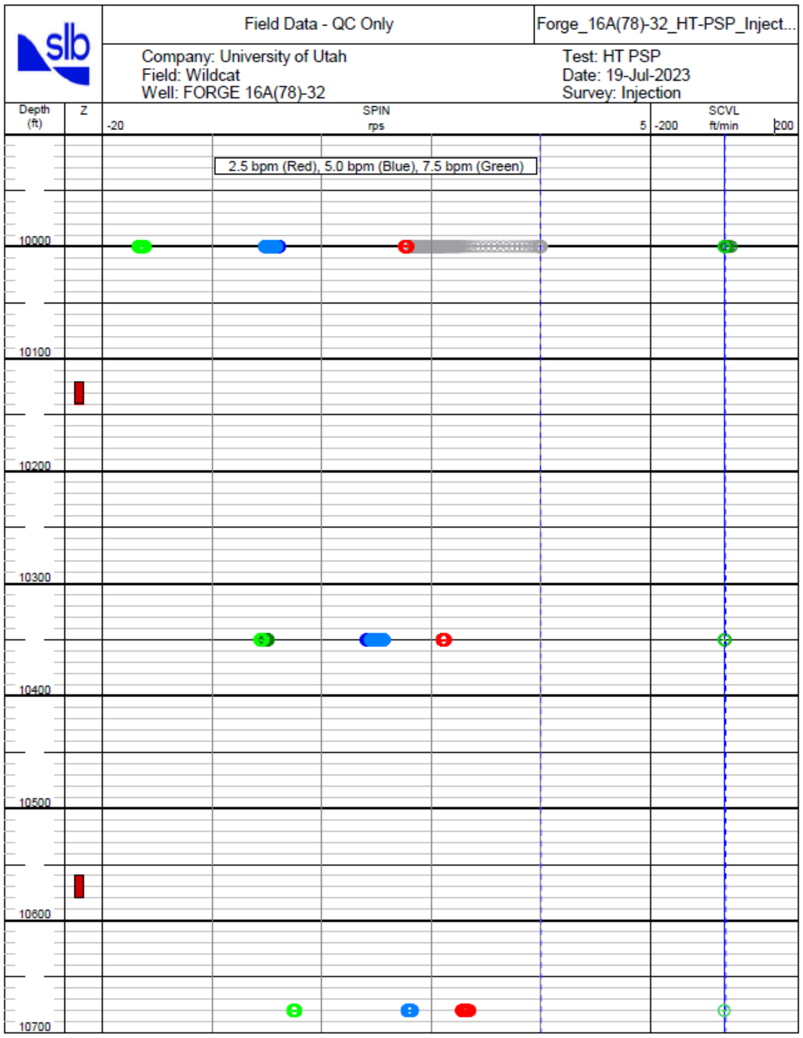


Figure B.2-15. *Field print of SLB data showing flow partitioning at various depths of the spinner. The tool was allowed to stabilize at 10,000 ft MD, 10,350 ft MD, and 10,680 ft MD.*

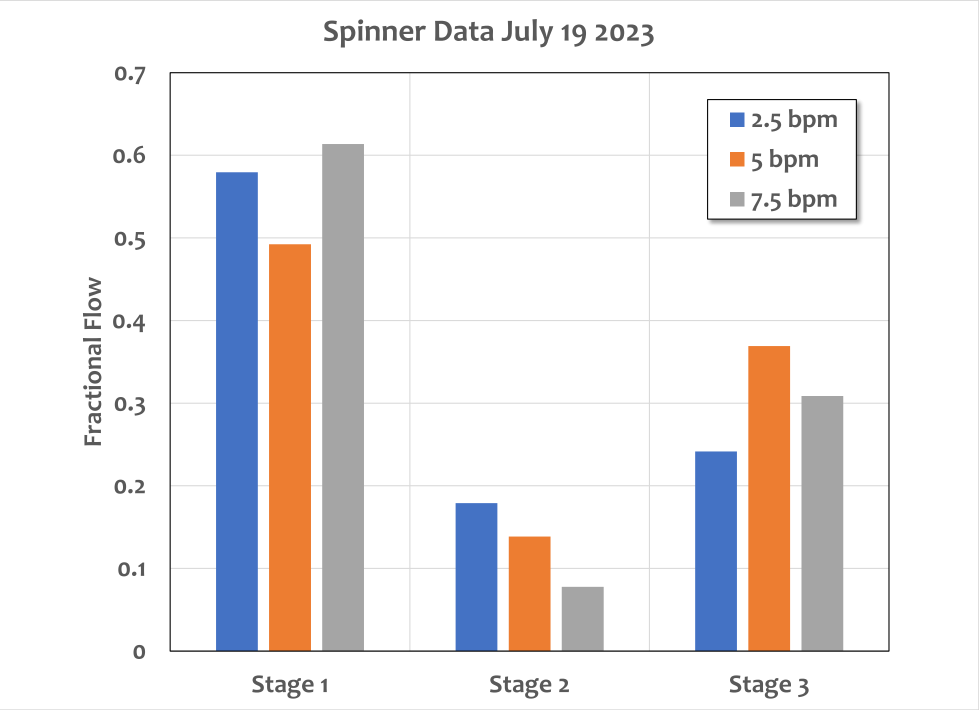
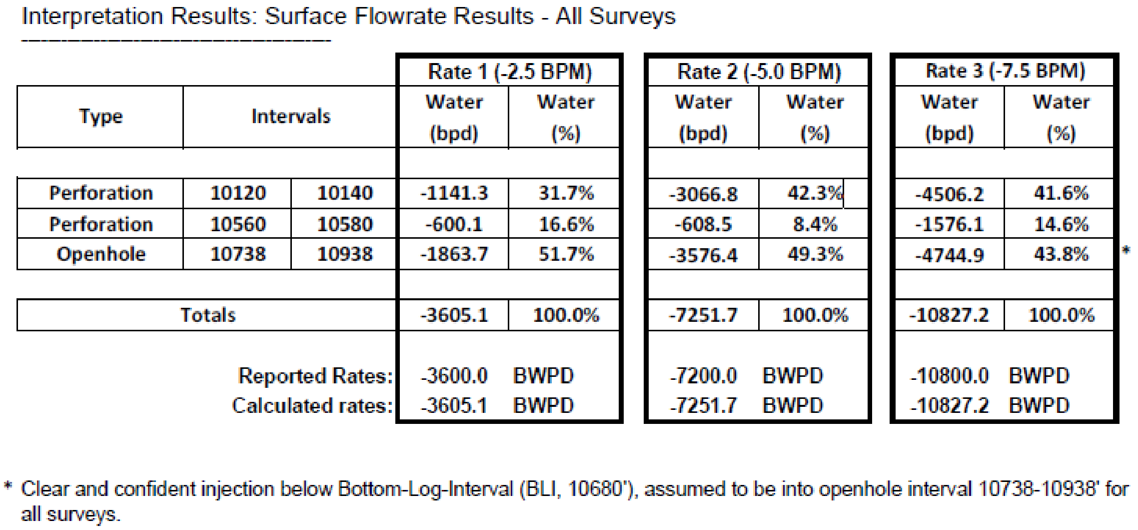


Figure B.2-16. *Preliminary partitioning of flow to different frac stages (based on field notes only).*

SLB tabulated results are shown in Figures B.2-17 and B.2-18. Note that as the rate becomes higher, progressively less flow goes into the Stage 1 open hole region.



Interpretation Results: Surface Flowrate Results - All Surveys

Type	Intervals		Rate 1 (-2.5 BPM) Water (bpd)	Rate 1 (-2.5 BPM) Water (%)	Rate 2 (-5.0 BPM) Water (bpd)	Rate 2 (-5.0 BPM) Water (%)	Rate 3 (-7.5 BPM) Water (bpd)	Rate 3 (-7.5 BPM) Water (%)	
Perforation	10120	10140	-1141.3	31.7%	-3066.8	42.3%	-4506.2	41.6%	
Perforation	10560	10580	-600.1	16.6%	-608.5	8.4%	-1576.1	14.6%	
Openhole	10738	10938	-1863.7	51.7%	-3576.4	49.3%	-4744.9	43.8%	*
Totals			-3605.1	100.0%	-7251.7	100.0%	-10827.2	100.0%	
		Reported Rates:	-3600.0	BWPD	-7200.0	BWPD	-10800.0	BWPD	
		Calculated rates:	-3605.1	BWPD	-7251.7	BWPD	-10827.2	BWPD	

* Clear and confident injection below Bottom-Log-Interval (BLI, 10680'), assumed to be into openhole interval 10738-10938' for all surveys.

Figure B.2-17. *SLB tabulated the distribution of flow in the three zones and the three rates. This should be taken as the final distribution of flow – shown graphically in Figure B.2-18.*

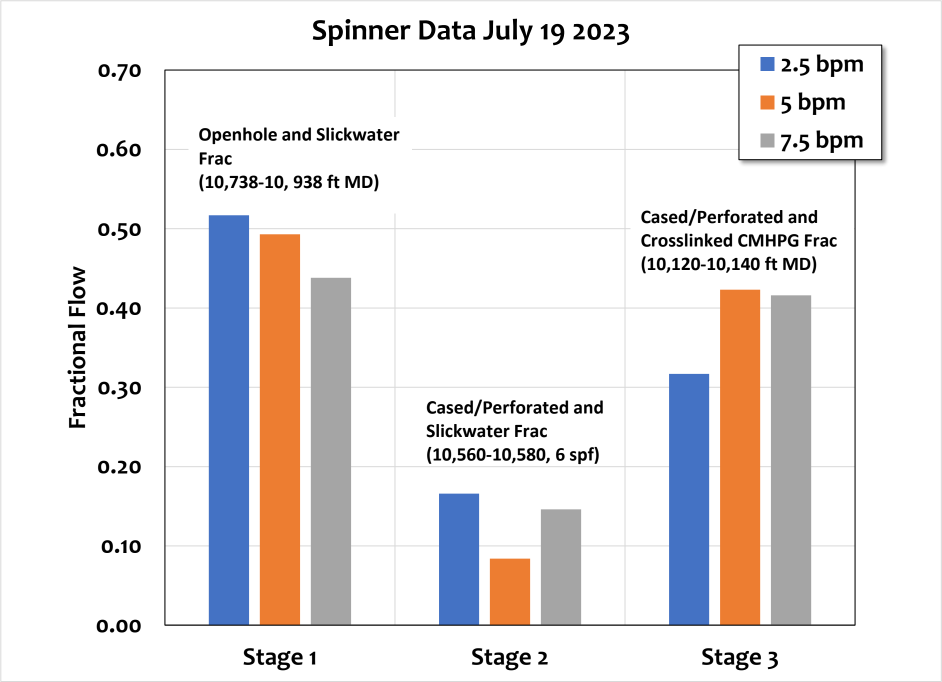


Figure B.2-18. *Final flow distribution as per SLB interpretation.*

The pressure records for both wells are shown in Figures B.2-19 through 22.

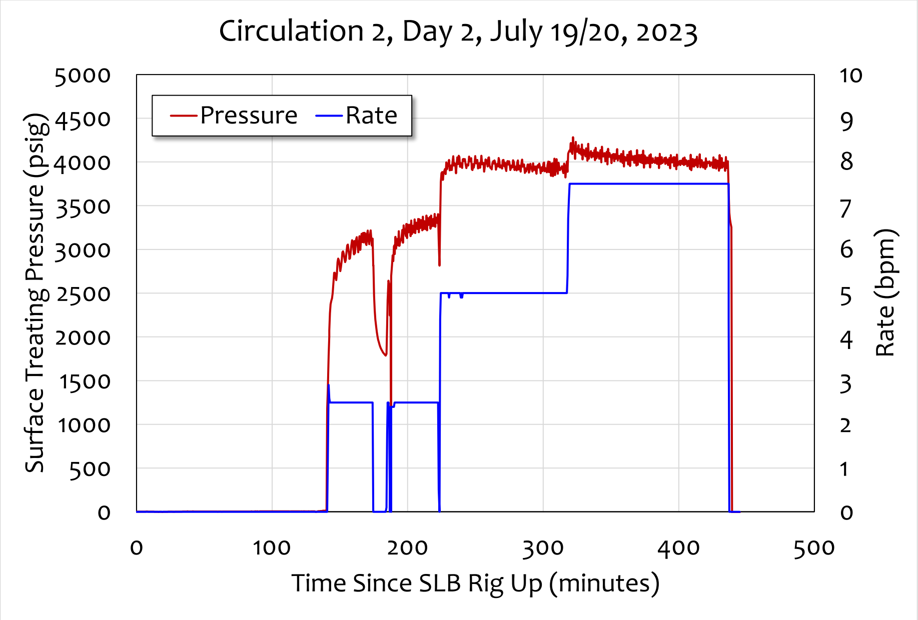


Figure B.2-19. *SLB data for Circulation 2, Day 2. Spinner data were acquired in 16A(78)-32 while pumping.*

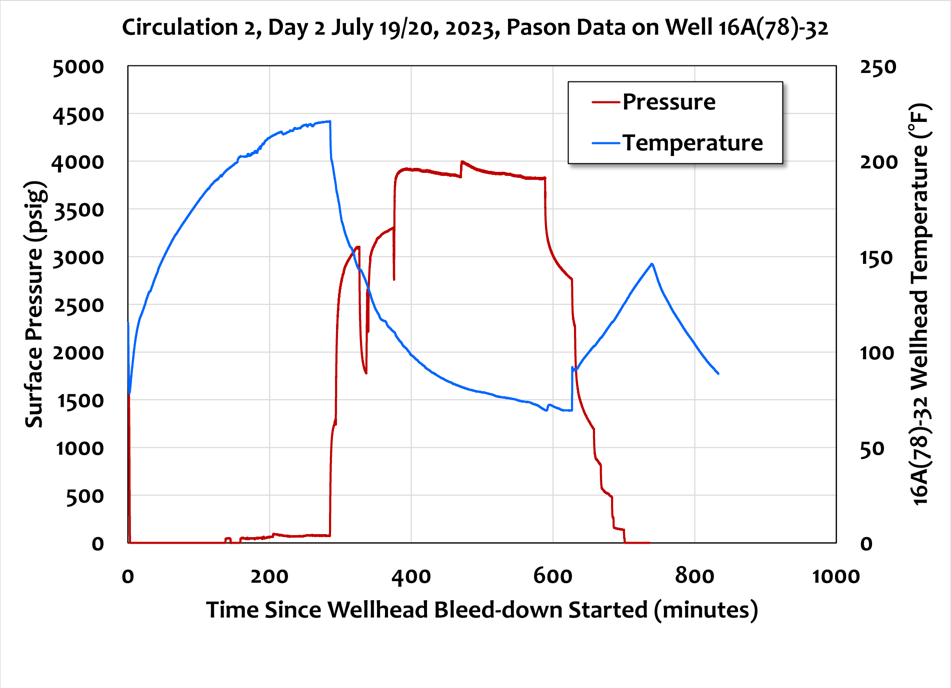


__Figure B.2-20.__ Pason data for Circulation 2, Day 2. Spinner data were acquired in this 16A(78)-32 while pumping.

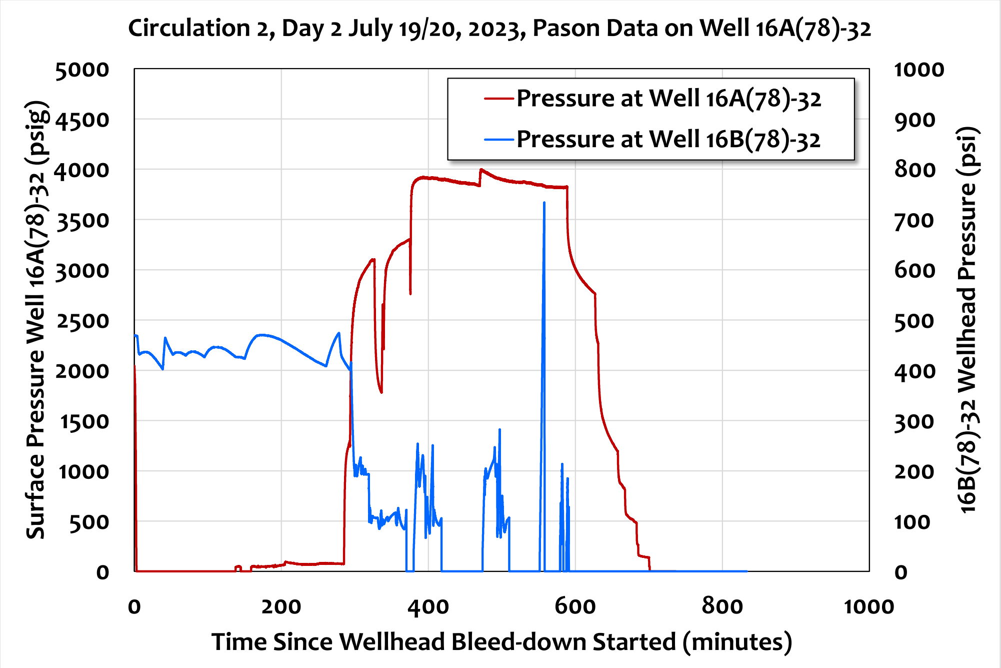


__Figure B.2-21.__ Pason data for Circulation 2, Day 2. Spinner data were acquired in well 16B(78)-32 while pumping into the offset well.

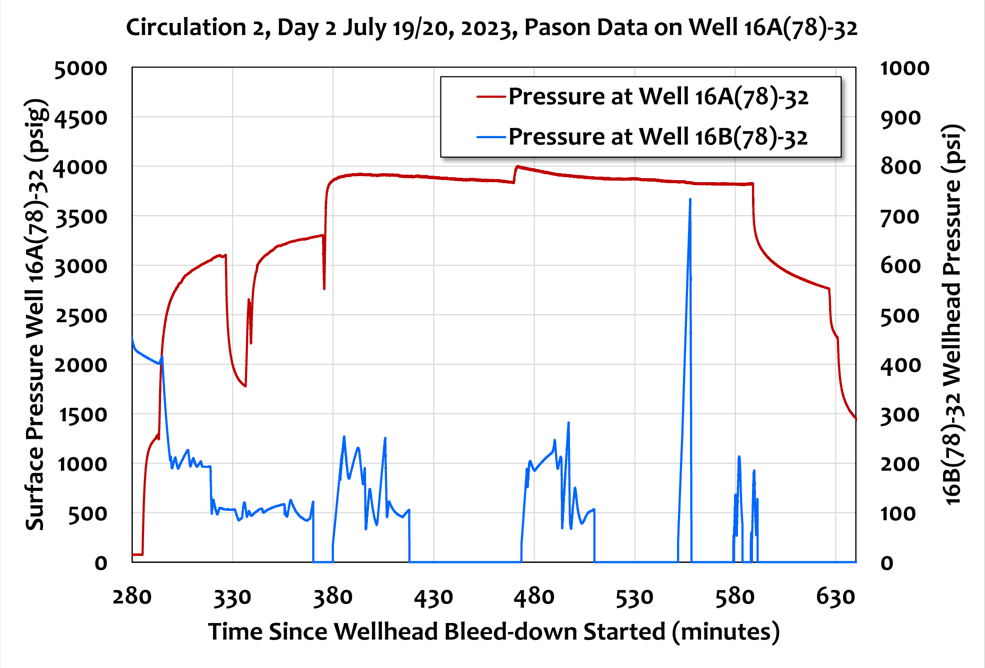


Figure B.2-22. *Pason data for Circulation 2, Day 2. Spinner data were acquired in well 16B(78)-32 while pumping into the offset well. This is a zoomed-in view of Figure B.2-19.*

Produced Fluid

Chloride sampling up through July 13 has been reported in previous tables (see for example Table B.2-6). Tables B.2-9 through 13 compile additional data. Tracer data will be added as it becomes available.

Table B.2-9. *July 16, 2023, Circulation Event*

Time	Chloride Concentration (ppm)	Time	Chloride Concentration (ppm)
12:15 x 2	1,550	15:15 x 2	1,650
12:30 x 2	1,550	15:30 x 2	2,200
12:45 x 2	1,700	15:45 x 2	1,700
13:00 x 2	1,700	16:00 x 2	1,650
13:15 x 2	1,600	16:15 x 2	1,650
13:30 x 2	1,650	16:30 x 2	1,500
13:45 x 2	1,500	16:45 x 2	1,750
14:00 x 2	1,600	17:00 x 2	1,750
14:15 x 2	1,650	17:15 x 2	1,800

14:30 x 2	1,600	17:30 x 2	2,650
14:45 x 2	1,650	17:45 x 2	2,650
15:00 x 2	2,000		

Table B.2-10. *July 18, 2023, Monitoring Communication Between Wells*

Time	Chloride Concentration (ppm)	Time	Chloride Concentration (ppm)
12:25	950	17:45	1,600
13:15	1,650	18:15	1,550
13:45	1,750	18:45	1,550
14:15	1,750	19:15	1,750
14:45	1,600	19:30	1,650
15:15	1,650	20:26	1,600
15:45	1,550	20:31	1,600
16:15	1,550	21:30	1,650
16:45	1,550	21:50	1,600
17:15	1,550		

Table B.2-11. *July 19, 2023, Monitoring Communication Between Wells (Flowing Back Well 16A(78)-32)*

Time	Chloride Concentration (ppm)	Time		Chloride Concentration (ppm)
17:15	250	19:15		1,100
17:32	250	19:30		1,350
17:45	NA	19:45		1,300
18:00	NA	20:00		1,300
18:15	NA	20:15		1,300
18:30	250	20:30		1,400
18:45	1,050	20:45		1,400
19:04	1,300	21:00		1,350

Table B.2-12. *July 19 and 20, 2023, Monitoring Communication Between Wells (Injecting into 16A(78)-32)*

Time	Chloride Concentration (ppm)	Time	Chloride Concentration (ppm)
21:30	1,700	00:00	1,650
22:00	1,800	00:30	1,650
22:30	1,650	01:00	1,750
23:00	1,700	01:30	1,600
23:35	1,650	02:00	1,750

Table B.2-13. *July 20, 2023, Monitoring Flow from Well 16B(78)-32 (Flow Back Well 16A(78)-32 and Circulate in Completion Fluid in Well 16B(78)-32*

Time	Chloride Concentration (ppm)	Time	Chloride Concentration (ppm)
07:50	4,400 Flowback Event	14:20	2,750
07:50	4,500 Flowback Event	14:25	400
13:40	2,450	14:30	400
13:45	2,450	14:35	300
13:50	2,650	14:40	350
13:55	3,500	14:45	350
14:00	2,900	14:50	350
14:05	2,100	14:55	450
14:10	2,200	15:00	350
14:15	2,650		

Bucket samples were taken from the discharge of Well 16B(78)-32 at regular intervals. The results are shown in Table B.2-9 and Figures B.2-23 and B.2-24.

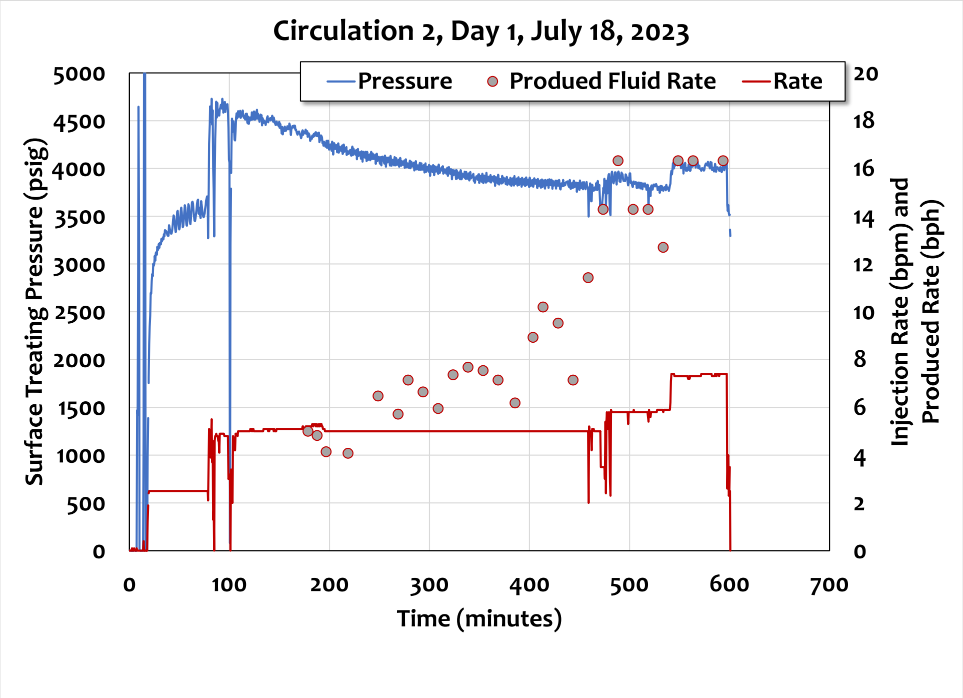


Figure B.2-23. *Produced fluid volumetric flow rates measured downstream of the separator at Well 16B(78)-32 while injecting into Well 16A(78)-32 on July 18, 2023.*

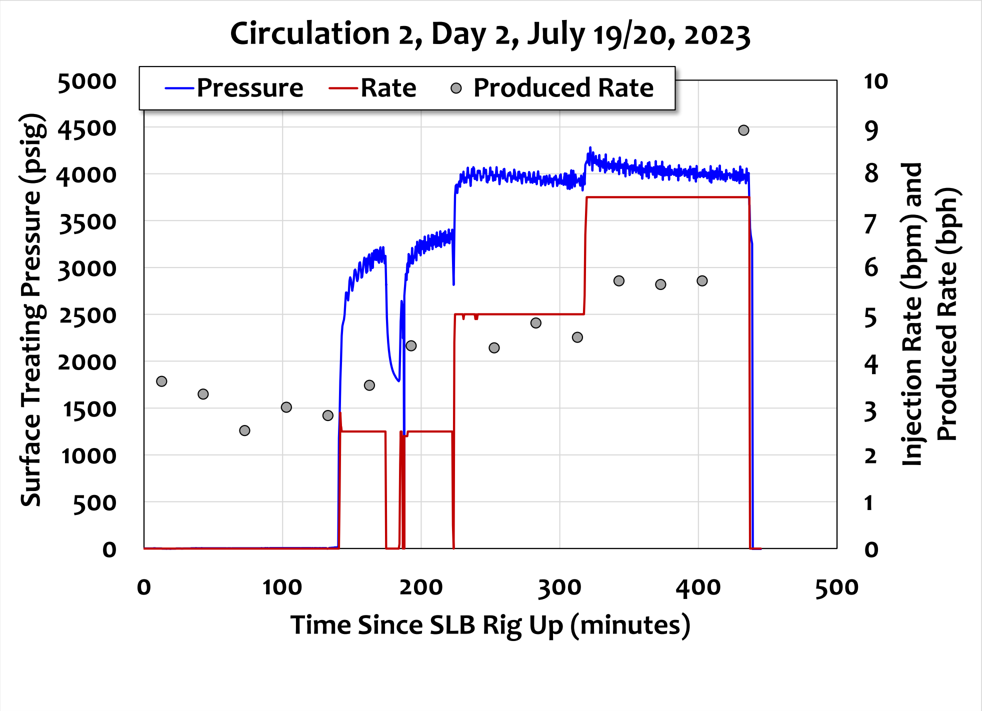


Figure B.2-24. *Produced fluid volumetric flow rates measured downstream of the separator at Well 16B(78)-32 while injecting into Well 16A(78)-32 on July 19/20, 2023.*

Key Observations

1. Injection needs to occur above the minimum in situ principal stress. Pressure rapidly increases to those levels regardless of the rate.
2. A connection was definitively established. Tracer data will be added when they are available.
3. Stimulation previously established a fracture network in a nominally impermeable domain (mixed domain of extensionally opened and propagated natural fractures and hydraulically induced and propagated fractures, with pressure-dependent leakoff into subsidiary fractures with varying degrees of self-propping if any.
4. Initial cycles, like the stimulations in April 2022 showed pressure decline although the mechanisms may be different. In 2022, the mechanisms could have been height growth, pressure-dependent leakoff, and reduction of tortuosity along with possibly some thermal effects. In these 2023 treatments there is limited propagation (although anecdotally Silixa recorded a few detectable microseisms) but reopening and recharging of the finite reservoir container is evident (pressure maintained over days of shut-in) and there is speculation that some precipitation needed to be removed.

Table B.2-14. *Produced Fluid Rates for Circulation 2, Both Days*

Sample Date	Sample Time	Sampling Duration (seconds)	Volume Sampled	Produced Rate (gpm)	Produced Rate (bpm)	Produced Rate (bph)	Time Interval (hh: mm)	Cumulative Time (minutes)	Produced Volume (bbl)	Time from start of SLB recording (minutes) C2,D1[1]
7/18/23	**10:51**									0.00
7/18/23	13:50	5.71	quart	2.63	0.06	3.75				178.57
7/18/23	13:59	5.92	quart	2.53	0.06	3.62	0:09	9	0.54	187.57
7/18/23	14:08	6.9	quart	2.17	0.05	3.11	0:09	9	0.47	196.57
7/18/23	14:30	7	quart	2.14	0.05	3.06	0:22	22	1.12	218.57
7/18/23	15:00	4.41	quart	3.40	0.08	4.86	0:30	30	2.43	248.57
7/18/23	15:20	5	quart	3.00	0.07	4.29	0:20	20	1.43	268.57
7/18/23	15:30	4	quart	3.75	0.09	5.36	0:10	10	0.89	278.57
7/18/23	15:45	4.3	quart	3.49	0.08	4.98	0:15	15	1.25	293.57
7/18/23	16:00	4.8	quart	3.13	0.07	4.46	0:15	15	1.12	308.57
7/18/23	16:15	3.88	quart	3.87	0.09	5.52	0:15	15	1.38	323.57
7/18/23	16:30	3.72	quart	4.03	0.10	5.76	0:15	15	1.44	338.57
7/18/23	16:45	3.79	quart	3.96	0.09	5.65	0:15	15	1.41	353.57
7/18/23	17:00	4	quart	3.75	0.09	5.36	0:15	15	1.34	368.57
7/18/23	17:17	4.62	quart	3.25	0.08	4.64	0:17	17	1.31	385.57
7/18/23	17:35	3.2	quart	4.69	0.11	6.70	0:18	18	2.01	403.57
7/18/23	17:45	2.8	quart	5.36	0.13	7.65	0:10	10	1.28	413.57
7/18/23	18:00	3	quart	5.00	0.12	7.14	0:15	15	1.79	428.57
7/18/23	18:15	4	quart	3.75	0.09	5.36	0:15	15	1.34	443.57
7/18/23	18:30	10	1 gallon	6.00	0.14	8.57	0:15	15	2.14	458.57
7/18/23	18:45	8	1 gallon	7.50	0.18	10.71	0:15	15	2.68	473.57
7/18/23	19:00	7	1 gallon	8.57	0.20	12.24	0:15	15	3.06	488.57
7/18/23	19:15	8	1 gallon	7.50	0.18	10.71	0:15	15	2.68	503.57
7/18/23	19:30	8	1 gallon	7.50	0.18	10.71	0:15	15	2.68	518.57

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[11] C2,D1 designates circulation test 2 and day 1

7/18/23	19:45	9	1 gallon	6.67	0.16	9.52	0:15	15	2.38	533.57
7/18/23	20:00	7	1 gallon	8.57	0.20	12.24	0:15	15	3.06	548.57
7/18/23	20:15	7	1 gallon	8.57	0.20	12.24	0:15	15	3.06	563.57
7/18/23	20:30	6	1 gallon	10.00	0.24	14.29	0:15	15	3.57	578.57
7/18/23	20:45	7	1 gallon	8.57	0.20	12.24	0:15	15	3.06	593.57
7/18/23	21:00	6	1 gallon	10.00	0.24	14.29	0:15	15	3.57	608.57
7/18/23	21:15	6	1 gallon	10.00	0.24	14.29	0:15	15	3.57	623.57
7/18/23	21:30	6	1 gallon	10.00	0.24	14.29	0:15	15	3.57	638.57
7/19/23	6:40	11.46	1 gallon	5.24	0.12	7.48				1188.57
7/19/23	7:30	13.96	1 gallon	4.30	0.10	6.14	0:50	50	5.12	1238.57
7/19/23	8:00	13.55	1 gallon	4.43	0.11	6.33	0:30	30	3.16	1268.57
7/19/23	8:30	13.93	1 gallon	4.31	0.10	6.15	0:30	30	3.08	1298.57
7/19/23	9:00	16.38	1 gallon	3.66	0.09	5.23	0:30	30	2.62	1328.57
7/19/23	9:30	15.3	1 gallon	3.92	0.09	5.60	0:30	30	2.80	1358.57
7/19/23	9:45	61	5 gallons	4.92	0.12	7.03	0:15	15	1.76	1373.57
7/19/23	10:00	61	5 gallons	4.92	0.12	7.03	0:15	15	1.76	1388.57
7/19/23	10:30	62.94	5 gallons	4.77	0.11	6.81	0:30	30	3.40	1418.57
7/19/23	11:00	63.23	5 gallons	4.74	0.11	6.78	0:30	30	3.39	1448.57
7/19/23	11:30	66.07	5 gallons	4.54	0.11	6.49	0:30	30	3.24	1478.57
7/19/23	12:00	68.02	5 gallons	4.41	0.11	6.30	0:30	30	3.15	1508.57
7/19/23	12:30	67.67	5 gallons	4.43	0.11	6.33	0:30	30	3.17	1538.57
7/19/23	13:00	68.4	5 gallons	4.39	0.10	6.27	0:30	30	3.13	1568.57
7/19/23	13:30	70.7	5 gallons	4.24	0.10	6.06	0:30	30	3.03	1598.57
7/19/23	14:00	71.91	5 gallons	4.17	0.10	5.96	0:30	30	2.98	1628.57
7/19/23	14:30	74.69	5 gallons	4.02	0.10	5.74	0:30	30	2.87	1658.57
7/19/23	15:00	68.66	5 gallons	4.37	0.10	6.24	0:30	30	3.12	1688.57
7/19/23	15:30	77.63	5 gallons	3.86	0.09	5.52	0:30	30	2.76	1718.57
7/19/23	16:00	72.78	5 gallons	4.12	0.10	5.89	0:30	30	2.94	1748.57
7/19/23	16:30	70	5 gallons	4.29	0.10	6.12	0:30	30	3.06	1778.57
7/19/23	17:00	84.95	5 gallons	3.53	0.08	5.04	0:30	30	2.52	1808.57

7/19/23	18:00	120	5 gallons	2.5	0.06	3.57	1:00	60	3.57	1868.57
7/19/23	18:30	130	5 gallons	2.31	0.05	3.30	0:30	30	1.65	1898.57
7/19/23	19:00	170	5 gallons	1.76	0.04	2.52	0:30	30	1.26	1928.57
7/19/23	19:30	142	5 gallons	2.11	0.05	3.02	0:30	30	1.51	1958.57
7/19/23	20:00	151	5 gallons	1.99	0.05	2.84	0:30	30	1.42	1988.57
7/19/23	20:30	123	5 gallons	2.44	0.06	3.48	0:30	30	1.74	2018.57
7/19/23	21:00	99	5 gallons	3.03	0.07	4.33	0:30	30	2.16	2048.57
7/19/23	22:00	100	5 gallons	3.00	0.07	4.29	1:00	60	4.29	2108.57
7/19/23	22:30	89	5 gallons	3.37	0.08	4.82	0:30	30	2.41	2138.57
7/19/23	23:00	95	5 gallons	3.16	0.08	4.51	0:30	30	2.26	2168.57
7/19/23	23:30	75	5 gallons	4.00	0.10	5.71	0:30	30	2.86	2198.57
7/20/23	0:00	76	5 gallons	3.95	0.09	5.64	0:30	30	2.82	2228.57
7/20/23	0:30	75	5 gallons	4.00	0.10	5.71	0:30	30	2.86	2258.57
7/20/23	1:00	48	5 gallons	6.25	0.15	8.93	0:30	30	4.46	2288.57
			Cumulative						159.96	

5. Proppant will be a prerequisite for future treatments.
6. Larger volume stages will be required. Fibers in Well 16B(78)-32 should help with constraining the fracture size.
7. Microseismicity, as expected, overestimates the fracture domain.
8. There is definitive communication that can be improved with sustained injection into Well 16A(78)-32 and possibly reciprocal injection into Well 16B(78)-32 which is high-graded by the fiber optics.

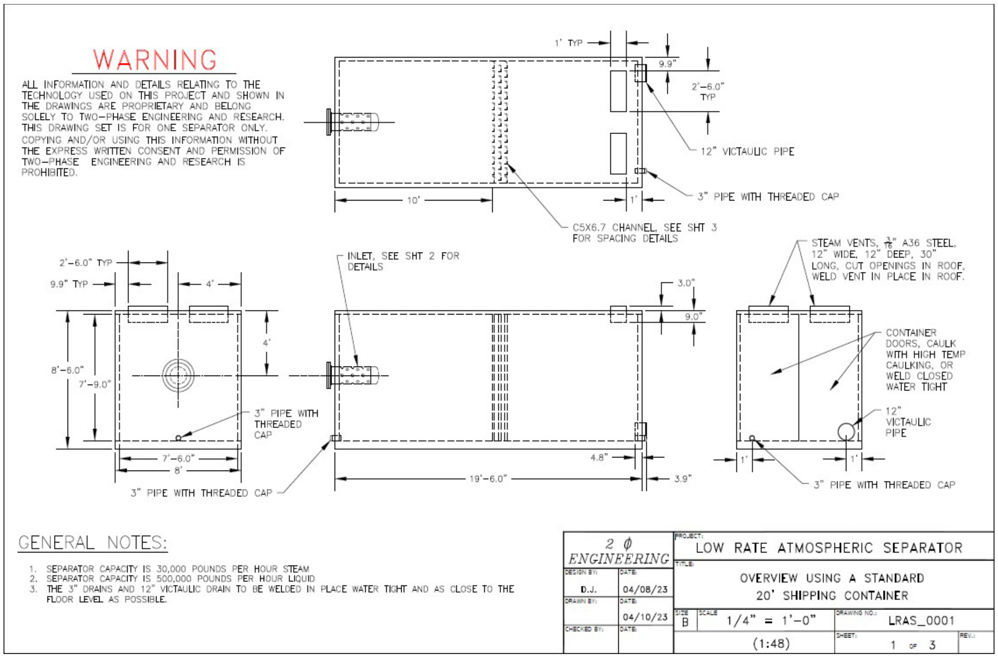
Running PLT in Well 16A(78)-32 during Circulation Test #2

Openhole Circulation Evaluation

Connection Evaluation from 16A(78)-32

It is desirable to establish connectivity but not to create additional fracture geometry or connections with Well 16B(78)-32. It is very likely however that pressure will be above the minimum principal stress. For this reason, before running 7” casing in 16B(78)-32, only inject into 16A(78)-32 to establish where the hydraulic fractures from the three-stage stimulation treatment pumped in April 2022 have grown. Initially, the procedures are:

- Rig up flow lines system with monitoring instrumentation on 16B(78)-32 to a geothermal separator (as shown in Figure B.2-25). The surface flow lines and monitoring equipment on the 16-32 pad are shown in Figures B.2-26 (with and without wireline lubricator for PLT) and B.2-27.
- Rig up treating iron from the SLB pumping equipment to the 16A(78)-32 wellhead. Confirm what sort of connections are required to be able to isolate the fluid injection line for flowback, the addition of a wireline lubricator for potentially running a spinner survey while pumping, etc. Be prepared to pump at surface pressure up to 5,000 psi and pressure test all treating lines and wellhead equipment to 5,000 psi. **Limit any pressure on Well 16B(78)-32 fittings to 3,000 psi in the event (probably unlikely, but nevertheless) that this is experienced.**



WARNING

ALL INFORMATION AND DETAILS RELATING TO THE TECHNOLOGY USED ON THIS PROJECT AND SHOWN IN THE DRAWINGS ARE PROPRIETARY AND BELONG SOLELY TO TWO-PHASE ENGINEERING AND RESEARCH. THIS DRAWING SET IS FOR ONE SEPARATOR ONLY. COPYING AND/OR USING THIS INFORMATION WITHOUT THE EXPRESS WRITTEN CONSENT AND PERMISSION OF TWO-PHASE ENGINEERING AND RESEARCH IS PROHIBITED.

GENERAL NOTES:

1. SEPARATOR CAPACITY IS 30,000 POUNDS PER HOUR STEAM
2. SEPARATOR CAPACITY IS 500,000 POUNDS PER HOUR LIQUID
3. THE 3" DRAINS AND 12" VICTAULIC DRAIN TO BE WELDED IN PLACE WATER TIGHT AND AS CLOSE TO THE FLOOR LEVEL AS POSSIBLE.

Figure B.2-25. *Preliminary separator drawings.*

- Start pumping on Well 16A(78)-32 according to the schedule shown in Table B.2-15. Tag this fluid with a discrete tracer (probably 2,7-nts). Start with Well 16B(78)-32 shut-in. This is the only way to overcome wellbore storage and build back pressure. As back-pressure is developed, Well 16B(78)-32 will be progressively flowed to the separator, as described in Table B.2-15.
- Sample fluids and save for tracer and water analysis on Well 16B(78)-32. **At least every 30 minutes, starting as soon as testing starts. It is desirable to look for background, residual (from the three frac stages pumped in April 2022) and new tracer pumped during the circulation test.**

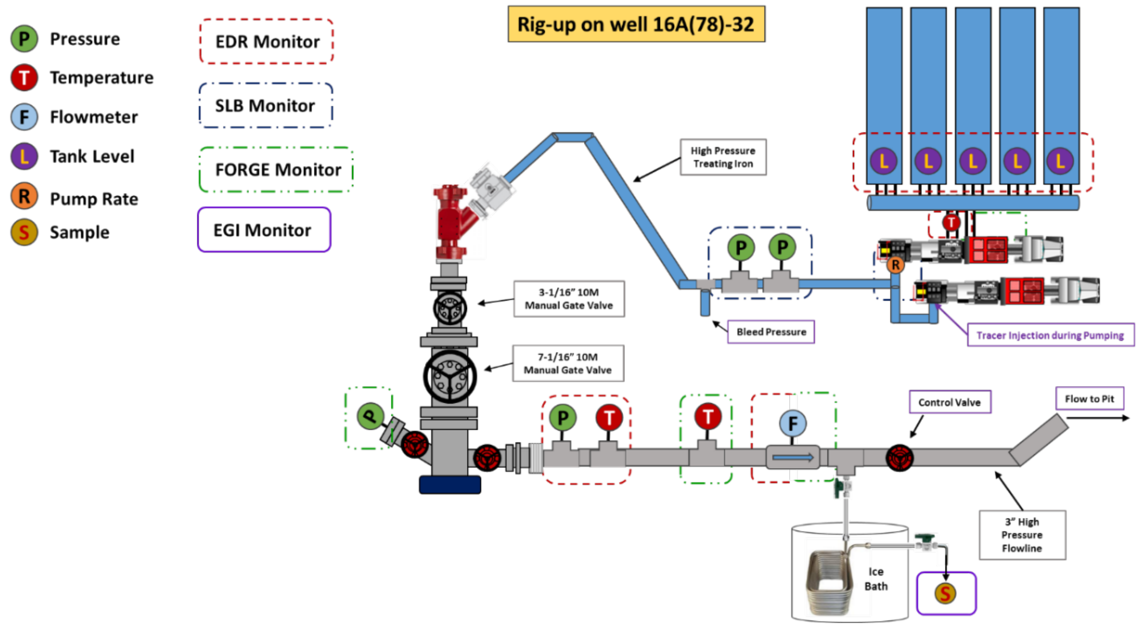


Figure B.2-26A. *Proposed installation of monitoring and flow equipment and plumbing on the 16-32 pad for injection Well 16A(78)-32 without PLT.*

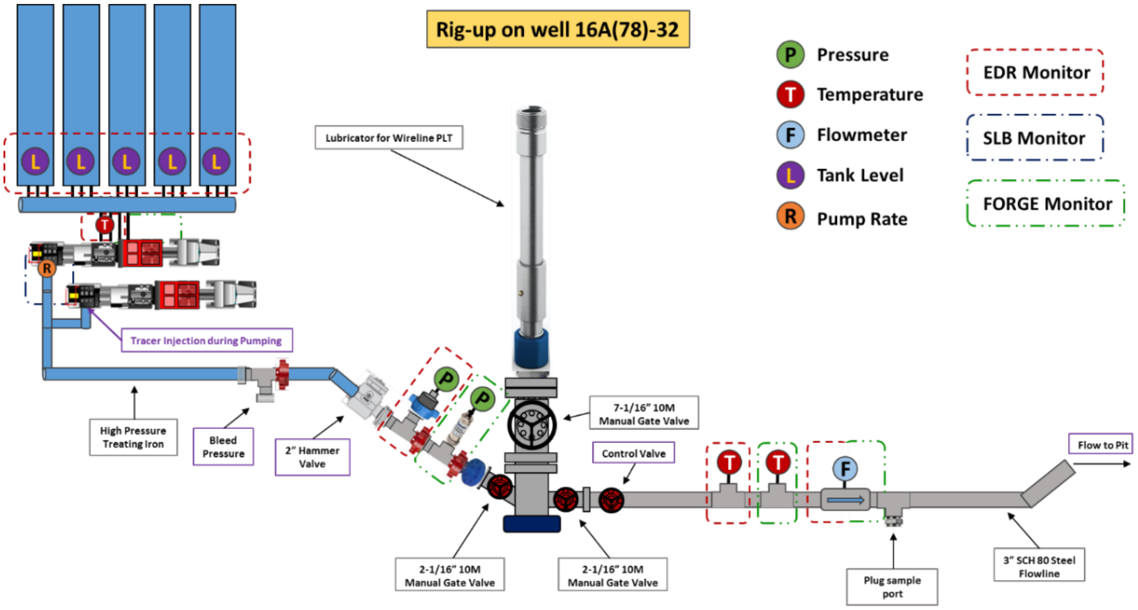


Figure B.2-26B. *Proposed installation of monitoring and flow equipment and plumbing on the 16-32 pad for injection Well 16A(78)-32 with PLT.*

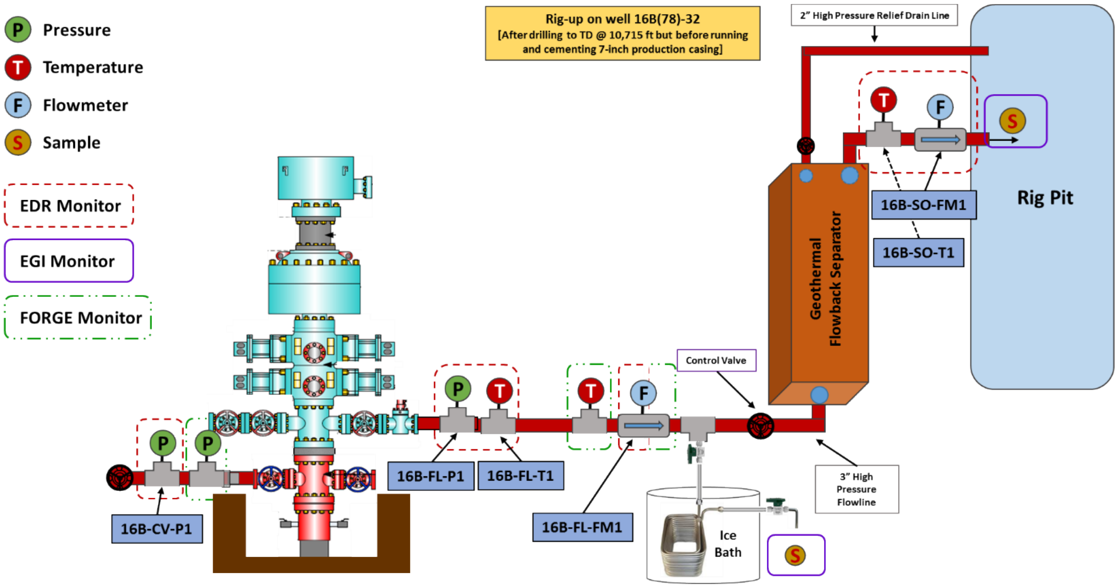


Figure B.2-27. *Proposed installation of monitoring and flow equipment and plumbing on the 16-32 pad for injection Well 16B(78)-32 – before running 7-inch casing.*

Table B.2-15. *Openhole measurements before 7” casing is run and cemented*

Injection Rate (BPM)	Stage Time (min)	Cumulative Time (min) [hr]	Stage Volume (bbl)	Cumulative Volume (bbl)	Comment
0.5	90	90 [1.5]	45	45	Keep well 16B(78)-32 shut-in until pressure reaches 400 psi, then flow to separator to maintain approximately 400 psi back pressure. If wellhead pressure on 16A reaches 5,000 psi shutdown pumping and decide the next steps.
2.5	90	180 [3]	225	270	Keep well 16B(78)-32 shut-in until pressure reaches 400 psi, then flow to separator to maintain approximately 400 psi back pressure. Or continue flowing to the separator depending on the previous step. If wellhead pressure on 16A reaches 5,000 psi, slow pump rate. If pressure continues to increase to5,000 psi shutdown pumping and decide the next steps.
5.0	90	270 [4.5]	450	720	flowing to the separator depending on the previous step. If wellhead pressure on 16A reaches 5,000 psi slow pump rate. If pressure continues to increase to 5,000 psi shutdown pumping and decide the next steps.
5.0	90	360 [6.0]			Maintain rate at 5.0 bpm and adjust the control valve to decrease back-pressure to 200 psi.
2.5	60	420 [7.0]	150	870	separator to maintain approximately 200 psi back pressure.
0.5	60	480 [8.0]	30	930	separator to maintain approximately 200 psi back pressure.

0	720	1200 [20.0]	0	930	200 psi back-pressure, then 0 back-pressure as flow declines. Refill all frac tanks with Milford City water.
5.0	360	1,560 [26.0]	1,800	2,730	Keep well 16B(78)-32 shut-in until pressure reaches 500 psi, then flow to the separator and maintain 400 psi back pressure. If wellhead pressure on 16A reaches 5,000 psi slow pump rate. If pressure continues to increase to 5,000 psi shut down pumping and decide the next steps. open the throttle (control) valve to the separator and maintain a back-pressure of 200 psi, which will keep water from flashing to steam up to ~375°F.
0	TBD				Shut in both wells. Minimum shut-in time of six hours – more depending on operational considerations and schedules.

Repeated Connection Evaluation from 16A(78)-32 to 16B(78)-32

The procedures (tentatively July 18-19, 2023) will be as follows.

- Rig up flow line system at 16B(78)-32. This configuration is shown in Figure B.2-28.
- Rig up treating iron from the SLB pumping equipment to the 16A(78)-32 casing valve and SLB wireline lubricator for running a spinner survey while pumping the circulation test. This configuration is shown in Figure B.2-29. Be prepared to pump at surface pressure up to 5,000 psi and pressure test all treating lines and wellhead equipment to 5,000 psi.
- Well 16B(78)-32 will be initially shut in while pumping into 16A(78)-32 and pressure will be monitored continuously to detect changes in pressure due to the connectivity between wellbores. When wellhead pressure on 16B(78)-32 reaches 200 psi start opening the throttling valve and flow to the separator maintaining a back-pressure of 100 psi. [Note: The back pressure may be decreased based on flow behavior. The decision will be made by the Utah FORGE manager and relayed to the DSM to be implemented].
- Pump water down the casing in Well 16A(78)-32 according to the schedule shown in Table 1. Tag this fluid with a discrete tracer (2,7-nts) by injecting into the suction manifold of the SLB pump truck.

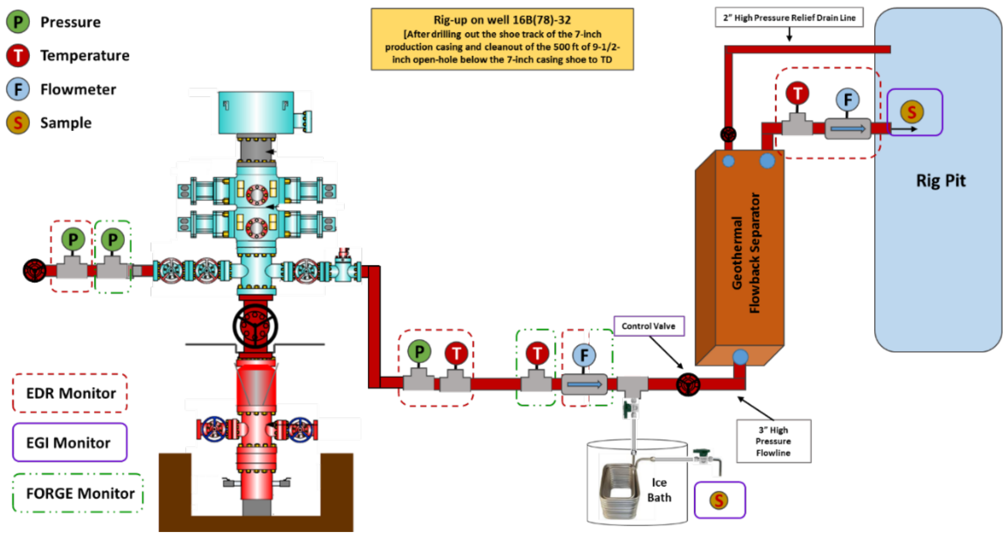


Figure B.2-28. *Flow line and data measurement configuration on Well 16B(78)-32 for short-term flow measurements after cementing the 7-inch casing.*

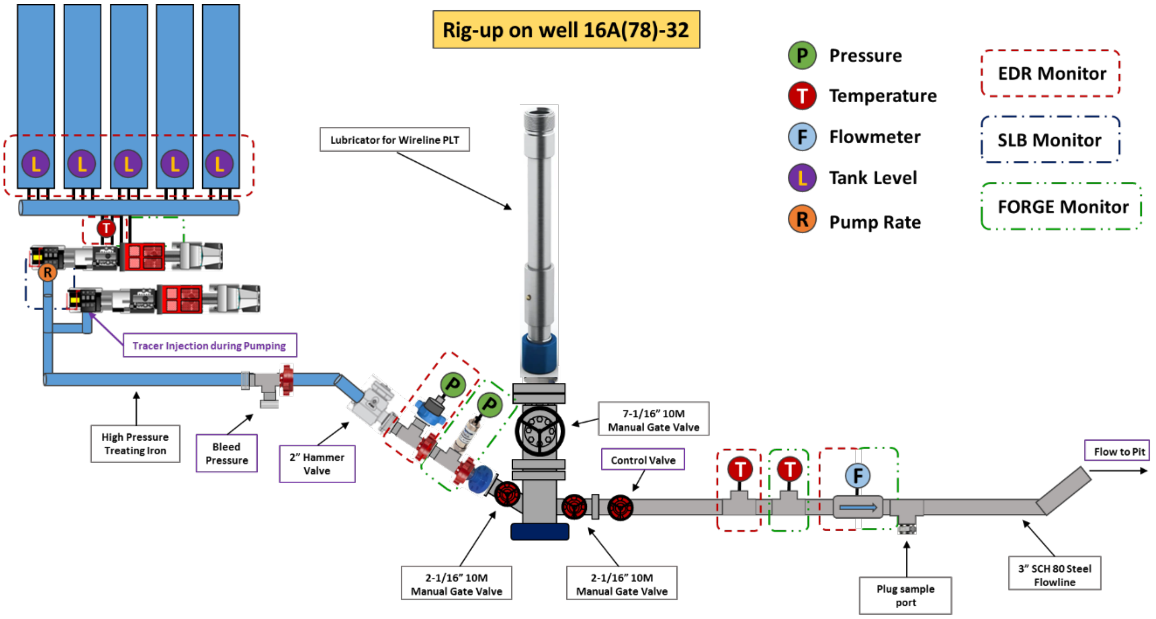


Figure B.2-29. *Flow line and data measurement configuration on Well 16A(78)-32 for short-term flow measurements after cementing the 7-inch casing.*

Table B.2-16. *Open-hole measurements after the 7-inch casing is run and cemented*

Injection Rate (BPM)	**Stage Time (min)**	**Cumulative Time (min) [hr]**	**Stage volume (bbl)**	**Cumulative volume (bbl)**	**Comment**
2.5	60	60 [1]	150	150	With Well 16B(78)-32 initially shut-in, start pumping water down the casing on Well 16A(78)-32. If wellhead pressure on Well 16B(78)-32 reaches 200 psi, start opening the throttling valve and flow to the separator while maintaining a back-pressure of 100 psi.
5.0	360	420 [7]	1800	1950	Increase injection rate to 5 bpm into Well 16A(78)-32 and maintain 100 psi back-pressure on Well 16B(78)-32 using the throttling valve while allow flow to the separator. [**Note:** The back pressure may be decreased based on flow behavior. The decision will be made by the Utah FORGE manager and relayed to the DSM to be implemented.]

10.0	30	450 [7.5]	300	2250	Depending on 16A(78)-32 wellhead pressure and flow conditions on Well 16B(78)-32 increase the injection rate to 10 bpm (or the highest rate achievable to keep wellhead pressure <5,000 psi). Inject the remaining volume of water available in the frac tanks and then shut down.
0	840	1290 [21.5]	0	0	Shut in Well 16A(78)-32 and Well 16B(78)-32 and monitor pressure while re-filling the frac tanks with water. Reset Cumulative Volume to 0 bbl.
5	450	1740 [29]	2250	2250	With Well 16B(78)-32 initially shut-in, start pumping water down the casing on Well 16A(78)-32. If wellhead pressure on Well 16B(78)-32 reaches 100 psi, start opening the throttling valve and flow to the separator while maintaining a back-pressure of 100 psi. [**Note:** The pressure to start opening the throttling valve and the amount of back pressure may be modified as described previously. Please follow the instructions of the DSM for controlling the pressure.]
0	480	2220 [37]	0	960	Shut in Well 16A(78)-32 and Well 16B(78)-32 for up to 8 hours and monitor pressure.

Revised Circulation 2 Program (Day 2)

SLB will run their UHT PLT logging tool in Well 16A(78)-32 during Circulation Test #2 on July 19, 2023. The objective of the PLT is to determine the injected fluid distribution profile into three separate intervals. The injection fluid for the circulation test is fresh water. The intervals correspond with the three hydraulic fracturing stages that were pumped on Well 16A(78)-32 in April 2022. All the intervals are in the 65° deviated portion of the wellbore near the toe. The lower interval is the 200 ft of open-hole section below the 7” casing shoe at 10,787 ft MD. The middle interval is a 20 ft perforated section in the 7” casing from 10,560 – 10,580 ft MD. The upper interval is a 20 ft perforated section in the 7” casing from 10,120 – 10,140 ft MD.

The PLT will be conveyed into the deviated section of the wellbore by the Petromac taxi with added weight bars. It is desirable to measure the rate distribution of the injected water into the three intervals at each different surface injection rate (see Circulation Test #2 procedure for pumping schedule).

Just before the beginning of the circulation test RIH with the PLT tool string on the Petromac taxi to a depth of ~10,000 ft MD to be above the upper perforated section. Begin pumping the circulation test at a rate of 2.5 bpm. Once the surface rate and spinner rate have stabilized move the PLT to a depth of ~10,350 ft MD, which is in between the perforated intervals, and take measurements until the spinner rate has stabilized. Move the PLT to a depth of 10,680 ft MD, which is below the lower perforated interval and above the 7” casing shoe. See the schematic of PLT setting depths in Figure B.2-30. [**Note:** Check to see if the sum of the last two spinner rates equals the spinner rate from above the upper perforated interval.]

At the end of the 2.5 bpm stage pull the PLT up the hole to 10,350 ft MD to make a measurement and then up to 10,000 ft MD to make a final measurement. [**Note:** Even at a constant surface injection rate the injected fluid distribution into the three intervals may also be highly dependent upon the surface injection pressure.]

After noting a stable spinner rate at 10,000 ft MD, increase the surface pump rate from 2.5 bpm to 5.0 bpm. Once the surface rate and spinner rate have stabilized move the PLT to a depth of ~10,350 ft MD and take measurements until the spinner rate has stabilized. Move the PLT to a depth of 10,680 ft MD and take measurements until the spinner rate has stabilized.

After approximately 2 hours of pumping at 5.0 bpm pull the PLT up the hole to 10,350 ft MD to measure until the spinner rate has stabilized and then up to 10,000 ft MD to make a measurement. [**Note:** Check to see if the injected fluid distribution into the three intervals is similar on the downward pass and upward pass at 5.0 bpm.]

If the results are quite a bit different continue pumping at 5.0 bpm for another hour and then, if the spinner rate is stable, move the PLT to a depth of ~10,350 ft MD, and take measurements until the spinner rate has stabilized then to a depth of 10,680 ft MD and take measurements until the spinner rate has stabilized. [**Note:** Check to see if the injected fluid distribution into the three intervals is similar on the downward pass and upward pass at 5.0 bpm.]

If the results of the downward and upward passed are similar at 5.0 bpm check to see if the fluid distribution into the three intervals is similar when comparing the results at 5.0 bpm with the results at 2.5 bpm.

If the results at the different rates are quite a bit different, consider increasing the surface pump rate from 5.0 bpm to 7.5 bpm (depending on pressure). Perform the same downward and upward passes with the PLT at this higher pump rate. It is important to understand the impact of changing surface injection rate and injection pressure on the distribution of injected fluid into the three separate intervals. [**Note:** If changing the rate from 5.0 to 7.5 bpm please recalculate the pumping time based on the volume of water remaining in the frac tanks. Leave at least 30 minutes of pumping time if planning to increase the surface pump rate to 10.0 bpm to allow time for moving the PLT to the different measurement depths.]

After pumping the available water volume from the frac tanks shut down the pumping equipment and POOH with the PLT. Shut in the 7-1/16” wellhead master valve and monitor pressure overnight while refilling the frac tanks with water.

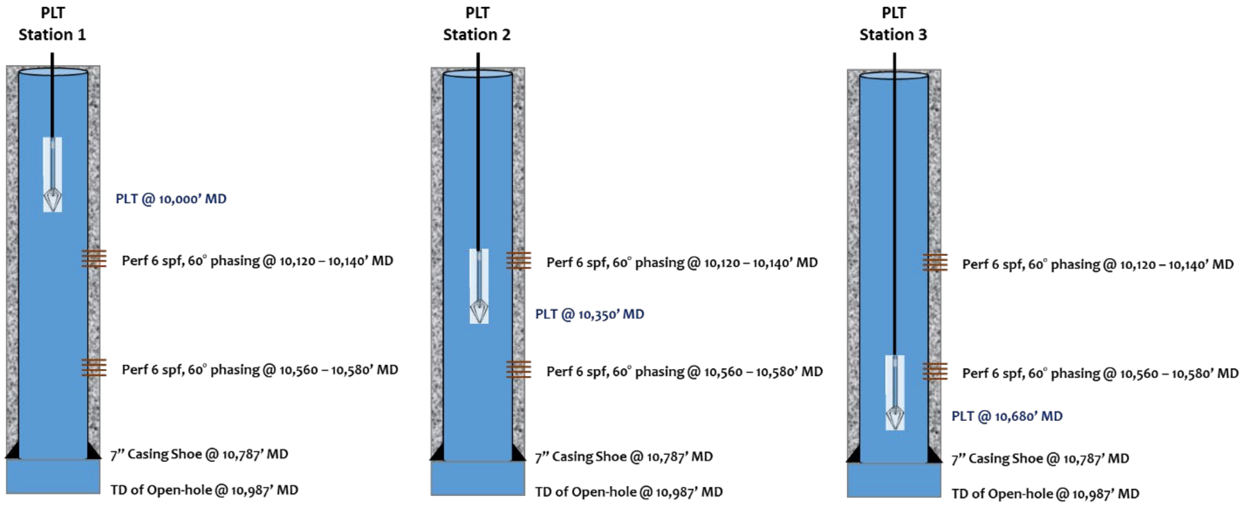


Figure B.2-30. *Proposed depths for PLT measurements*

Abbreviated Near-Final Program for Circulation 2, Day 2

The approximate protocol followed (pumping plan) is shown below (times may vary according to decisions made on location.

SLB will run their UHT PLT logging tool in Well 16A(78)-32 during Circulation Test #2 on July 19, 2023. The objective of the PLT is to determine the injected fluid distribution profile into three separate intervals. The injection fluid for the circulation test is fresh water. The intervals correspond with the three hydraulic fracturing stages that were pumped on Well 16A(78)-32 in April 2022. All the intervals are in the 65° deviated portion of the wellbore near the toe. The lower interval is the 200 ft of open-hole section below the 7” casing shoe at 10,787 ft MD. The middle interval is a 20 ft perforated section in the 7” casing from 10,560 – 10,580 ft MD. The upper interval is a 20 ft perforated section in the 7” casing from 10,120 – 10,140 ft MD.

The PLT will be conveyed into the deviated section of the wellbore by the Petromac taxi with added weight bars. It is desirable to measure the rate distribution of the injected water into the three intervals at each different surface injection rate (see Circulation Test #2 procedure for pumping schedule).

1. RU SLB Wireline to run PLT.
2. SLB pumping equipment is already rigged up to the wellhead casing valve.
3. Bleed some pressure off the well if necessary.
4. Open 7-1/16” wellhead valve.
5. RIH with PLT to a depth of **10,000 ft MD**.
6. Open the SLB 2” hammer valve.
7. Start pumping at **2.5 bpm**.

8. After 15 minutes (confirm that pump rate and spinner rate are stable) move PLT down to **10,350 ft MD**.
9. After 5 minutes at 10,350 ft MD (confirm pump rate and spinner rate are stable) move PLT down to **10,680 ft MD**.
10. After 5 minutes at 10,680 ft MD (confirm pump rate and spinner rate are stable) move PLT up to **10,350 ft MD**.
11. After 5 minutes at 10,350 ft MD (confirm pump rate and spinner rate are stable) move PLT up to **10,000 ft MD**.
12. After 5 minutes at 10,000 ft MD (confirm pump rate and spinner rate are stable) increase pump rate to **5.0 bpm**.
13. After 15 minutes (confirm pump rate and spinner rate are stable) move PLT down to **10,350 ft MD**.
14. After 5 minutes at 10,350 ft MD (confirm pump rate and spinner rate are stable) move PLT down to **10,680 ft MD**.
15. After 5 minutes at 10,680 ft MD (confirm pump rate and spinner rate are stable) move PLT up to **10,350 ft MD**.
16. After 5 minutes at 10,350 ft MD (confirm pump rate and spinner rate are stable) move PLT up to **10,000 ft MD**.
17. After 1 additional hour of pumping at **5.0 bpm**, move PLT down to **10,350 ft MD**.
18. After 5 minutes at 10,350 ft MD (confirm pump rate and spinner rate are stable) move PLT down to **10,680 ft MD**.
19. After 5 minutes at 10,680 ft MD (confirm pump rate and spinner rate are stable) move PLT up to **10,350 ft MD**.
20. After 5 minutes at 10,350 ft MD (confirm pump rate and spinner rate are stable) move PLT up to **10,000 ft MD**.
21. At this time, a decision may be made to increase the rate to **7.5 bpm** and, after 15 minutes (confirm pump rate and spinner rate are stable), **repeat steps 13 to 16 at this rate** or as directed by the Utah FORGE manager.
22. Continue pumping at **7.5 bpm** and move the PLT down to **10,350 ft MD** and monitor.
23. 30 minutes before the end of pumping move the PLT down to **10,680 ft MD**.
24. After 5 minutes at 10,680 ft MD (confirm pump rate and spinner rate are stable) move PLT up to **10,350 ft MD**.
25. After 5 minutes at 10,350 ft MD (confirm pump rate and spinner rate are stable) move PLT up to **10,000 ft MD**.

26. Continue pumping at **7.5 bpm** until a decision is made to shut down pumping. Close SLB 2” hammer valve. Bleed pressure off the treating line upstream of the 2” hammer valve. RD SLB pumping equipment.
27. POOH with SLB PLT
28. Close 7-1/16” wellhead valve.
29. Bleed off pressure to lubricator and RD SLB Wireline.
30. Monitor pressure.

Spinner Survey Methods

Well Bore Information:

Casing	7" 38.00#, T-95, 0 - 10738' MD.
Production Tubing	None.
KOP	5957' MD / 5955.66' TVD / 5.67 degrees deviation.
EOB	7377' MD / 7045.98' TVD / 67.49 degrees deviation.
Toe	10995' MD / 8558.83' TVD / 68.6 degrees deviation.
Perforations	10120-10140', 10560-10580', and Openhole 10738-10938' MD.
Correlation:	Schlumberger SlimXtreme Sonic Log CBL-VDL dated 16-Aug-2021.

Ultra-High Temperature PSP Logging Procedure:

1. RU SLB Wireline to run PLT.
2. SLB pumping equipment is already rigged up to the wellhead casing valve.
3. Bleed some pressure off the well if necessary.
4. Open 7-1/16” wellhead valve.
5. RIH with PLT to a depth of 10,000 ft MD.
6. Open the SLB 2” hammer valve.
7. Start pumping at 2.5 bpm.
8. After 5 minutes at 10,350 ft MD (confirm pump rate and spinner rate are stable) move PLT down to 10,680 ft MD.
9. After 15 minutes (confirm that pump rate and spinner rate are stable) move PLT down to 10,350 ft MD.
10. After 15 minutes (confirm pump rate and spinner rate are stable) move PLT down to 10,350 ft MD.

11. After 5 minutes at 10,000 ft MD (confirm pump rate and spinner rate are stable) increase pump rate to 5.0 bpm.
12. After 5 minutes at 10,350 ft MD (confirm pump rate and spinner rate are stable) move PLT up to 10,000 ft MD.
13. After 5 minutes at 10,350 ft MD (confirm pump rate and spinner rate are stable) move PLT up to 10,000 ft MD.
14. After 5 minutes at 10,680 ft MD (confirm pump rate and spinner rate are stable) move PLT up to 10,350 ft MD.
15. After 5 minutes at 10,350 ft MD (confirm pump rate and spinner rate are stable) move PLT down to 10,680 ft MD.
16. After 5 minutes at 10,680 ft MD (confirm pump rate and spinner rate are stable) move PLT up to 10,350 ft MD.
17. After 5 minutes at 10,350 ft MD (confirm pump rate and spinner rate are stable) move PLT up to 10,000 ft MD.
18. After 1 additional hour of pumping at 5.0 bpm, move PLT down to 10,350 ft MD.
19. After 5 minutes at 10,350 ft MD (confirm pump rate and spinner rate are stable) move PLT down to 10,680 ft MD.
20. After 5 minutes at 10,680 ft MD (confirm pump rate and spinner rate are stable) move PLT up to 10,350 ft MD.
21. At this time, a decision may be made to increase the rate to 7.5 bpm and, after 15 minutes (confirm pump rate and spinner rate are stable), repeat steps 13 to 16 at this rate or as directed by the Utah FORGE manager.
22. Continue pumping at 7.5 bpm and move the PLT down to 10,350 ft MD and monitor.
23. 30 minutes before the end of pumping move the PLT down to 10,680 ft MD.
24. POOH with SLB PLT
25. Close 7-1/16” wellhead valve.
26. Bleed off pressure to lubricator and RD SLB Wireline.
27. Monitor pressure.

B.3 STIMULATION PROGRAM WELLS 16A(78)-32 AND 16B(78)-32

Operational and Scientific Objectives

The previous stimulation of well 16A(78)-32, in April 2022, consisted of one (1) open hole stage and two (2) single cluster perforation stages and moderate injection rates up to 50 bpm. An EOJ report is available on GDR. The operations in March and April 2024 included eight (8) additional stages in well 16A(78)-32, and four (4) stages in well 16B(78)-32 along with nine hours of confirmatory circulation testing. The stimulations included the use of proppant, stages with multiple clusters, newly designed frac plugs, slickwater and viscosified fluid, and injection rates up to 80 bpm. The frac spread is shown in Figure B.3-1.

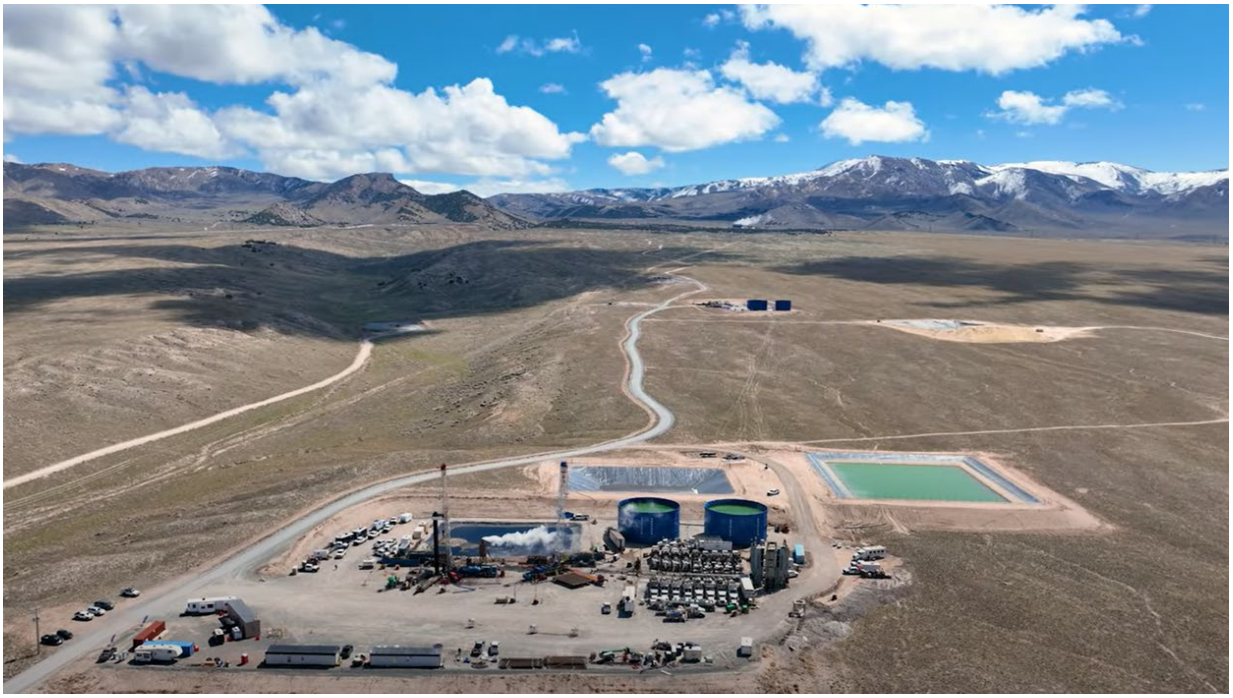


Figure B.3-1. *An aerial view (looking east, north is to the left of the photograph) of the frac spread on the 16A/16B well pad including two 25,000 bbl (each) Harpoon frac tanks and a workover rig on each well. In the background, two Harpoon tanks are visible on the 58-32 pad (a 15,000 bbl tank and a 25,000 bbl tank). The remote tanks are connected to a 125,000-bbl treating water pit (southernmost pit). To its immediate north is a 75,000 bbl pit used to accommodate flowback water.*

Stimulation Program Overview

Introduction

In July 2023, well 16B(78)-32, the production well, was completed to a measured depth of 10,947 ft MD and 300 ft vertically above well 16A(78)-32; the latter serves as the injection well (Fig. 2). Well 16A(78)-32 was drilled to 10,987 ft MD. Short-term interwell tests demonstrated connections between the two wells in July 2023. Both wells were stimulated (well 16A(78)-32 and 16B(78)-32) in April 2024. Three surrounding vertical wells were used for seismic and fiber optics monitoring.

The planned stimulation and circulation programs are summarized in Table B.3-1. Actual activities are detailed subsequently. Both wells 16A(78)-32 and 16B(78)-32 were stimulated and a moderate circulation test (9 hours) was conducted to assess connections between them. The stimulations were intended to test the use of silica sand proppant (and an ultralightweight proppant), stages with multiple clusters, frac plugs, slickwater and viscosified fluid, and injection rates up to 80 bpm (Table B.3-1). The planned sequence of tests is shown in Figure B.3-3.

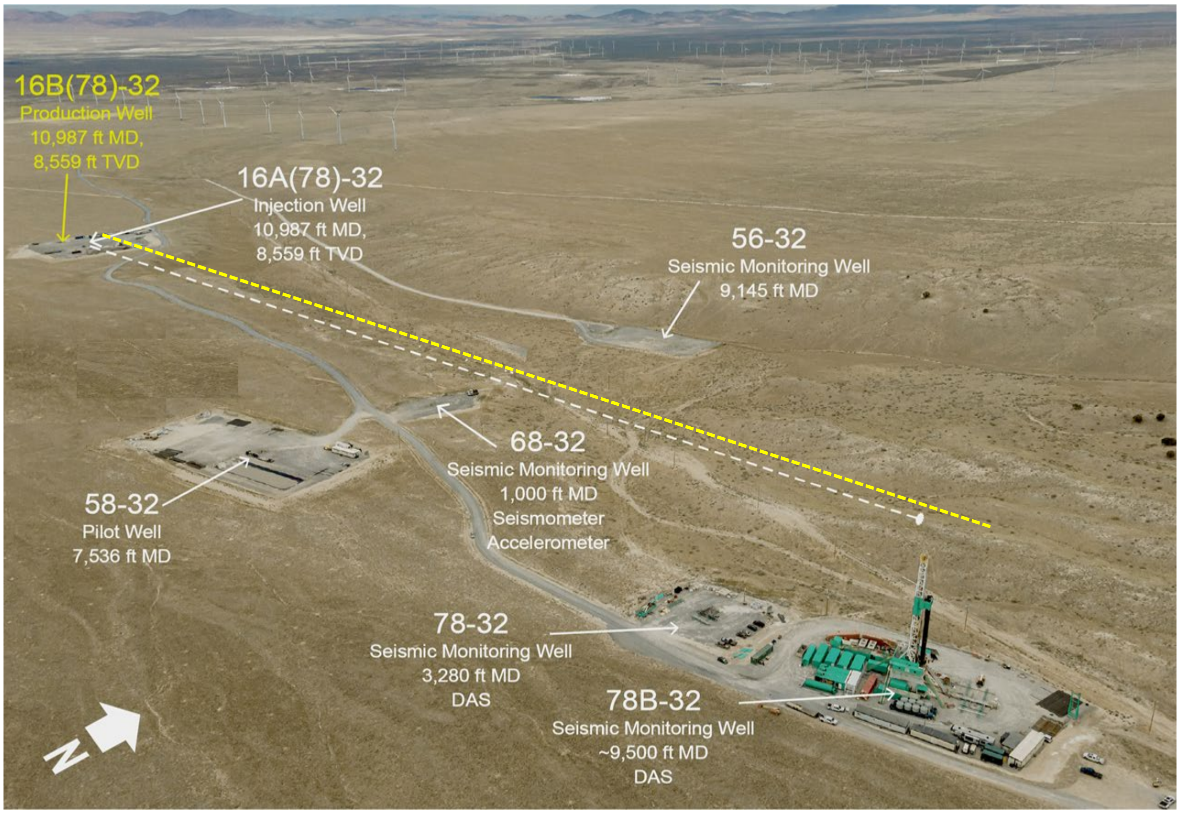


Figure 2. *The injection well (16A(78)-32) was drilled just south of east in the anticipated direction of the horizontal minimum stress. The well as-drilled at 65° to the vertical and its projection onto the surface is approximated by the white dashed line. Its counterpart (producer) is well 16B(78)-32 and that well was drilled 300 ft vertically above and parallel to the injector. Its projection on a horizontal plane is approximated by the white dashed line.*

Table B.3-1. Summary of the as-planned individual stimulation and circulation tests.

Well	Stage Name	# of Clusters	Fluid Type	Fluid Volume (bbl)	Pump Rate (bpm)	100-mesh Prop Vol (lbm)	40/70-mesh Prop Vol (lbm)	Pump Time (hr)	Comments
Re-treatment of three zones stimulated in 2022 – no new perforating required.									
16A(78)-32+	Stage 3R (16A)	2 + OH	Water	10,000	50	136,500	199,500	3.5	Refrac of the 3 stages pumped in April 2022 w/ proppant
New treatment stages in well 16A(78)-32. Isolation and perforating will be required for each of these stages.									
16A(78)-32	Stage 4 (16A)	1	Slickwater	4,000	35	54,600	79,800	2.5	Evaluate frac fluid viscosity/fracture geometry & proppant placement
16A(78)-32	Stage 5 (16A)	1	XL CMHPG	4,000	35	54,600	79,800	2.5	Evaluate frac fluid viscosity/fracture geometry & proppant placement
16A(78)-32	Stage 6 (16A)	1	XL CMHPG	4,000	35	54,600	79,800	2.5	Evaluate alternative proppant transport/placement technology
16A(78)-32	Stage 7 (16A)	4	XL CMHPG	16,000	80-100[2]	218,400	319,200	4.0	Evaluate multiples clusters / Spacing = 50 ft
16A(78)-32	Stage 8 (16A)	8	XL CMHPG	32,000	80-100[1]	436,800	638,400	7.0	Evaluate multiples clusters / Spacing = 25 ft
16A(78)-32	Stage 9 (16A)	8	Slickwater	32,000	80-100[1]	436,800	638,400	7.0	Evaluate frac fluid viscosity / Spacing = 25 ft

---

[2] Depending on the surface treating pressure

Well	Stage Name	# of Clusters	Fluid Type	Fluid Volume (bbl)	Pump Rate (bpm)	100-mesh Prop Vol (lbm)	40/70-mesh Prop Vol (lbm)	Pump Time (hr)	Comments
New treatment stages in well 16B(78)-32. Perforating will be required for each of these stages.									
16B(78)-32	Stage 1 (16B)	4	Slickwater	4,000	60	54,600	79,800	1.25	Perf cluster depths are based on the interpretation of frac hit from stimulation stages pumped in well 16A(78)-32
16B(78)-32	Stage 2 (16B)	4-6	Slickwater	4,000	60	54,600	79,800	1.25	Perf cluster depths are based on the interpretation of frac hit from stimulation stages pumped in well 16A(78)-32
16B(78)-32	Stage 3 (16B)	4-6	Slickwater	4,000	60	54,600	79,800	1.25	Perf cluster depths are based on the interpretation of frac hit from stimulation stages pumped in well 16A(78)-32
16B(78)-32	Stage 4 (16B)	4-6	Slickwater	4,000	60	54,600	79,800	1.25	Perf cluster depths are based on the interpretation of frac hit from stimulation stages pumped in well 16A(78)-32
After all frac plugs have been drilled out in 16A(78)-32 and stimulation stages have been performed in 16B(78)-32 – Pump new circulation test in 16A(78)-32.									
16A(78)-32	Circ Test 3 (16A)	25 + OH	Water	10,800	20	N/A	N/A	9.0	The pump rate will depend on the surface treating pressure

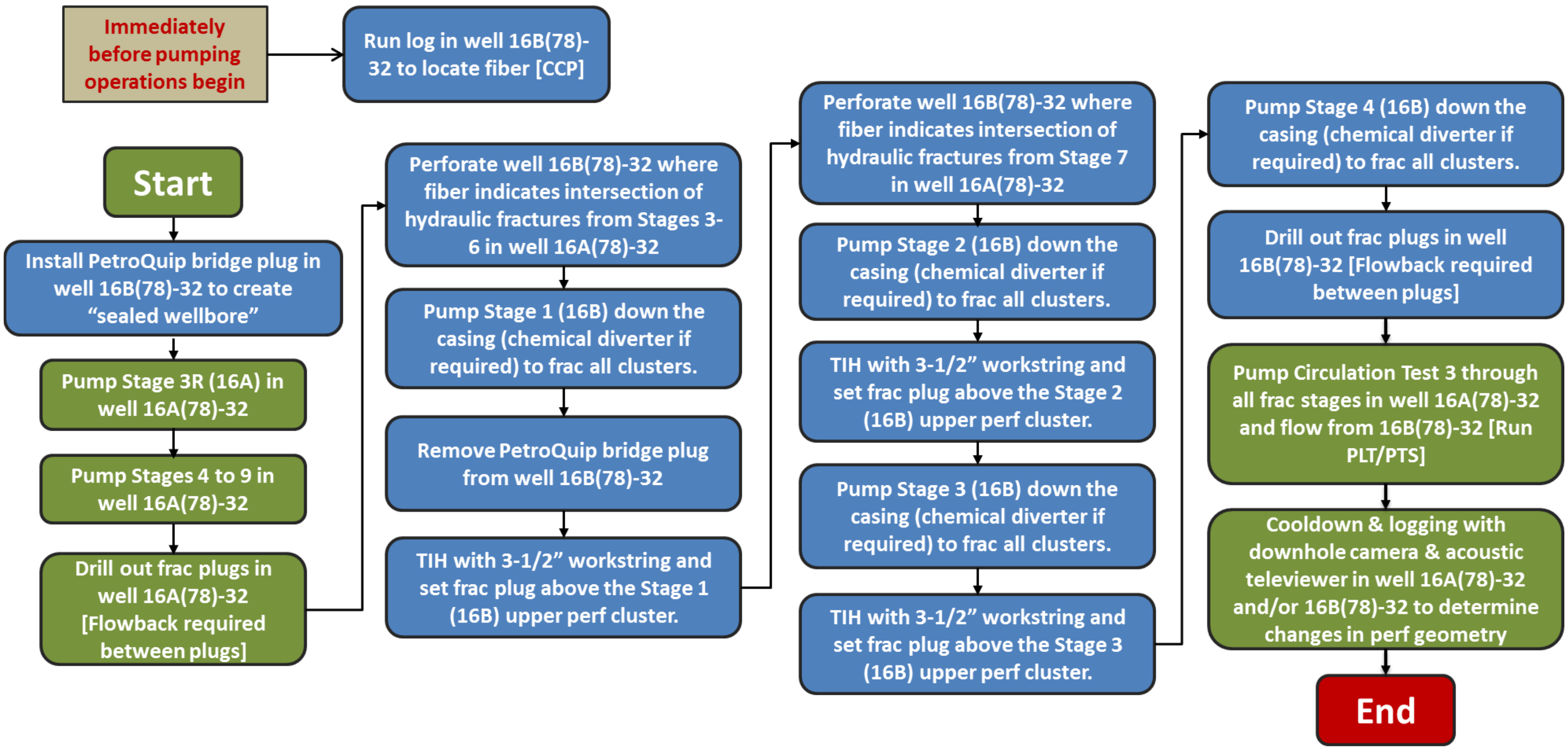


Figure B.3-3. *Summary of the stimulation prognosis workflow*

The stimulations were monitored continuously for microseismicity using fiber optic cables cemented in the annulus of well 16B(78)-32, 78-32, and 78B-32. The fibers in well 16B(78)-32 were also used to monitor frac hits. Geophone chains were run in wells 58-32, 56-32, and 78B-32. The number and locations of the microseismic events during each stimulation stage were determined by Geo Energie Suisse AG, Rice University, Silixa, the University of Texas-Austin, and SLB. Event magnitudes and frequencies were evaluated in comparison to the limits established by the Traffic Light System developed for Utah FORGE which has been in use since well 16A(78)-32 was drilled. This mitigation plan is contained within the Utah FORGE Induced Seismic Mitigation Plan (ISMP) and will be posted at the site during the stimulation. At no time did the Traffic Light System go to amber. All recorded events were less than 2 M.

General Considerations

The following section describes the major considerations that were incorporated into the stimulation plan.

1. Before moving in equipment for the stimulation treatments a workover rig provided by UDES (Delsco Northwest) was spotted on well 16B(78)-32 to MIRU wireline to run logs to map the location of the fiber optic cables cemented in the annulus of the 7", 38 lb/ft casing. The mapping of the fiber optic cables was determined to allow orienting the perforating guns away from the fiber optic lines when perforating the 7" casing in well 16B(78)-32.
2. The workover rig on well 16B(78)-32 was also used to run Nine Energy frac plugs, Halliburton perforating guns, and to drill out frac plugs.
3. An additional UDES workover rig was moved in and rigged up over well 16A(78)-32 to drill out frac plugs after stimulation.
4. Two Harpoon tanks (40,000 bbl total) were assembled and filled by Shalestone on the pad of well 58A-32. A water well (well 58B-32) had been drilled on that pad. The tankage is connected to the 16A/B pad by a 6-inch diameter hard line laid on the surface. There were two 25,000 bbl (each) Harpoon tanks on the 16A/B pad and a 125,000 bbl pit for frac fluid (east of the pad). There is also a 75,000 bbl flowback pit.
5. The objective was to evaluate hydraulic fracture initiation and propagation as a function of fracturing fluid viscosity, pump rate, proppant type and size, number and spacing of perforation clusters, etc. Some of the stages were designed to pump a higher-viscosity fluid system. A crosslinked CMHPG fluid system was used in the previous fracture stimulation treatments on well 16A(78)-32 in April 2022. The crosslinked CMHPG fluid is an appropriate high-viscosity fluid system, but other systems proposed will be considered. Rheological degradation will occur at higher temperatures. The proppant used was 100-mesh and 40/70-mesh Genoa Sand for each of the frac stages in well 16A(78)-32 and well 16B(78)-32.
6. Chemical and nanoparticulate tracers were used during the pumping operations to determine the connection(s) present between wells 16A(78)-32 and 16B(78)-32.

7. Both wells 16A(78)-32 and 16B(78)-32 had flow lines rigged up to a sand separator and an atmospheric geothermal separator that had flow lines to the pit on Pad 16A/B (This is the Pad where the 16A(78)-32 and 16B(78)-32 wellheads are located). As part of the water management plan, there was the ability to transfer water out of the pit in case it filled. Both wells 16A(78)-32 and 16B(78)-32 were instrumented with sensors to monitor and record pressure, temperature, and flow rates for the duration of the operations (refer to Figure B.3-4).
8. Well 16A(78)-32 has been successfully logged where the bottomhole temperature was found to be 430°F. Well 16B(78)-32 was drilled so that the 65° tangent section of the wellbore is ±300 ft directly above the 65° tangent section of the 16A(78)-32 wellbore. Figure B.3-5 shows the final trajectories of the wellbores from the survey data in elevation (side) view.
9. Geophones were installed as appropriate in three wells (58-32, 56-32, 78B-32). These wells allowed triangulation on microseismicity from treatments pumped in both well 16A(78)-32 and well 16B(78)-32. The maximum temperature that the geophones can be exposed to is 302°F (150˚C), which will determine the depth to which they are run.

Figure B.3-4. *Some of the flow equipment and instrumentation. The atmospheric separator and liquid flow line are shown in the background. A choke manifold (to control the flow rate from the well) is seen in the foreground.*

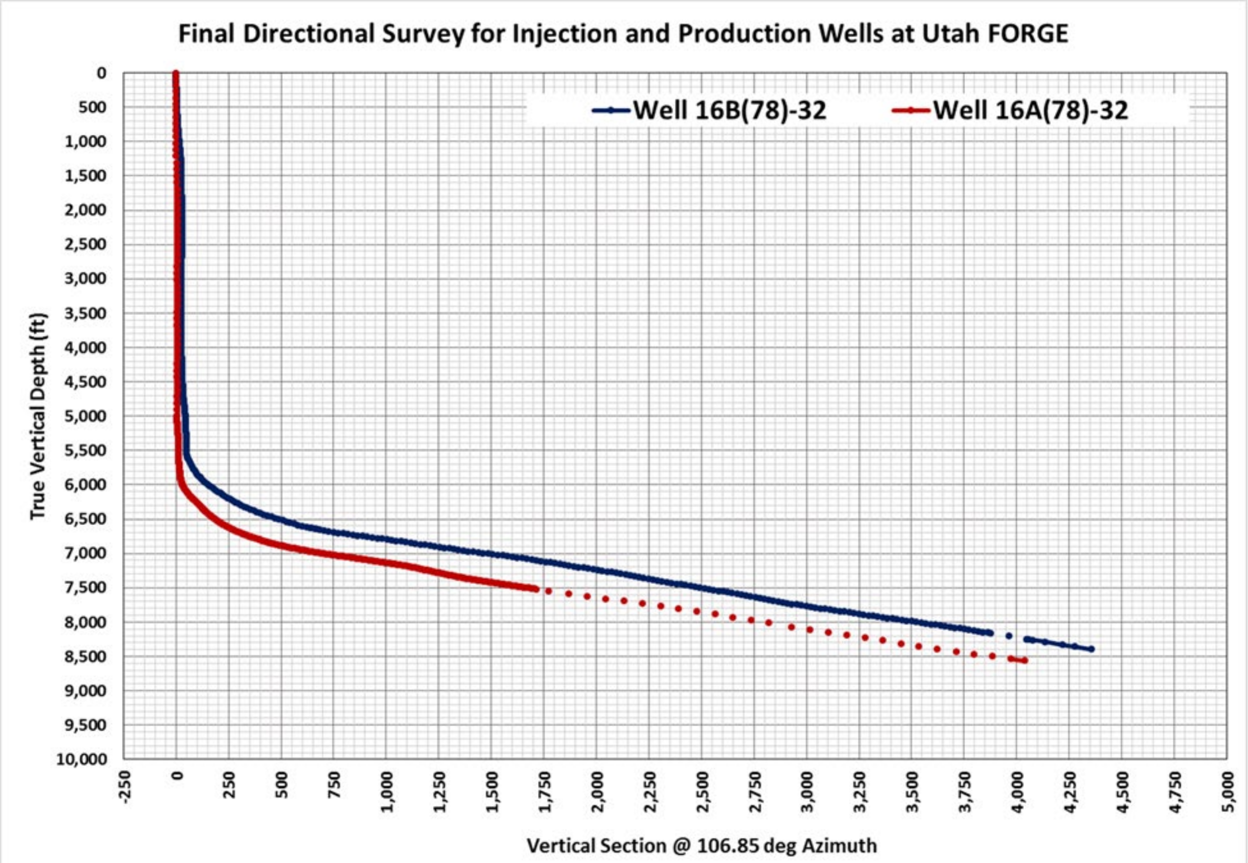


Figure B.3-5. *Final Trajectory of wells 16A(78)-32 and 16B(78)-32 in elevation (Side) view. The dotted section of well 16A(78)-32 is where stimulation was carried out. In fact, it continues a little heelward because an additional stage was added on the fly.*

Workover Operations on Well 16B(78)-32

As indicated above, a workover rig was rigged up on well 16B(78)-32 before rigging up a workover rig on well 16A(78)-32. Part of the overall wellsite operations plan was to test a 7” bridge plug that was developed by PetroQuip Energy Services as part of an R&D project that was awarded to PetroQuip from Utah FORGE Solicitation 2020-1, Topic 1 - Devices suitable for sectional (zonal) isolation along both cased and open-hole wellbores under geothermal conditions. The initial work included making a bit and scraper run (scraper was positioned in the 3-1/2” workstring so that it did not pass through the PetroQuip landing profile sub) to ensure the wellbore is fully accessible and clear of any debris to the TD of the open-hole wellbore below the 7” casing shoe. A second trip into the wellbore was performed with a drift sub (OD = 5.70”) to ensure that the PetroQuip landing profile sub had the proper clearance for setting of the bridge plug. A mechanical casing collar locator run failed.

The rig tripped into well 16B(78)-32 with the 3-1/2” tubing and the PetroQuip bridge plug. The bridge plug was latched into the landing profile sub. The setting tool was disconnected from the bridge plug and the 3-1/2” workstring was TOOH. The bridge plug was successfully pressure tested to 7,500 psi. A “sealed wellbore” test was envisioned. Unfortunately, some days later when it was desirable to pressurize this sealed wellbore before treating well 16A(78)-32, the seal on the bridge plug was lost. It was not possible to retrieve the bridge plug. However, the response of the fiber optic lines on the outside of the 7” casing string on well 16B(78)-32 was able to verify the locations of “frac hits” and approaching strain fronts.

SLB logged the well with an isolation scanner and a WPP tool to locate fibers. Even with cooldown, the WPP tool could only tolerate limited on bottom time.

Hydraulic Fracturing of Well 16A(78)-32

High-pressure pumping equipment, backside equipment (blender, hydration unit, chemical additive systems, proppant silos, etc.), and the frac treatment control van were all rigged up. Calfrac was the pumping services provider. Measurement of all critical treatment parameters (rates, pressure, density, additives.) had some redundancy (backup) in case there was any failure of the primary measurement. Pressure measurement was required for the wellhead, annulus (if pumping any treatment through a 3-1/2” workstring), and frac pumps. Rig-up of frac treating iron provided for isolation of the high-pressure pumps from the wellhead so that wellhead pressure and annulus pressure can be measured without the possibility of pressure bleeding back through the pumping equipment and real-time recording even if pumping equipment is disconnected. Frac operations were performed 24/7.

A unique chemical tracer was added to each different frac stage according to the following procedure. Tracer services were provided by Resman and QuantumPro. The collection of samples was performed by university and vendor personnel.

Generic procedures for the hydraulic fracturing operations are as follows. The planned operations for each stage are summarized in Table B.3-2.

1. Safety meetings were performed as scheduled and appropriate.
2. Confirm all microseismic and fiber optic monitoring systems are functional and able to provide near real-time locations of events detected (microseismic and waterfall plots). Confirm all communication systems and real-time microseismic processing are running and functional and can be communicated as required. Ensure that the permanent fiber optic cables on the outside of the 7” casing in well 16B(78)-32 are being monitored and data are being archived for the duration of the operation.
3. **The maximum allowable surface pressure for pumping operations on both well 16A(78)-32 and well 16B(78)-32 will be 8,000 psi.** Calfrac provided in-line automatic pressure relief valves. Pressure test all frac treating lines upstream of the wellhead to 8,500 psi or higher (wellhead isolated).

Planned – Stage 3R (16A)

Stage 3R (16A): This stage was pumped into the three existing frac stages in well 16A(78)-32 that were performed in April 2022. No proppant was pumped in 2022 (a small amount of micropropant was pumped into Stage 3) but this refrac of those 3 stages included the addition of proppant. The pump (injection) rate, surface treating pressure, proppant concentration, additive rates, etc. were monitored and recorded by the pressure pumping provider and on the EDR equipment. Utah FORGE was responsible for monitoring wellhead pressure (independently from Calfrac) along with flow rate and temperature on well 16B(78)-32 between the wellhead and separator, flow rate and temperature at the discharge of the separator along with microseismic in three offset wells, fiber optics in offset wells and on the outside of the 7” casing in well 16B(78)-32, along with other instrumentation that was provided.

The generic plan was as follows.

a) Begin the fracture stimulation treatment by pumping slickwater at a rate of 5 bpm to determine the formation breakdown pressure. Hold the rate for 5 minutes and then perform a hard shutdown to get the ISIP.
b) Resume pumping, work the pump rate up to 50 bpm, and begin injecting the chemical tracer.

Note: If at any time the surface pressure exceeds approximately 7,900 psi, reduce the rate by 5 bpm. Continue reducing the rate, as necessary.

Stage 3R (16A) Fracturing Treatment Schedule

Step Name	Step Pump Rate (bpm)	Step Fluid Volume (bbl)	Step Fluid Type	Cum Fluid Volume (bbl)	Step Prop Conc (PPA)	Step Prop Type (US mesh)	Step Prop Volume (lbm)	Cum Prop Volume (lbm)	Step Slurry Volume (bbl)	Step Pump Time (min)	Cum Pump Time (min)
Pad	50	2,000	Slickwater	2,000	0.00		0	0	2,000	40.0	40.0
0.5 PPA	50	1,000	Slickwater	3,000	0.50	100	21,000	21,000	1,023	20.5	60.5
0.75 PPA	50	1,000	Slickwater	4,000	0.75	100	31,500	52,500	1,034	20.7	81.1
1.00 PPA	50	2,000	Slickwater	6,000	1.00	100	84,000	136,500	2,091	41.8	122.9
1.00 PPA	50	2,000	Slickwater	8,000	1.00	40/70	84,000	220,500	2,091	41.8	164.8
1.25 PPA	50	1,000	Slickwater	9,000	1.25	40/70	52,500	273,000	1,057	21.1	185.9
1.50 PPA	50	1,000	Slickwater	10,000	1.50	40/70	63,000	336,000	1,068	21.4	207.3
Flush	50	350	Slickwater	10,350	0.00		0	336,000	350	7.0	214.3
Slickwater		10,350	bbl	434,700	gal		100-mesh sand		136,500	lbm	
							40/70-mesh sand		199,500	lbm	

c) Just before the end of the final proppant stage, stop pumping the chemical tracer.

d) With ~20 bbl left to pump, begin stepping down the pump rate and shut down.

e) After shutdown open/close the necessary valves and coordinate with wireline for the pump down plug and guns operation.

f) Begin pumping to deploy the frac plug and perforation guns into the 16A(78)-32 wellbore at the recommended pump rate. Maintain effective communication to monitor surface pumping pressure, plug depth, wireline tension, etc.

g) Slow rate when the frac plug is near the desired setting depth. Stop pumping when the plug is at the desired setting depth, verify measurements, and set the plug.

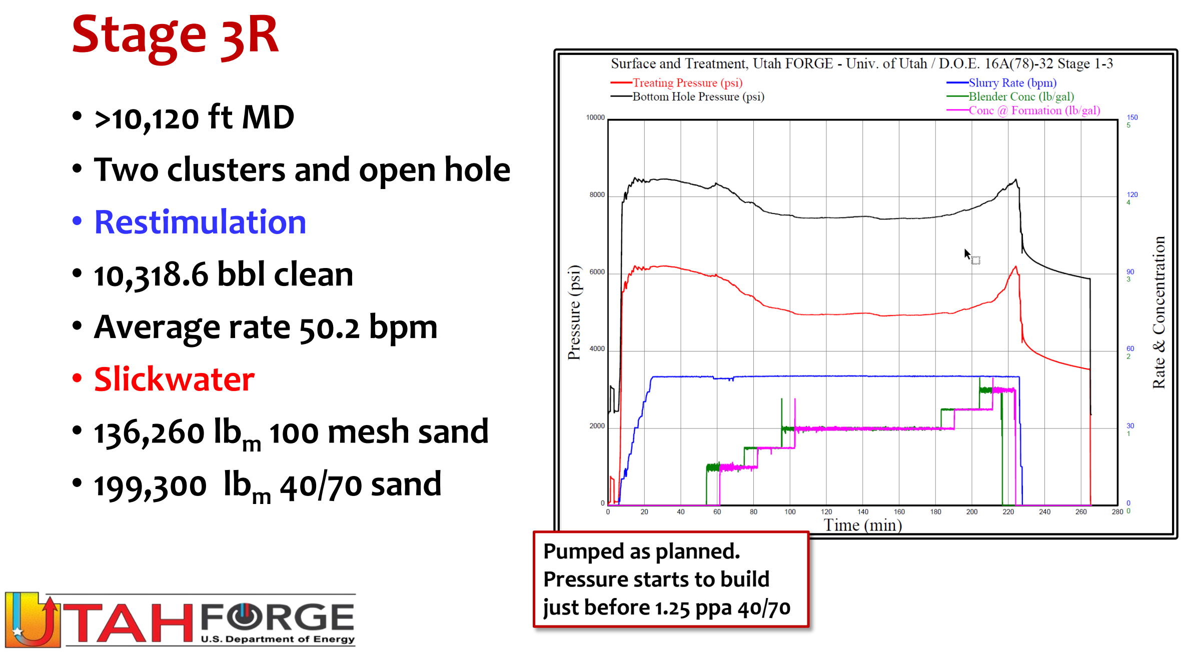
h) After the plug has been set, pull off of the plug and POOH with wireline to position the perforating guns at the desired depth. Stop POOH with wireline when perforating guns are at depth. Verify measurement and fire the guns.

i) POOH with wireline and associated tools. Verify all tools successfully retrieved at the surface and all perforation charges have fired. Close the upper valve to isolate the wireline.

j) Open/close necessary valves in preparation to pump the next frac stage.

As Pumped – Stage 3R (16A)

Figure B.3-6 summarizes the treatment parameters. The bottomhole pressure is preliminary and could be adjusted following additional estimates of friction pressure. The stage was pumped nearly to plan as shown in the figure (compare this with the foregoing table). Pressure was building and screenout/pressure out was imminent.



Stage 3R

- >10,120 ft MD
- Two clusters and open hole
- Restimulation
- 10,318.6 bbl clean
- Average rate 50.2 bpm
- Slickwater
- 136,260 lb_m 100 mesh sand
- 199,300 lb_m 40/70 sand

Pumped as planned. Pressure starts to build just before 1.25 ppa 40/70

***Figure B.3-6.** Treatment records for stage 3R.*

Planned – Stage 4 (16A)

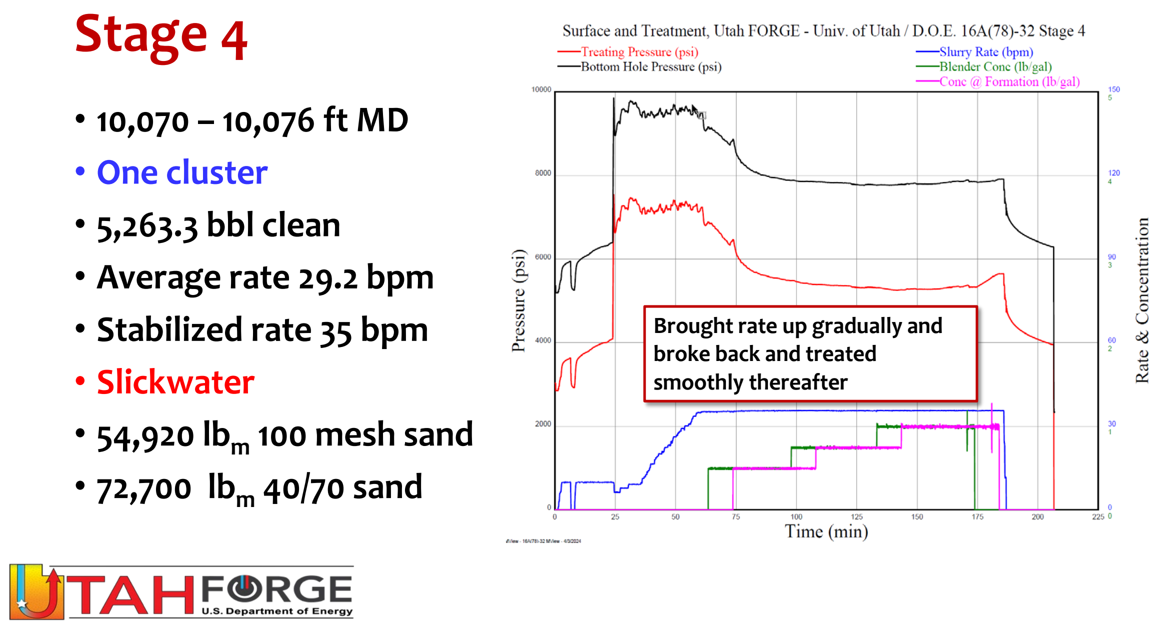
Stage 4 (16A): This stage design was like that of **Stage 2 (16A)** which was pumped on well 16A(78)-32 in April 2022 – but, with a larger volume of fluid and the addition of proppant. The operational procedures for lining out the rate and running the next plug and perforating are like those described above.

Stage 4 (16A) Fracturing Treatment Schedule

Step Name	Step Pump Rate (bpm)	Step Fluid Volume (bbl)	Step Fluid Type	Cum Fluid Volume (bbl)	Step Prop Conc (PPA)	Step Prop Type (US mesh)	Step Prop Volume (lbm)	Cum Prop Volume (lbm)	Step Slurry Volume (bbl)	Step Pump Time (min)	Cum Pump Time (min)
Pad	35	800	Slickwater	800	0.00		0	0	800	22.9	22.9
0.5 PPA	35	400	Slickwater	1,200	0.50	100	8,400	8,400	409	11.7	34.5
0.75 PPA	35	400	Slickwater	1,600	0.75	100	12,600	21,000	414	11.8	46.4
1.00 PPA	35	800	Slickwater	2,400	1.00	100	33,600	54,600	836	23.9	70.3
1.00 PPA	35	800	Slickwater	3,200	1.00	40/70	33,600	88,200	836	23.9	94.1
1.25 PPA	35	400	Slickwater	3,600	1.25	40/70	21,000	109,200	423	12.1	106.2
1.50 PPA	35	400	Slickwater	4,000	1.50	40/70	25,200	134,400	427	12.2	118.4
Flush	35	350	Slickwater	4,350	0.00		0	134,400	350	10.0	128.4

As Pumped – Stage 4 (16A)

This treatment was pumped near plan (refer to Figure B.3-7). There was a single cluster (two three-foot guns with 6 shots per foot at 60° phasing). After bringing the rate up in a controlled fashion, the formation broke back and treated easily. Some of the fiber optics data suggest communication with Stage 3R, but this cannot be verified from the treating records alone.



Stage 4

- 10,070 – 10,076 ft MD
- One cluster
- 5,263.3 bbl clean
- Average rate 29.2 bpm
- Stabilized rate 35 bpm
- Slickwater
- 54,920 lb_m 100 mesh sand
- 72,700 lb_m 40/70 sand

Brought rate up gradually and broke back and treated smoothly thereafter

Figure B.3-7. *Treatment records for Stage 4.*

Planned – Stage 5 (16A)

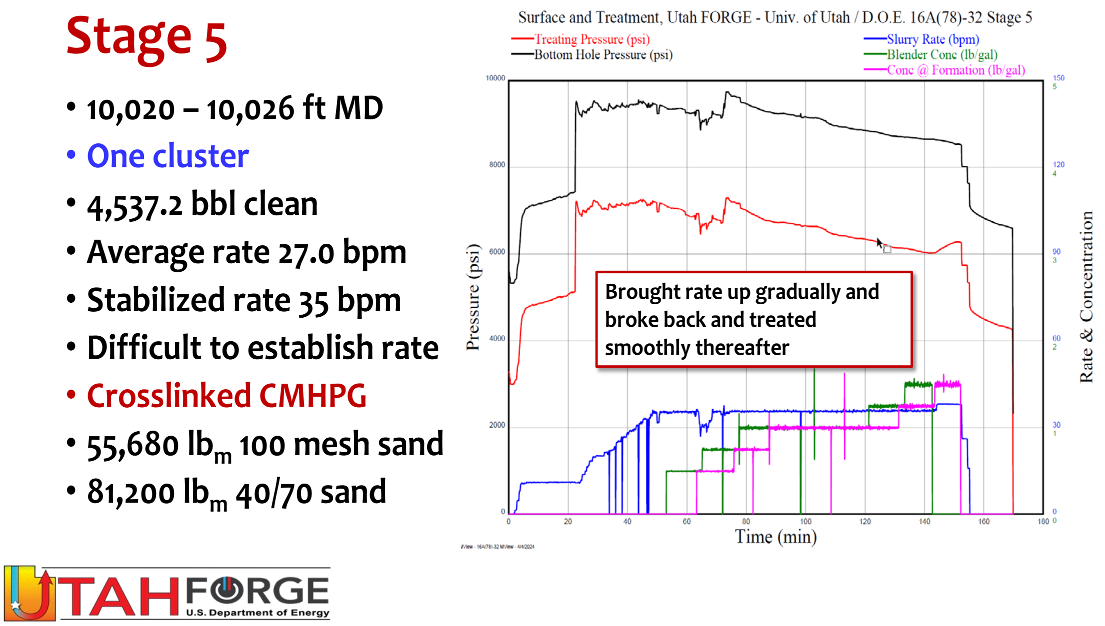
Stage 5 (16A): This stage design is like that of **Stage 3 (16A)** which was pumped on well 16A(78)-32 in April 2022 with a larger volume of fluid and the addition of proppant. The pump (injection) rate, surface treating pressure, proppant concentration, additive rates, etc. will be monitored and recorded. This stage used XL CMHPG.

Stage 5 (16A) Fracturing Treatment Schedule

Step Name	Step Pump Rate (bpm)	Step Fluid Volume (bbl)	Step Fluid Type	Cum Fluid Volume (bbl)	Step Prop Conc (PPA)	Step Prop Type (US mesh)	Step Prop Volume (lbm)	Cum Prop Volume (lbm)	Step Slurry Volume (bbl)	Step Pump Time (min)	Cum Pump Time (min)
Pad	35	800	XL CMHPG	800	0.00		0	0	800	22.9	22.9
0.5 PPA	35	400	XL CMHPG	1,200	0.50	100	8,400	8,400	409	11.7	34.5
0.75 PPA	35	400	XL CMHPG	1,600	0.75	100	12,600	21,000	414	11.8	46.4
1.00 PPA	35	800	XL CMHPG	2,400	1.00	100	33,600	54,600	836	23.9	70.3
1.00 PPA	35	800	XL CMHPG	3,200	1.00	40/70	33,600	88,200	836	23.9	94.1
1.25 PPA	35	400	XL CMHPG	3,600	1.25	40/70	21,000	109,200	423	12.1	106.2
1.50 PPA	35	400	XL CMHPG	4,000	1.50	40/70	25,200	134,400	427	12.2	118.4
Flush	35	350	Slickwater	4,350	0.00		0	134,400	350	10.0	128.4

As Pumped – Stage 5 (16A)

This treatment was pumped near-plan (refer to Figure B.3-8). There was a single cluster (two three-foot guns with 6 shots per foot at 60° phasing).



Stage 5

- 10,020 – 10,026 ft MD
- One cluster
- 4,537.2 bbl clean
- Average rate 27.0 bpm
- Stabilized rate 35 bpm
- Difficult to establish rate
- Crosslinked CMHPG
- 55,680 $\mathrm{lb_m}$ 100 mesh sand
- 81,200 $\mathrm{lb_m}$ 40/70 sand

Brought rate up gradually and broke back and treated smoothly thereafter

__Figure B.3-8.__ Treatment records for Stage 5.

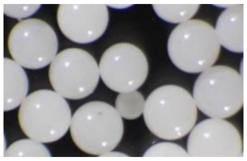
Planned – Stage 6 (16A)

Stage 6 (16A): In the RFP document, prospective vendors were requested/encouraged to recommend technology to improve proppant transport/placement in the hydraulic fracture. The pump (injection) rate, surface treating pressure, proppant concentration, additive rates, etc. will be monitored and recorded by the pressure pumping provider. No suggestions were provided. Utah FORGE implemented trying an ultralightweight proppant to inhibit downward settlement during shut-in. Proppant specifications are shown in Figure B.3-9.

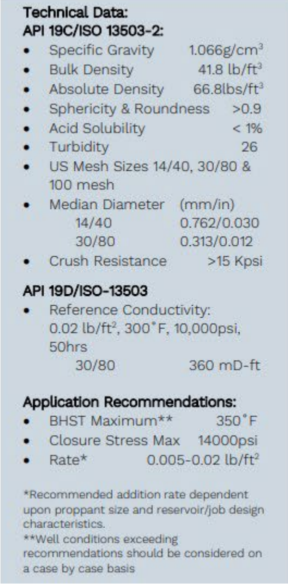
Stage 6 (16A) Fracturing Treatment Schedule

Step Name	Step Pump Rate (bpm)	Step Fluid Volume (bbl)	Step Fluid Type	Cum Fluid Volume (bbl)	Step Prop Conc (PPA)	Step Prop Type (US mesh)	Step Prop Volume (lbm)	Cum Prop Volume (lbm)	Step Slurry Volume (bbl)	Step Pump Time (min)	Cum Pump Time (min)
Pad	35	800	XL CMHPG	800	0.00		0	0	800	22.9	22.9
0.5 PPA	35	400	XL CMHPG	1,200	0.50	100	8,400	8,400	409	11.7	34.5
0.75 PPA	35	400	XL CMHPG	1,600	0.75	100	12,600	21,000	414	11.8	46.4
1.00 PPA	35	800	XL CMHPG	2,400	1.00	100	33,600	54,600	836	23.9	70.3
1.00 PPA	35	800	XL CMHPG	3,200	1.00	40/70	33,600	88,200	836	23.9	94.1
1.25 PPA	35	400	XL CMHPG	3,600	1.25	40/70	21,000	109,200	423	12.1	106.2
1.50 PPA	35	400	XL CMHPG	4,000	1.50	40/70	25,200	134,400	427	12.2	118.4
Flush	35	350	Slickwater	4,350	0.00		0	134,400	350	10.0	128.4

Stage 6 (16A): Improved Proppant transport and placement



- **Advantages of SUN OMNIPROP® ULWP Over Conventional Proppants:**
  - Near-neutral buoyancy facilitates placement in far-field fractures
  - Perfect for slick water or low-viscosity fluids; fewer fluid additives needed, minimizing damage risk
  - Chemically inert, physically smooth and spherical
  - Deformable – does not crush, chip, break, or generate migrating fines like sand proppants. Resists embedment preserving propped fracture width and residual conductivity.
  - No dust during handling for improved HSE compliance
  - Non-abrasive – will not damage tubing, pumps or surface equipment during application or production
  - Manifests excellent dissipation of static electricity, facilitating ease in handling
  - No sticky resin coatings to impact fluid performance, pumping, or production equipment



Technical Data:
API 19C/ISO 13503-2:

- Specific Gravity 1.066g/cm^3
- Bulk Density 41.8 lb/ft^3
- Absolute Density 66.8lbs/ft^3
- Sphericity & Roundness >0.9
- Acid Solubility < 1%
- Turbidity 26
- US Mesh Sizes 14/40, 30/80 & 100 mesh
- Median Diameter (mm/in)
  14/40 0.762/0.030
  30/80 0.313/0.012
- Crush Resistance >15 Kpsi

API 19D/ISO-13503

- Reference Conductivity:
  0.02 lb/ft^2, 300˚F, 10,000psi, 50hrs
  30/80 360 mD-ft

Application Recommendations:

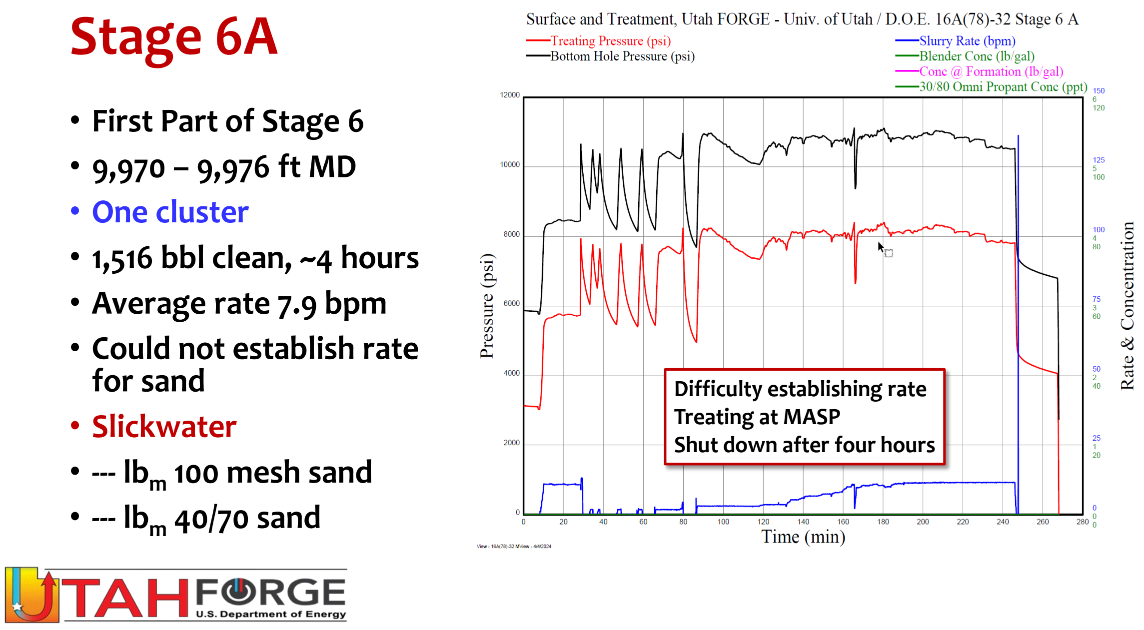
- BHST Maximum** 350˚F
- Closure Stress Max 14000psi
- Rate* 0.005-0.02 lb/ft^2

*Recommended addition rate dependent upon proppant size and reservoir/job design characteristics.
**Well conditions exceeding recommendations should be considered on a case by case basis

Figure B.3-9. *Ultralightweight proppant was planned to be blended (added on-the-fly) with conventional silica frac sand.*

As Pumped – Stage 6 (16A)

This stage treated unexpectedly. As can be seen in Figure B.3-10, an adequate rate could not be developed without reaching the maximum allowable surface pressure. As can be seen, repeated pressure cycling (injection followed by shut-in) and extended pumping still resulted in a surface injection pressure that was reaching the maximum allowable value. After this, it was decided to add a three-foot length of perforations just above the existing cluster. This new perforation was located in an area where the FMI suggested that natural fracturing could be present. Figure B.3-11 shows the treatment records for pumping with the original and new perforated zones exposed to treating fluid. After an extended period of pumping the rate was not adequate to pump proppant and the stage was ended.

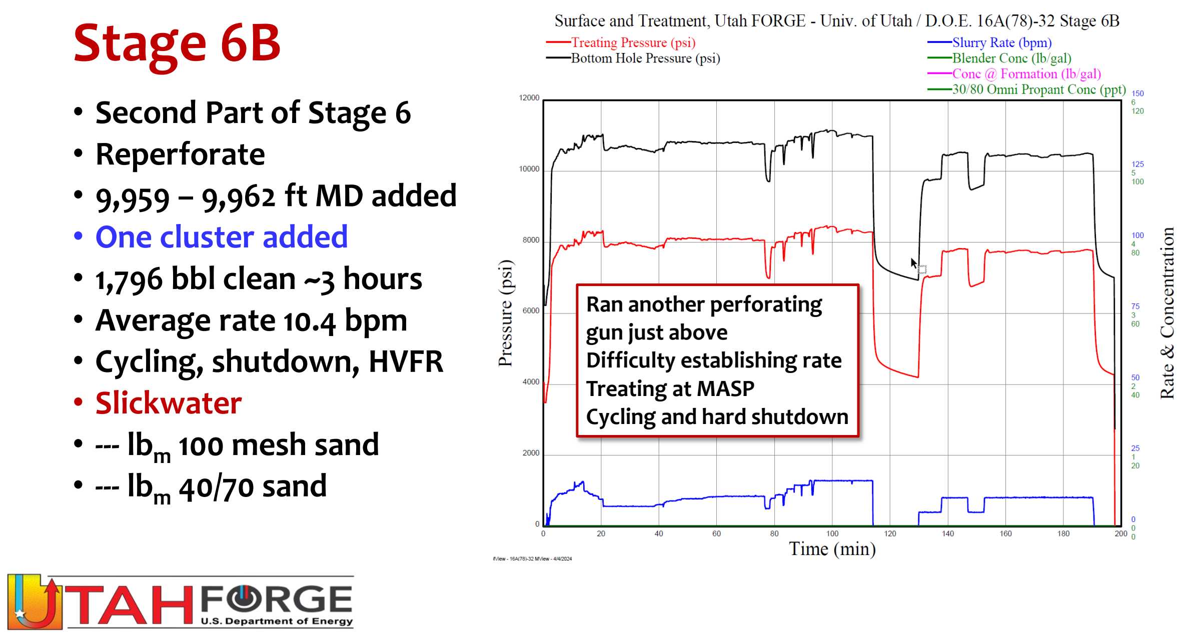


Stage 6A

- First Part of Stage 6
- 9,970 – 9,976 ft MD
- One cluster
- 1,516 bbl clean, ~4 hours
- Average rate 7.9 bpm
- Could not establish rate for sand
- Slickwater
- --- lb_m 100 mesh sand
- --- lb_m 40/70 sand

Difficulty establishing rate
Treating at MASP
Shut down after four hours

Figure B.3-10. *Treatment records for the first attempt at stimulation of Stage 6A.*



Stage 6B

- Second Part of Stage 6
- Reperforate
- 9,959 – 9,962 ft MD added
- One cluster added
- 1,796 bbl clean ~3 hours
- Average rate 10.4 bpm
- Cycling, shutdown, HVFR
- Slickwater
- --- lb_m 100 mesh sand
- --- lb_m 40/70 sand

Ran another perforating gun just above
Difficulty establishing rate
Treating at MASP
Cycling and hard shutdown

__Figure B.3-11.__ Treatment records for the second attempt at stimulation of Stage 6B with a second cluster.

Planned – Stage 7 (16A)

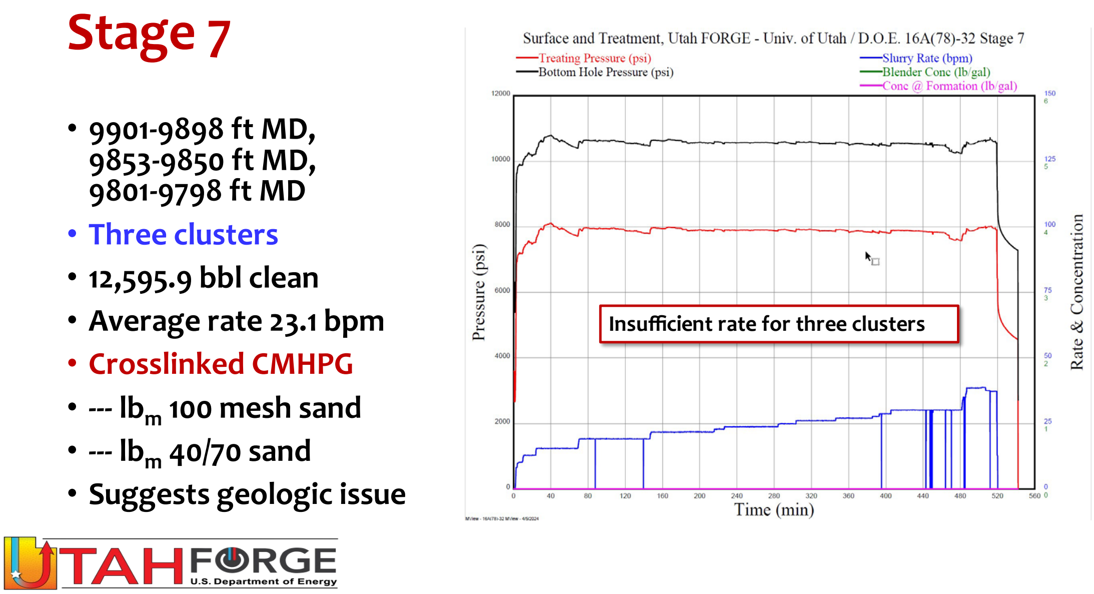
Stage 7 (16A): This stage had four (4) perforation clusters and the pump schedule is based on the same design methodology (fluid and volume per perforation cluster) as the previous **Stage 6 (16A)**. The cluster spacing for this stage was 50 ft. The planned pump rate was increased to 80 bpm if the surface treating pressure remained below 8,000 psi.

Stage 7 (16A) Fracturing Treatment Schedule

Step Name	Step Pump Rate (bpm)	Step Fluid Volume (bbl)	Step Fluid Type	Cum Fluid Volume (bbl)	Step Prop Conc (PPA)	Step Prop Type (US mesh)	Step Prop Volume (lbm)	Cum Prop Volume (lbm)	Step Slurry Volume (bbl)	Step Pump Time (min)	Cum Pump Time (min)
Pad	80	3,200	XL CMHPG	3,200	0.00		0	0	3,200	40.0	40.0
0.5 PPA	80	1,600	XL CMHPG	4,800	0.50	100	33,600	33,600	1,636	20.5	60.5
0.75 PPA	80	1,600	XL CMHPG	6,400	0.75	100	50,400	84,000	1,654	20.7	81.1
1.00 PPA	80	3,200	XL CMHPG	9,600	1.00	100	134,400	218,400	3,345	41.8	122.9
1.00 PPA	80	3,200	XL CMHPG	12,800	1.00	40/70	134,400	352,800	3,345	41.8	164.8
1.25 PPA	80	1,600	XL CMHPG	14,400	1.25	40/70	84,000	436,800	1,691	21.1	185.9
1.50 PPA	80	1,600	XL CMHPG	16,000	1.50	40/70	100,800	537,600	1,709	21.4	207.3
Flush	80	350	Slickwater	16,350	0.00		0	537,600	350	4.4	211.6

As Pumped – Stage 7 (16A)

The number of clusters for Stage 7 was reduced to three from the original plan of four. This was due to using the extra perforation gun for Stage 6 and the desire to have two guns remaining to add a Stage 10 to the plan. Like Stage 6, this zone treated high and adequate rate for the three clusters could not be achieved, even after extended pumping. This can be seen in Figure B.3-12.



Stage 7

- **9901-9898 ft MD, 9853-9850 ft MD, 9801-9798 ft MD**
- **Three clusters**
- **12,595.9 bbl clean**
- **Average rate 23.1 bpm**
- **Crosslinked CMHPG**
- **--- lb_m 100 mesh sand**
- **--- lb_m 40/70 sand**
- **Suggests geologic issue**

Figure B.3-12. Treatment records for Stage 7.

The natural question is why these local variations occurred and how could they have been foreseen. There were no strong indications from processed sonic data. Variations in the Young's modulus are shown in Figure B.3-13. They may show a stiff zone where Stage 6 was initially perforated, but more analysis is required. Figure B.3-14 might provide a clue. Despite casual references to homogeneity, this reservoir shows lithologic variation. At the depth where the higher treating pressure occurred, the cuttings track at the left shows lighter color (granitic rather than gneissic), the gamma ray is elevated and the spectral potassium count is lower. The overall message is that there is room for improved logging evaluation in these igneous reservoirs and that, for example, the gamma ray may turn out to have as much value as it does in lithology discrimination in sedimentary sequences.

Geologic Perspective for Stages 6 and 7

- Stage 6: 9,959 – 9,976 ft MD
- Stage 7: 9,798 – 9,901 ft MD
- Stage 8: 9,545 – 9,723 ft MD
- Stage 5: 10,020 – 10,026 ft MD
- Not too obvious on sonic

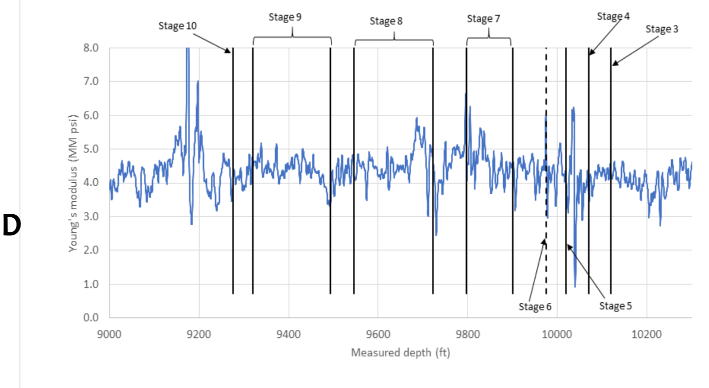


Figure B.3-13. *This is an overlay of logging derived Young's modulus which could increase treating pressure. Stress variation may be more relevant. Correlation is not obvious and as will be described below, subsequent stages treated more easily.*

Geologic Perspective for Stages 6 and 7

- Stage 6: 9,959 – 9,976 ft MD
- Stage 7: 9,797 – 9,901 ft MD
- Stage 8: 9,545 – 9,723 ft MD
- Stage 5: 10,020 – 10,026 ft MD
- Notice GR for Stage 6 and 7 depths (higher total, lower K, higher Th, higher U
- Not too obvious on sonic

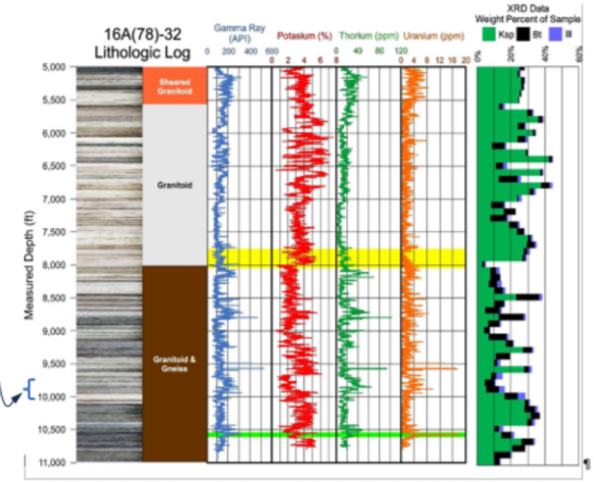


Figure B.3-14. *There may be a smoking gun. Notice the elevated gamma ray and the reduced potassium over the zone where the stages treated at higher pressure.*

Planned – Stage 8 (16A)

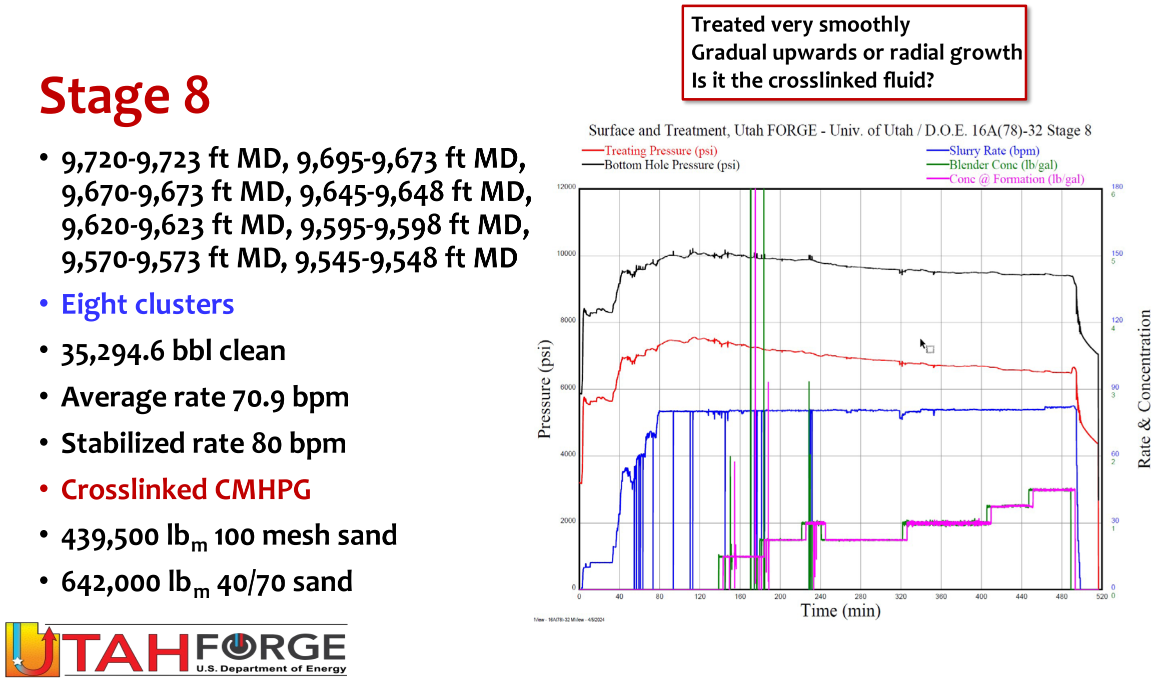
Stage 8 (16A): This stage had eight (8) perforation clusters (25 feet center to center) and the pump schedule was planned to be the same as what had been planned for Stage 7 (16A).

Stage 8 (16A) Fracturing Treatment Schedule

Step Name	Step Pump Rate (bpm)	Step Fluid Volume (bbl)	Step Fluid Type	Cum Fluid Volume (bbl)	Step Prop Conc (PPA)	Step Prop Type (US mesh)	Step Prop Volume (lbm)	Cum Prop Volume (lbm)	Step Slurry Volume (bbl)	Step Pump Time (min)	Cum Pump Time (min)
Pad	80	6,400	XL CMHPG	6,400	0.00		0	0	6,400	80.0	80.0
0.5 PPA	80	3,200	XL CMHPG	9,600	0.50	100	67,200	67,200	3,273	40.9	120.9
0.75 PPA	80	3,200	XL CMHPG	12,800	0.75	100	100,800	168,000	3,309	41.4	162.3
1.00 PPA	80	6,400	XL CMHPG	19,200	1.00	100	268,800	436,800	6,690	83.6	245.9
1.00 PPA	80	6,400	XL CMHPG	25,600	1.00	40/70	268,800	705,600	6,690	83.6	329.5
1.25 PPA	80	3,200	XL CMHPG	28,800	1.25	40/70	168,000	873,600	3,381	42.3	371.8
1.50 PPA	80	3,200	XL CMHPG	32,000	1.50	40/70	201,600	1,075,200	3,418	42.7	414.5
Flush	80	350	Slickwater	32,350	0.00		0	1,075,200	350	4.4	418.9

As Pumped – Stage 8 (16A)

As seen in Figure B.3-15, this was a large volume stage pumped according to plan. Unlike stages 6 and 7 it treated very smoothly with a moderate decline in surface pressure with time. It is informative to compare this treatment pumped with crosslinked CMHPG with the following stage, which was pumped with slickwater.



Treated very smoothly
Gradual upwards or radial growth
Is it the crosslinked fluid?

Stage 8

- 9,720-9,723 ft MD, 9,695-9,673 ft MD, 9,670-9,673 ft MD, 9,645-9,648 ft MD, 9,620-9,623 ft MD, 9,595-9,598 ft MD, 9,570-9,573 ft MD, 9,545-9,548 ft MD
- Eight clusters
- 35,294.6 bbl clean
- Average rate 70.9 bpm
- Stabilized rate 80 bpm
- Crosslinked CMHPG
- 439,500 lb_m 100 mesh sand
- 642,000 lb_m 40/70 sand

Figure B.3-15. Treatment records for Stage 8 (well 16A(78)-32).

Planned – Stage 9 (16A)

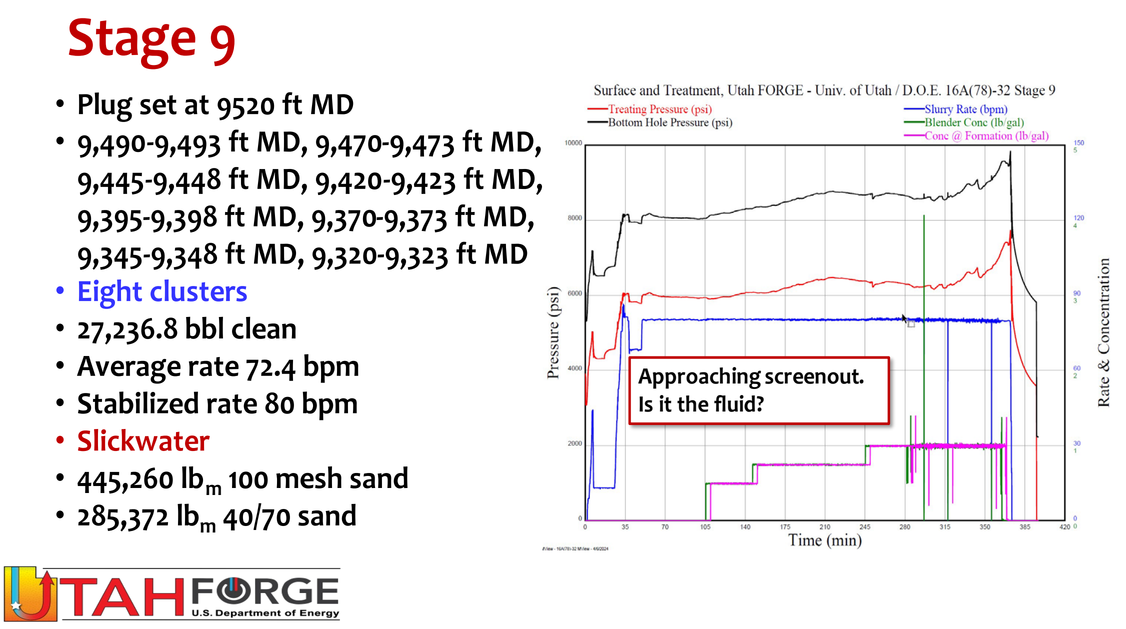
Stage 9 (16A): This stage had eight (8) perforation clusters at the same spacing (25 ft) as **Stage 8 (16A)** and the pump schedule was the same as the previous **Stage 8 (16A)**. The difference in this stage is the fracturing fluid was slickwater instead of crosslinked CMHPG.

Stage 9 (16A) Fracturing Treatment Schedule

Step Name	Step Pump Rate (bpm)	Step Fluid Volume (bbl)	Step Fluid Type	Cum Fluid Volume (bbl)	Step Prop Conc (PPA)	Step Prop Type (US mesh)	Step Prop Volume (lbm)	Cum Prop Volume (lbm)	Step Slurry Volume (bbl)	Step Pump Time (min)	Cum Pump Time (min)
Pad	80	6,400	Slickwater	6,400	0.00		0	0	6,400	80.0	80.0
0.5 PPA	80	3,200	Slickwater	9,600	0.50	100	67,200	67,200	3,273	40.9	120.9
0.75 PPA	80	3,200	Slickwater	12,800	0.75	100	100,800	168,000	3,309	41.4	162.3
1.00 PPA	80	6,400	Slickwater	19,200	1.00	100	268,800	436,800	6,690	83.6	245.9
1.00 PPA	80	6,400	Slickwater	25,600	1.00	40/70	268,800	705,600	6,690	83.6	329.5
1.25 PPA	80	3,200	Slickwater	28,800	1.25	40/70	168,000	873,600	3,381	42.3	371.8
1.50 PPA	80	3,200	Slickwater	32,000	1.50	40/70	201,600	1,075,200	3,418	42.7	414.5
Flush	80	350	Slickwater	32,350	0.00		0	1,075,200	350	4.4	418.9

As Pumped – Stage 9 (16A)

As seen in Figure B.3-16, this was a large volume stage pumped according to plan. The full amount of sand was not pumped as a result of the surface treating pressure building quickly. Questions include: Did the different surface treatment pressure (between Stages 8 and 9) relate to the fluid type? Did the different surface treatment pressure (between Stages 8 and 9) relate to fracture interference? There is some evidence that Stages 8, 9, and possibly 10 (see below) shared some of the same rock volume in the granite formation based on microseismic and fiber optic data analysis.



Stage 9

- Plug set at 9520 ft MD
- 9,490-9,493 ft MD, 9,470-9,473 ft MD, 9,445-9,448 ft MD, 9,420-9,423 ft MD, 9,395-9,398 ft MD, 9,370-9,373 ft MD, 9,345-9,348 ft MD, 9,320-9,323 ft MD
- Eight clusters
- 27,236.8 bbl clean
- Average rate 72.4 bpm
- Stabilized rate 80 bpm
- Slickwater
- 445,260 lb_m 100 mesh sand
- 285,372 lb_m 40/70 sand

Approaching screenout.
Is it the fluid?

Figure B.3-16. *Stage 9 treatment records in well 16A(78)-32. Notice the impending screenout.*

Planned – Stage 10 (16A)

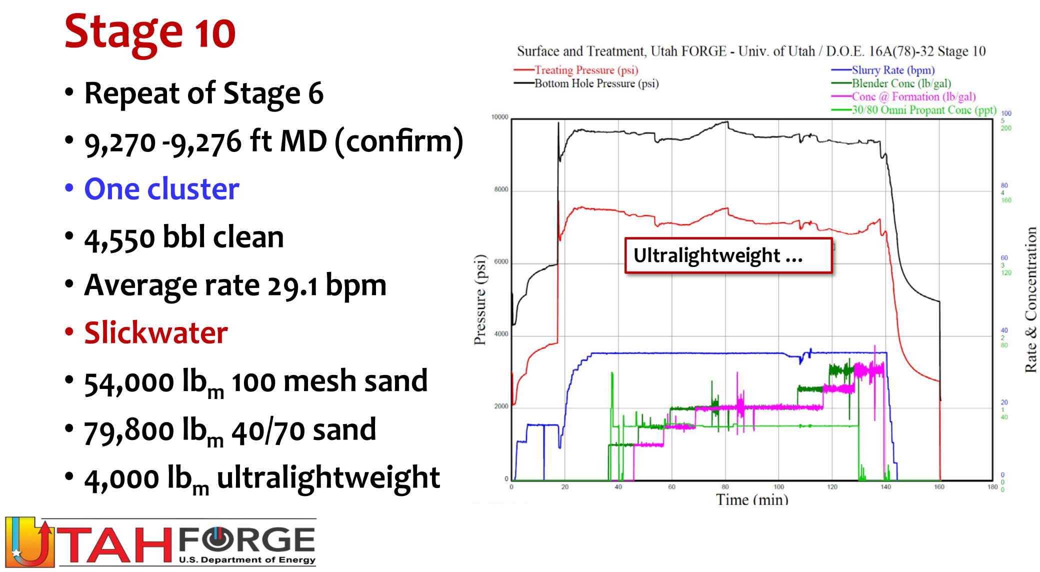
Stage 10 was not planned. Since proppant could not be pumped during Stage 6, it was still felt desirable to test the ultralightweight proppant. Hence, a repeat of the planned Stage 6 was pumped as Stage 10.

Stage 6 (16A) Fracturing Treatment Schedule

Step Name	Step Pump Rate (bpm)	Step Fluid Volume (bbl)	Step Fluid Type	Cum Fluid Volume (bbl)	Step Prop Conc (PPA)	Step Prop Type (US mesh)	Step Prop Volume (lbm)	Cum Prop Volume (lbm)	Step Slurry Volume (bbl)	Step Pump Time (min)	Cum Pump Time (min)
Pad	35	800	XL CMHPG	800	0.00		0	0	800	22.9	22.9
0.5 PPA	35	400	XL CMHPG	1,200	0.50	100	8,400	8,400	409	11.7	34.5
0.75 PPA	35	400	XL CMHPG	1,600	0.75	100	12,600	21,000	414	11.8	46.4
1.00 PPA	35	800	XL CMHPG	2,400	1.00	100	33,600	54,600	836	23.9	70.3
1.00 PPA	35	800	XL CMHPG	3,200	1.00	40/70	33,600	88,200	836	23.9	94.1
1.25 PPA	35	400	XL CMHPG	3,600	1.25	40/70	21,000	109,200	423	12.1	106.2
1.50 PPA	35	400	XL CMHPG	4,000	1.50	40/70	25,200	134,400	427	12.2	118.4
Flush	35	350	Slickwater	4,350	0.00		0	134,400	350	10.0	128.4

As Pumped – Stage 10 (16A)

As seen in Figure B.3-17, this zone (single cluster, 9,270 to 9,276 ft MD) treated reasonably well, and some sporadic propagation was possibly indicated. Some lightweight proppant has been recovered from the production well after both wells were fractured, suggesting a fully propped fracture network. Recall that the small volume of lightweight proppant is consistent with its low specific gravity (refer to Figure B.3-9).



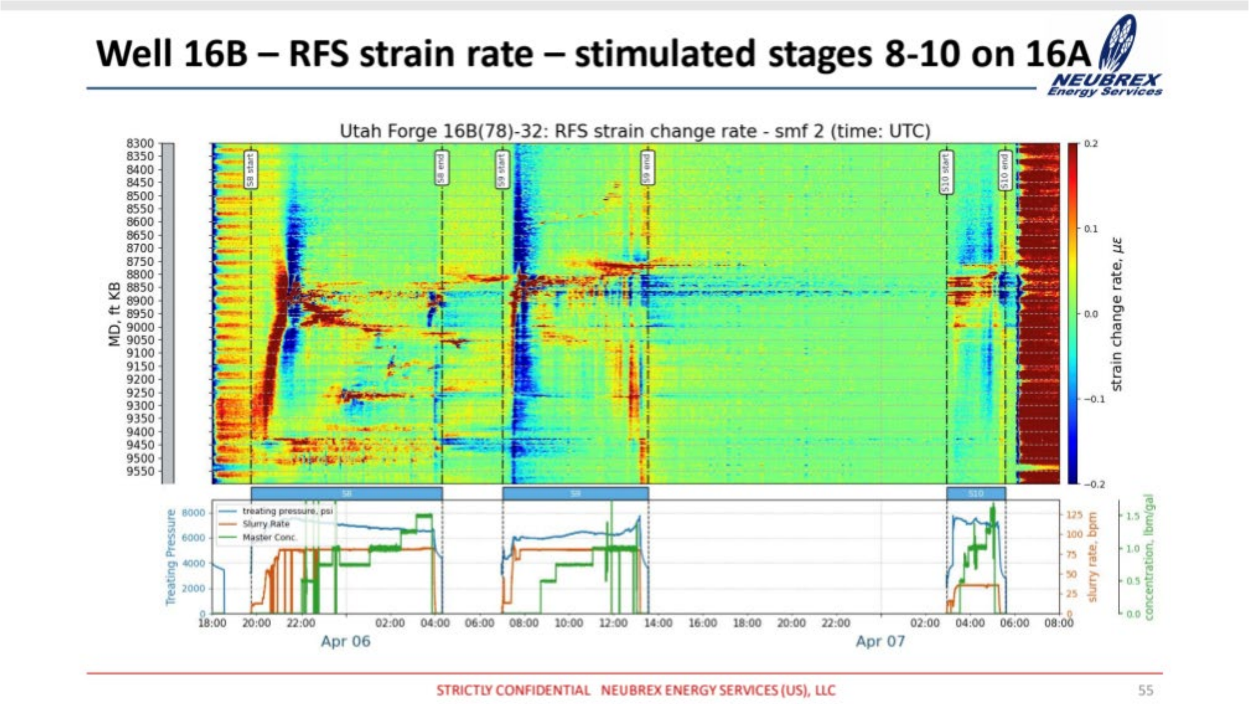
Stage 10

- Repeat of Stage 6
- 9,270 -9,276 ft MD (confirm)
- One cluster
- 4,550 bbl clean
- Average rate 29.1 bpm
- Slickwater
- 54,000 lb_m 100 mesh sand
- 79,800 lb_m 40/70 sand
- 4,000 lb_m ultralightweight

__Figure B.3-17.__ Treatment record for Stage 10.

Hydraulic Fracturing of Well 16B(78)-32

From the strain and temperature data recorded by the fiber optics in well 16B(78)-32, multiple vendors worked collaboratively with Utah FORGE to pick zones to perforate in well 16B(78)-32. These were zones that suggested an intersection(s) had occurred or was imminent (broad approaching strain front, for example). Figure B.3-18 shows an example waterfall plot covering Stages 8 through 10. Multiple clusters were assigned and the stage length was restricted to 180 feet to guarantee the effectiveness of the perforating operations. After analysis was completed, it was determined that five frac stages would be required instead of the four that were planned. This was mainly the result of the total spacing of the major fracture intersection or strain front identification locations along the 16B(78)-32 wellbore. Some of the fracture intersections targeted for perforating were further up the wellbore (shallower) than what was anticipated. Since there was no possibility of bringing more proppant to the Utah FORGE location, the fluid and proppant volumes for the four stages that were designed were redistributed evenly into five stages.



Well 16B – RFS strain rate – stimulated stages 8-10 on 16A

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Figure B.3-18. *Rayleigh frequency strain rate waterfall plot. Measured depth is the y-axis and time is the x-axis. The time is correlated with the treatment records for Stages 8 through 10 along the bottom. Stage 10 may have shared entries with Stage 9 and possibly Stage 8.*

Planned – Stage 1 (16B)

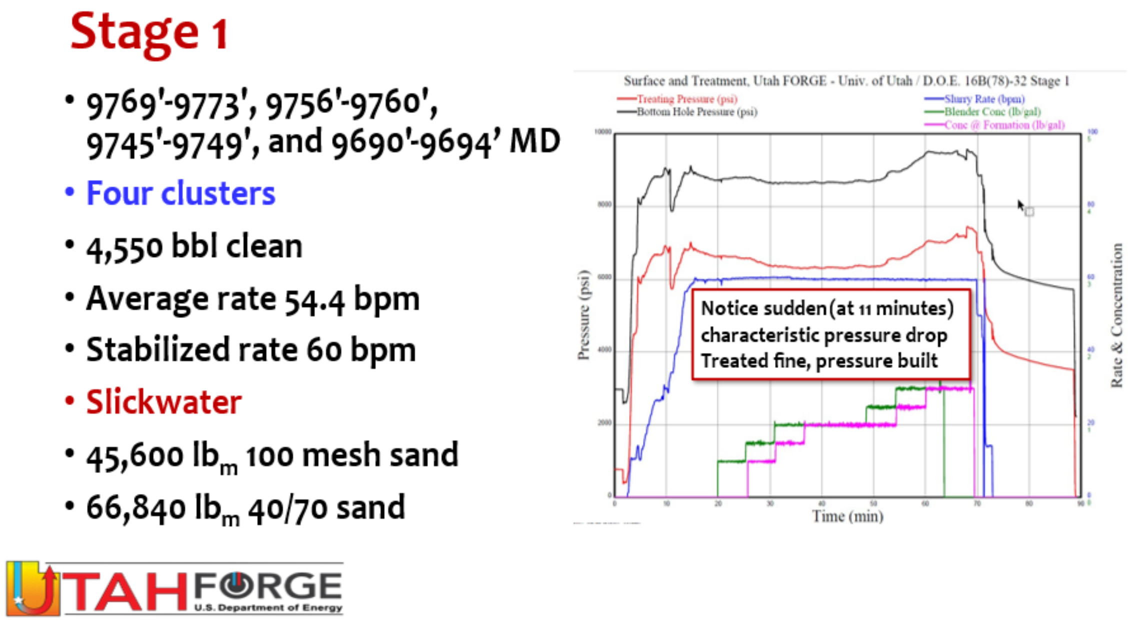
Stage 1 (16B): Based on the depths of the intersections that were determined, open the flow line to the separator to bleed down wellhead pressure and then open the wellhead master valve. [**Note:** Conveyance of perforating guns (multiple perf guns were run with spacer pipe in between to position over the desired depths) was performed with a 3-1/2” workstring since there had been no pumping into the wellbore for cooldown.] TIH with the 3-1/2” workstring and perforation guns and position at the depth that has been determined from analysis of the measured data. Verify measurement and fire guns. TOOH with perforation guns and verify all shots have fired. Begin pumping slickwater and work the rate up to 60 bpm down the 7” casing. The plan was to pump the treatment as per the designed pump schedule below.

Stage 1 (16B) Fracturing Treatment Schedule

Step Name	Step Pump Rate (bpm)	Step Fluid Volume (bbl)	Step Fluid Type	Cum Fluid Volume (bbl)	Step Prop Conc (PPA)	Step Prop Type (US mesh)	Step Prop Volume (lbm)	Cum Prop Volume (lbm)	Step Slurry Volume (bbl)	Step Pump Time (min)	Cum Pump Time (min)
Pad	60	640	Slickwater	640	0.00		0	0	640	10.7	10.7
0.5 PPA	60	320	Slickwater	960	0.50	100	6,720	6,720	327	5.5	16.1
0.75 PPA	60	320	Slickwater	1,280	0.75	100	10,080	16,800	331	5.5	21.6
1.00 PPA	60	640	Slickwater	1,920	1.00	100	26,880	43,680	669	11.2	32.8
1.00 PPA	60	640	Slickwater	2,560	1.00	40/70	26,880	70,560	669	11.2	43.9
1.25 PPA	60	320	Slickwater	2,880	1.25	40/70	16,800	87,360	338	5.6	49.6
1.50 PPA	60	320	Slickwater	3,200	1.50	40/70	20,160	107,520	342	5.7	55.3
Flush	60	350	Slickwater	3,550	0.00		0	107,520	350	5.8	61.1
Slickwater		3,550	bbl	149,100	gal		100-mesh sand		43,680	lbm	
							40/70-mesh sand		63,840	lbm	

As Pumped – Stage 1 (16B)

Figure B.3-19 shows the treatment records for this stage. Notice the characteristic rapid drop in treating pressure “long” after initiation and breakdown had occurred, suggesting connection(s) with fractures proximal to the wellbore – likely reinforcing the need to stimulate both wells for effective connectivity.



Stage 1

- 9769'-9773', 9756'-9760', 9745'-9749', and 9690'-9694' MD
- Four clusters
- 4,550 bbl clean
- Average rate 54.4 bpm
- Stabilized rate 60 bpm
- Slickwater
- 45,600 lb_m 100 mesh sand
- 66,840 lb_m 40/70 sand

Notice sudden (at 11 minutes) characteristic pressure drop Treated fine, pressure built

__Figure B.3-19.__ Treatment records for Stage 1 in well 16B(78)-32.

Planned – Stage 2 (16B)

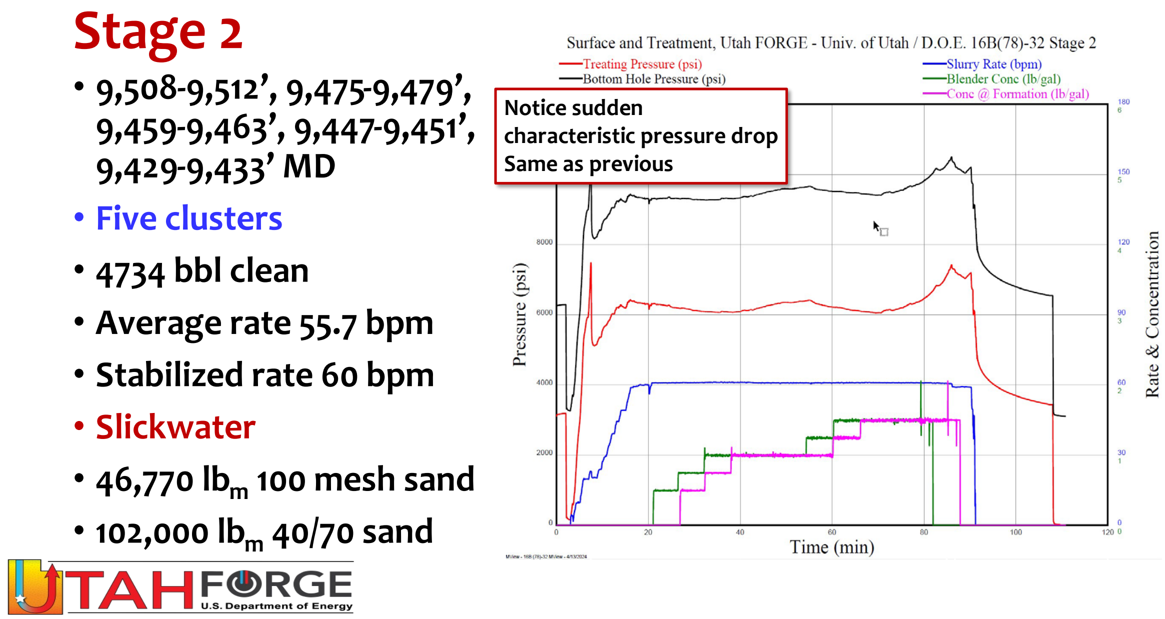
Stage 2 (16B): Based on the depth of intersection that has been determined to be most likely associated with **Stage 7 (16A)**, open the flow line to the separator to bleed down the wellhead pressure, and then open the wellhead master valve. [**Note:** Conveyance of perforating guns (multiple perf guns will be run with spacer pipe in between to position over desired depths) is planned to be performed with a 3-1/2" workstring since there has been no pumping into the wellbore for cooldown.] TIH with the 3-1/2" workstring and perforation guns and position at the depth that has been determined from analysis of the measured data. Verify measurement and fire guns. TOOH with perforation guns and verify all shots have fired. Begin pumping slickwater and work rate up to 60 bpm down the 7" casing. The plan was to pump the treatment as per the designed pump schedule below.

Stage 2 (16B) Fracturing Treatment Schedule

Step Name	Step Pump Rate (bpm)	Step Fluid Volume (bbl)	Step Fluid Type	Cum Fluid Volume (bbl)	Step Prop Conc (PPA)	Step Prop Type (US mesh)	Step Prop Volume (lbm)	Cum Prop Volume (lbm)	Step Slurry Volume (bbl)	Step Pump Time (min)	Cum Pump Time (min)
Pad	60	640	Slickwater	640	0.00		0	0	640	10.7	10.7
0.5 PPA	60	320	Slickwater	960	0.50	100	6,720	6,720	327	5.5	16.1
0.75 PPA	60	320	Slickwater	1,280	0.75	100	10,080	16,800	331	5.5	21.6
1.00 PPA	60	640	Slickwater	1,920	1.00	100	26,880	43,680	669	11.2	32.8
1.00 PPA	60	640	Slickwater	2,560	1.00	40/70	26,880	70,560	669	11.2	43.9
1.25 PPA	60	320	Slickwater	2,880	1.25	40/70	16,800	87,360	338	5.6	49.6
1.50 PPA	60	320	Slickwater	3,200	1.50	40/70	20,160	107,520	342	5.7	55.3
Flush	60	350	Slickwater	3,550	0.00		0	107,520	350	5.8	61.1
Slickwater		3,550	bbl	149,100	gal		100-mesh sand		43,680	lbm	
							40/70-mesh sand		63,840	lbm	

As Pumped – Stage 2 (16B)

Figure B.3-20 shows the treatment records for this stage. Notice the characteristic rapid drop in treating pressure "long" after initiation and breakdown had occurred, suggesting connection(s) with fractures proximal to the wellbore – likely reinforcing the need to stimulate both wells for effective connectivity. These records are very similar to Stage 1 in this well.



Stage 2

- 9,508-9,512', 9,475-9,479', 9,459-9,463', 9,447-9,451', 9,429-9,433' MD
- Five clusters
- 4734 bbl clean
- Average rate 55.7 bpm
- Stabilized rate 60 bpm
- Slickwater
- 46,770 lb_m 100 mesh sand
- 102,000 lb_m 40/70 sand

Notice sudden characteristic pressure drop
Same as previous

Figure B.3-20. Treatment records for Stage 2 in well 16B(78)-32.

Planned – Stage 3 (16B)

Stage 3 (16B): Based on the depth of intersection that has been determined to be most likely associated with **Stage 8 (16A)**, open the flow line to the separator to bleed down wellhead pressure and then open the wellhead master valve. [**Note:** Conveyance of perforating guns (multiple perf guns will be run with spacer pipe in between to position over desired depths) is planned to be performed with a 3-1/2" workstring since there has been no pumping into the wellbore for cooldown.] TIH with the 3-1/2" workstring and perforation guns and position at the depth that has been determined from analysis of the measured data. Verify measurement and fire guns. TOOH with perforation guns and verify all shots have fired. Begin pumping slickwater and work the rate up to 60 bpm down the 7" casing.

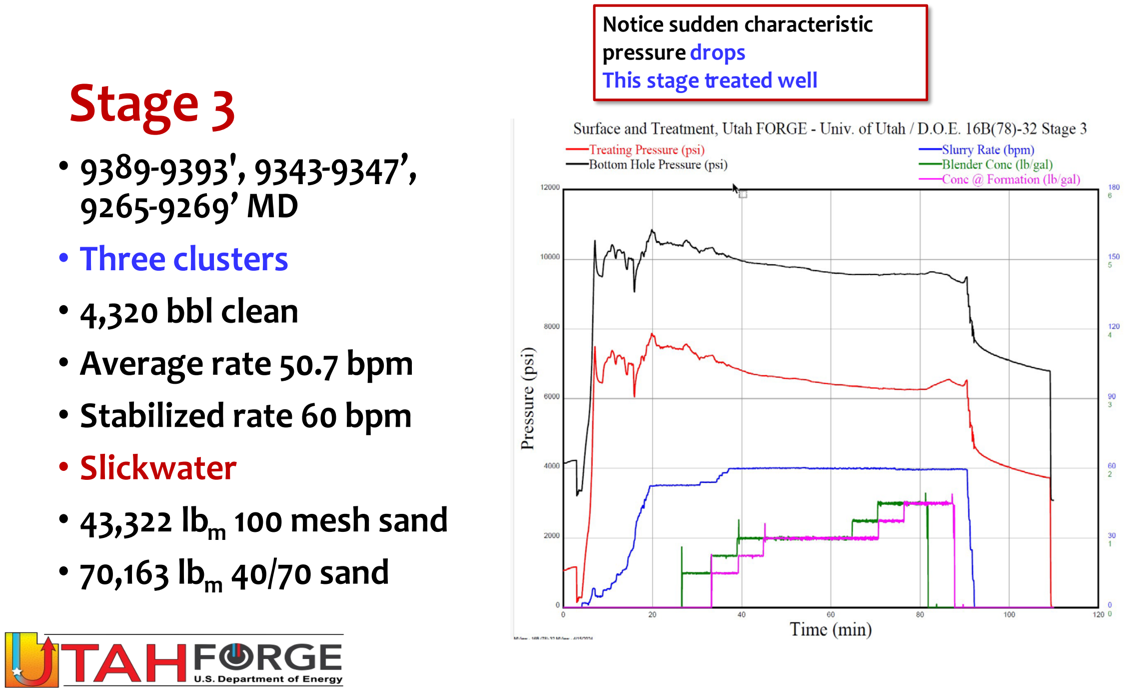
The plan (followed) was to pump the Stage 3 treatment as per the designed pump schedule below.

Stage 3 (16B) Fracturing Treatment Schedule

Step Name	Step Pump Rate (bpm)	Step Fluid Volume (bbl)	Step Fluid Type	Cum Fluid Volume (bbl)	Step Prop Conc (PPA)	Step Prop Type (US mesh)	Step Prop Volume (lbm)	Cum Prop Volume (lbm)	Step Slurry Volume (bbl)	Step Pump Time (min)	Cum Pump Time (min)
Pad	60	640	Slickwater	640	0.00		0	0	640	10.7	10.7
0.5 PPA	60	320	Slickwater	960	0.50	100	6,720	6,720	327	5.5	16.1
0.75 PPA	60	320	Slickwater	1,280	0.75	100	10,080	16,800	331	5.5	21.6
1.00 PPA	60	640	Slickwater	1,920	1.00	100	26,880	43,680	669	11.2	32.8
1.00 PPA	60	640	Slickwater	2,560	1.00	40/70	26,880	70,560	669	11.2	43.9
1.25 PPA	60	320	Slickwater	2,880	1.25	40/70	16,800	87,360	338	5.6	49.6
1.50 PPA	60	320	Slickwater	3,200	1.50	40/70	20,160	107,520	342	5.7	55.3
Flush	60	350	Slickwater	3,550	0.00		0	107,520	350	5.8	61.1
Slickwater		3,550	bbl	149,100	gal		100-mesh sand		43,680	lbm	
							40/70-mesh sand		63,840	lbm	

As Pumped – Stage 3 (16B)

Figure B.3-21 shows the treatment records for this stage. Notice the characteristic rapid pressure drop some finite time after the formation has definitively started to take fluid.



Notice sudden characteristic pressure drops
This stage treated well

Stage 3

- 9389-9393', 9343-9347', 9265-9269' MD
- Three clusters
- 4,320 bbl clean
- Average rate 50.7 bpm
- Stabilized rate 60 bpm
- Slickwater
- 43,322 lb_m 100 mesh sand
- 70,163 lb_m 40/70 sand

__Figure B.3-21.__ Treatment records for Stage 3 in well 16B(78)-32. There are a few more nuances in the early time surface pressure suggesting multiple connections established.

Planned – Stage 4 (16B)

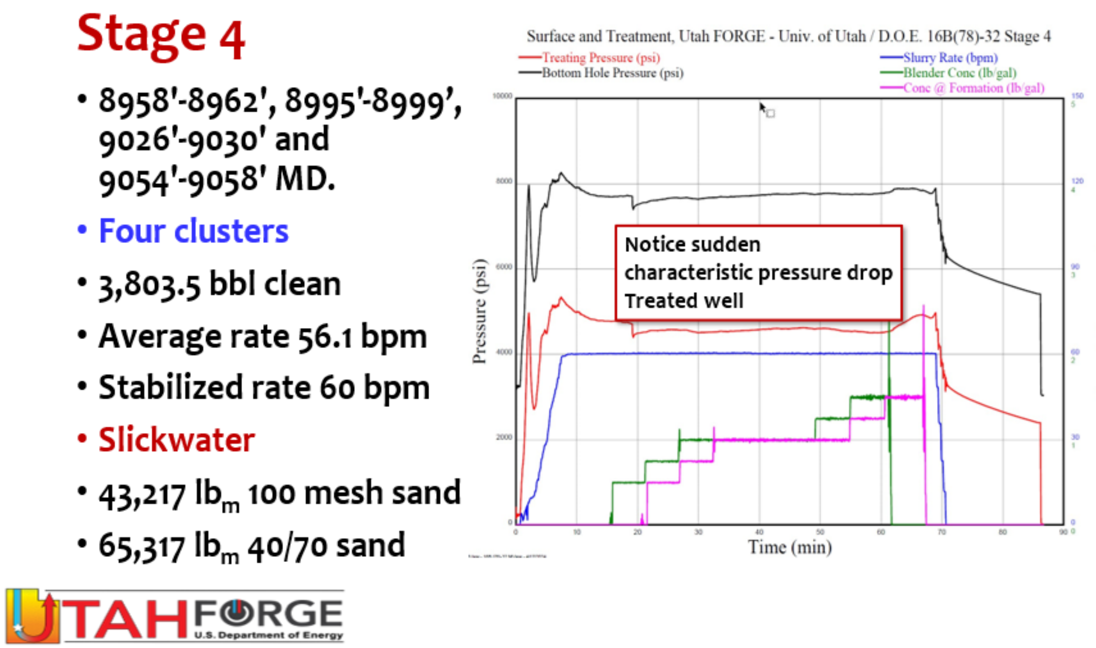
Stage 4 (16B): Based on the depth of intersection that has been determined to be most likely associated with **Stage 9 (16A),** open the flow line to the separator to bleed down the wellhead pressure, and then open the wellhead master valve. [**Note:** Conveyance of perforating guns (multiple perf guns will be run with spacer pipe in between to position over desired depths) is planned to be performed with a 3-1/2" workstring since there has been no pumping into the wellbore for cooldown.] TIH with the 3-1/2" workstring and perforation guns and position at the depth that has been determined from analysis of the measured data. Verify measurement and fire guns. TOOH with perforation guns and verify all shots have fired. Begin pumping slickwater and work rate up to 60 bpm down the 7" casing. The plan was to pump the treatment as per the designed pump schedule below.

Stage 4 (16B) Fracturing Treatment Schedule

Step Name	Step Pump Rate (bpm)	Step Fluid Volume (bbl)	Step Fluid Type	Cum Fluid Volume (bbl)	Step Prop Conc (PPA)	Step Prop Type (US mesh)	Step Prop Volume (lbm)	Cum Prop Volume (lbm)	Step Slurry Volume (bbl)	Step Pump Time (min)	Cum Pump Time (min)
Pad	60	640	Slickwater	640	0.00		0	0	640	10.7	10.7
0.5 PPA	60	320	Slickwater	960	0.50	100	6,720	6,720	327	5.5	16.1
0.75 PPA	60	320	Slickwater	1,280	0.75	100	10,080	16,800	331	5.5	21.6
1.00 PPA	60	640	Slickwater	1,920	1.00	100	26,880	43,680	669	11.2	32.8
1.00 PPA	60	640	Slickwater	2,560	1.00	40/70	26,880	70,560	669	11.2	43.9
1.25 PPA	60	320	Slickwater	2,880	1.25	40/70	16,800	87,360	338	5.6	49.6
1.50 PPA	60	320	Slickwater	3,200	1.50	40/70	20,160	107,520	342	5.7	55.3
Flush	60	350	Slickwater	3,550	0.00		0	107,520	350	5.8	61.1
Slickwater		3,550	bbl	149,100	gal		100-mesh sand		43,680	lbm	
							40/70-mesh sand		63,840	lbm	

As Pumped – Stage 4 (16B)

Figure B.3-22 shows the treatment records for this stage. Notice the characteristic rapid, delayed significant pressure drop.



Stage 4

- 8958'-8962', 8995'-8999', 9026'-9030' and 9054'-9058' MD.
- Four clusters
- 3,803.5 bbl clean
- Average rate 56.1 bpm
- Stabilized rate 60 bpm
- Slickwater
- 43,217 lb_m 100 mesh sand
- 65,317 lb_m 40/70 sand

Notice sudden
characteristic pressure drop
Treated well

Figure B.3-22. *Treatment data for Stage 4 (well 16B(78)-32). Notice a significant breakdown and a subsequent rapid pressure drop at about 19 minutes of pumping.*

Stage 5 (16B)

This stage was added based on the fiber optics mapping and the protocol to keep the overall gun deployment length below 180 ft or so. Unfortunately, it was perforated only and not stimulated because a frac plug could not be set below. The 7-inch frac plugs worked flawlessly in the cooled-down injection well (16A(78)-32). In the substantially hotter production wells plugs set but did not test or set prematurely. There were two premature sets and the plugs had to be drilled out. With these two unplanned sets and a problematic set earlier in the well, there were insufficient plugs to isolate Stage 5. Consequently, the zone was perforated only. The Halliburton G-Force deployment system worked flawlessly on all perforating runs in well 16B(78)-32. Figure B.3-23 shows the nominal zero-degree phasing. No fiber optic cables were lost during any of the perforating and only the very lower end was lost during the Stage 1 treatment. In stage five, the perforations were at 8,774 to 8,778 ft MD, 8,834 to 8,838\ ft MD, 9,026 to 9,030 ft MD, and 9,054 to 9,058 ft MD.

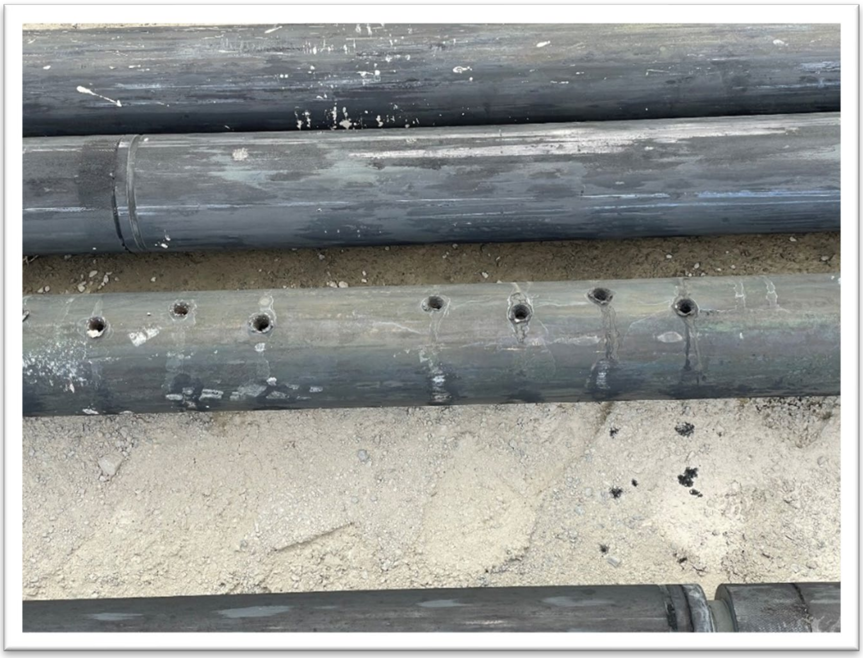


Figure B.3-23. Halliburton perforations giving a nominal zero-degree phasing (slightly offset in a regular pattern). The Halliburton G-Force deployment system effectively oriented the guns.

Microseismic data was triangulated to define fracture morphologies. These activities are reported elsewhere. Preliminary picks are shown in Figure B.3-24.

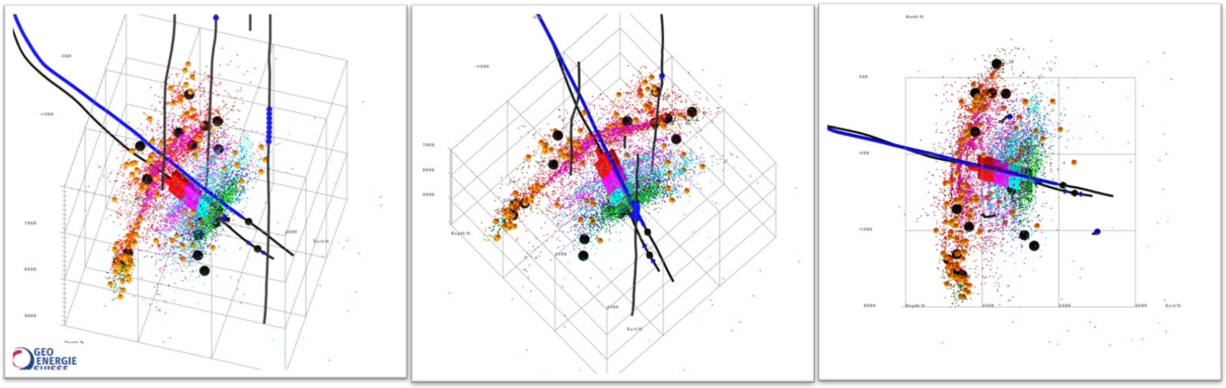


Figure B.3-24. *Preliminary microseismic mapping of well 16A(78)-32 fractures. The black dots indicate events with magnitudes over 1 M and the orange dots indicate events greater than 0.6 M. Further processed data for both wells will be forthcoming.*

Drill Out the Plugs in Both Wells

This operation was to drill out all the frac plugs that have been placed in the wellbore to isolate the different frac stages resulting in a wellbore that has unrestricted access to all the intervals that have been fracture stimulated. While numerous techniques were tried, with and without motors, the Badger fixed insert cutter bit[3] seemed to perform the best (Figure B.3-25). Several days of delays were experienced because of the flowback of high-temperature fluid.

Nine-Hour Circulation Test

The culmination of the fracturing experiment was a nine-hour circulation test, pumping down casing in well 16A(78)-32 and recovering produced fluid from well 16B(78)-32. Figure B.3-26 documents the events.

Refer to Figure B.3-26. The rate was gradually increased. With continued injection the pressure built. Much of the fluid that had been injected during stimulation had been flowed back (matrix permeability is low) and the previously created fracture system was partially refilled.

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[3] Manufactured by Throop Rock Bit Mfg. Co. in Tonkawa, Oklahoma (supplied by San Joaquin Bit).

Figure B.3-25. *This bit (the Badger) was effective in milling out the customized frac plugs.*

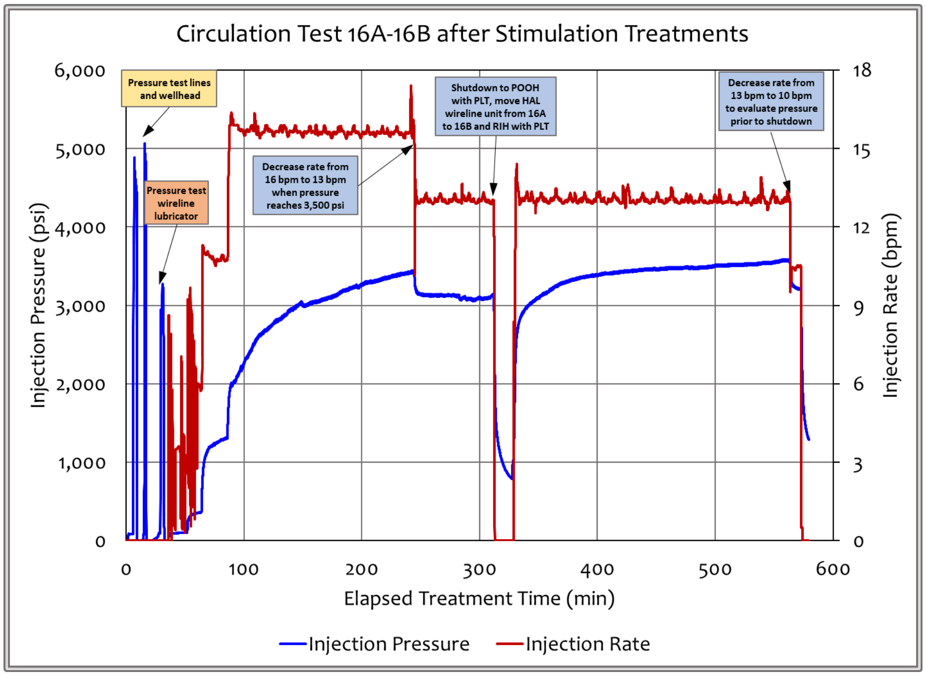


Figure B.3-26. *Surface injection pressure and rate while pumping into well 16A(78)-32.*

After pumping at about 16 bpm for some time, the pressure at the surface increased to where supplementary fracture propagation would be expected and there were some indications of this with the injection pressure. The rate was dropped. While this was ongoing a PLT/PTS (production logging tool/pressure-temperature-spinner) profiled well 16A(78)-32. The shutdown after about 310 minutes of pumping was so that this tool could be moved to the production well 16B(78)-32. After lubricating the PLT into the production well, a rate of about 13.5 bpm was re-established and maintained until shutdown just short of nine hours of operation.

The rate and temperature data are shown in Figure B.3-27. The rate of outflow from the production well gradually and fairly monotonically built to 8.2 bpm. This is close to a 70% recovery efficiency and it is hypothesized that this efficiency will increase with time as the created fracture system is filled and stiffened and connections improve. The temperature tracked the flow and reached 282°F before the termination of the test.

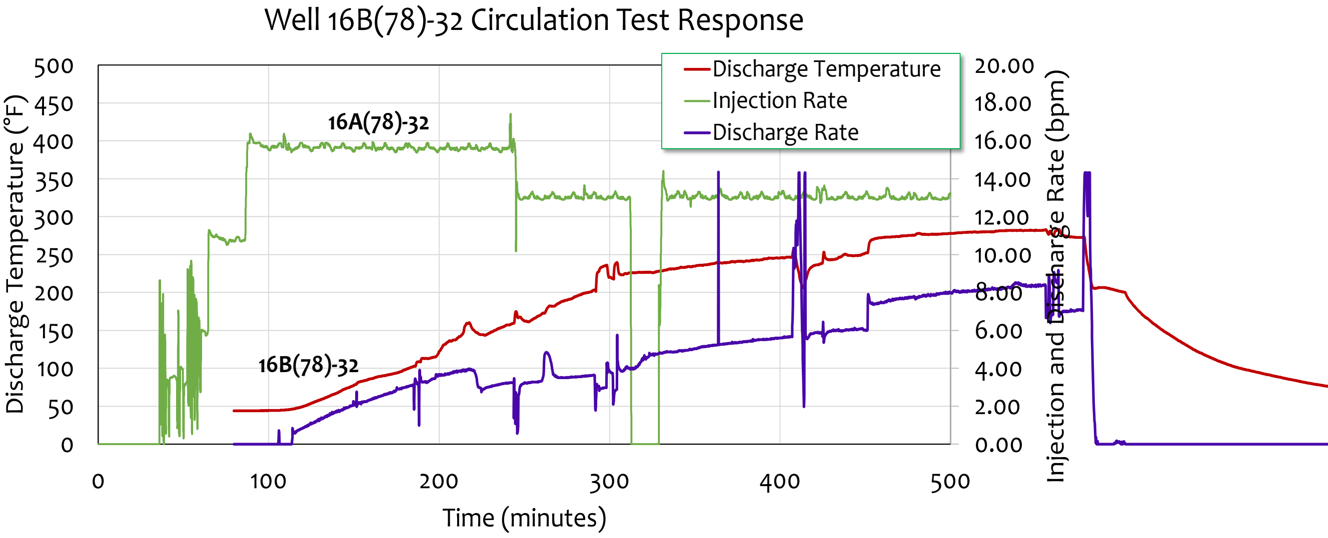
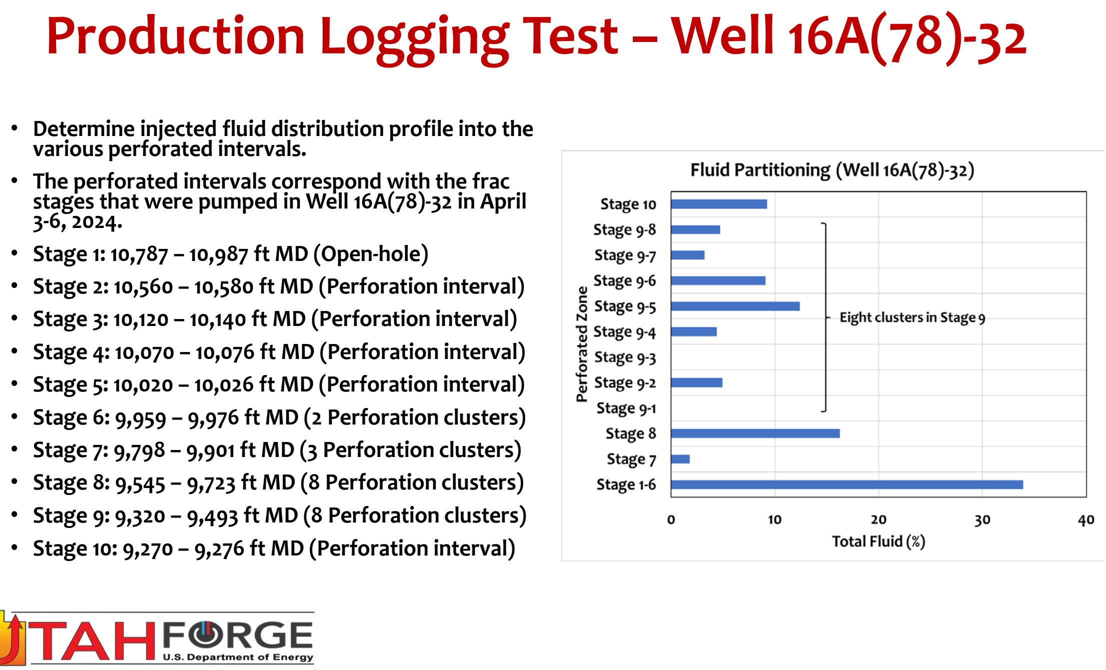


Figure B.3-27. *The rate of injection is shown in green (secondary y-axis). The rate of outflow from the production well gradually and monotonically built to 8.2 bpm (purple curve and secondary y-axis). This is close to a 70% recovery efficiency and it is hypothesized that this efficiency will increase with time as the created fracture system is filled and stiffened and connections improve. The temperature (red curve and primary y-axis) tracked the flow and reached 282°F before the termination of the test.*

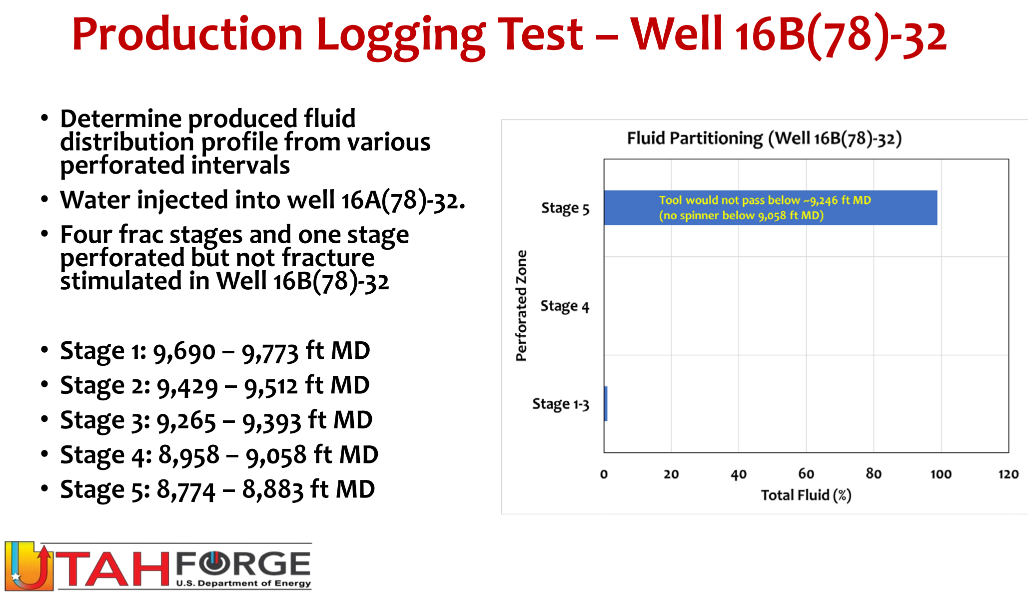
The flow partitioning data for well 16B(78)-32 are shown in Figure B.3-28. A high-level summary is that there appeared to be flow into the entire well. Stages 1 to 6 could not be mapped discretely and the individual clusters in Stage 8 were not resolved individually. However, the assessment of the distribution of flow in the eight clusters of Stage 9 is quite clear. Individual operators will need to decide if this degree of perforation efficiency meets their criteria or if they need to consider alternative completion strategies. For completeness, Figure B.3-29 is the flow partitioning for the PLT in well 16B(78)-32. The tool could not get down deep enough to discriminate the distribution of flow in the different zones.



Production Logging Test – Well 16A(78)-32

- Determine injected fluid distribution profile into the various perforated intervals.
- The perforated intervals correspond with the frac stages that were pumped in Well 16A(78)-32 in April 3-6, 2024.
- Stage 1: 10,787 – 10,987 ft MD (Open-hole)
- Stage 2: 10,560 – 10,580 ft MD (Perforation interval)
- Stage 3: 10,120 – 10,140 ft MD (Perforation interval)
- Stage 4: 10,070 – 10,076 ft MD (Perforation interval)
- Stage 5: 10,020 – 10,026 ft MD (Perforation interval)
- Stage 6: 9,959 – 9,976 ft MD (2 Perforation clusters)
- Stage 7: 9,798 – 9,901 ft MD (3 Perforation clusters)
- Stage 8: 9,545 – 9,723 ft MD (8 Perforation clusters)
- Stage 9: 9,320 – 9,493 ft MD (8 Perforation clusters)
- Stage 10: 9,270 – 9,276 ft MD (Perforation interval)

Figure B.3-28. *Flow partitioning while injecting into well 16A(78)-32.*



Production Logging Test – Well 16B(78)-32

- Determine produced fluid distribution profile from various perforated intervals
- Water injected into well 16A(78)-32.
- Four frac stages and one stage perforated but not fracture stimulated in Well 16B(78)-32

- Stage 1: 9,690 – 9,773 ft MD
- Stage 2: 9,429 – 9,512 ft MD
- Stage 3: 9,265 – 9,393 ft MD
- Stage 4: 8,958 – 9,058 ft MD
- Stage 5: 8,774 – 8,883 ft MD

Figure B.3-29. *Flow partitioning while injecting into well 16B(78)-32. Not reliable because the tool could not enter below the top section.*

B.4. CONTINUOUS ENVIRONMENTAL MONITORING

A summary of the results of environmental monitoring activities, including GPS, InSAR, gravity, groundwater, and geochemistry are covered below. A separate subsection summarizes the geology of the EGS reservoir.

Across the Utah FORGE site, a distributed network comprising 22 monuments are surveyed on a quarterly basis by the Utah Geological Survey using GPS methods to characterize ground deformation (Figure B.4-1). Between April 1, 2023 and March 31, 2024, four surveys were completed, and the cumulative measured differences for the last two years are shown in Figure B.4-2. The average displacement ranges from -10 to +25 mm. The observed deformation represents seasonal inflation and deflation that is primarily the result of seasonal climatic signals. Comparison with rainfall and water level data suggest the possibility of seasonal effects on the pattern of vertical movement. In the period April 1, 2023 to March 31, 2024, the variability in vertical ground movement is between 0 and 30 mm.

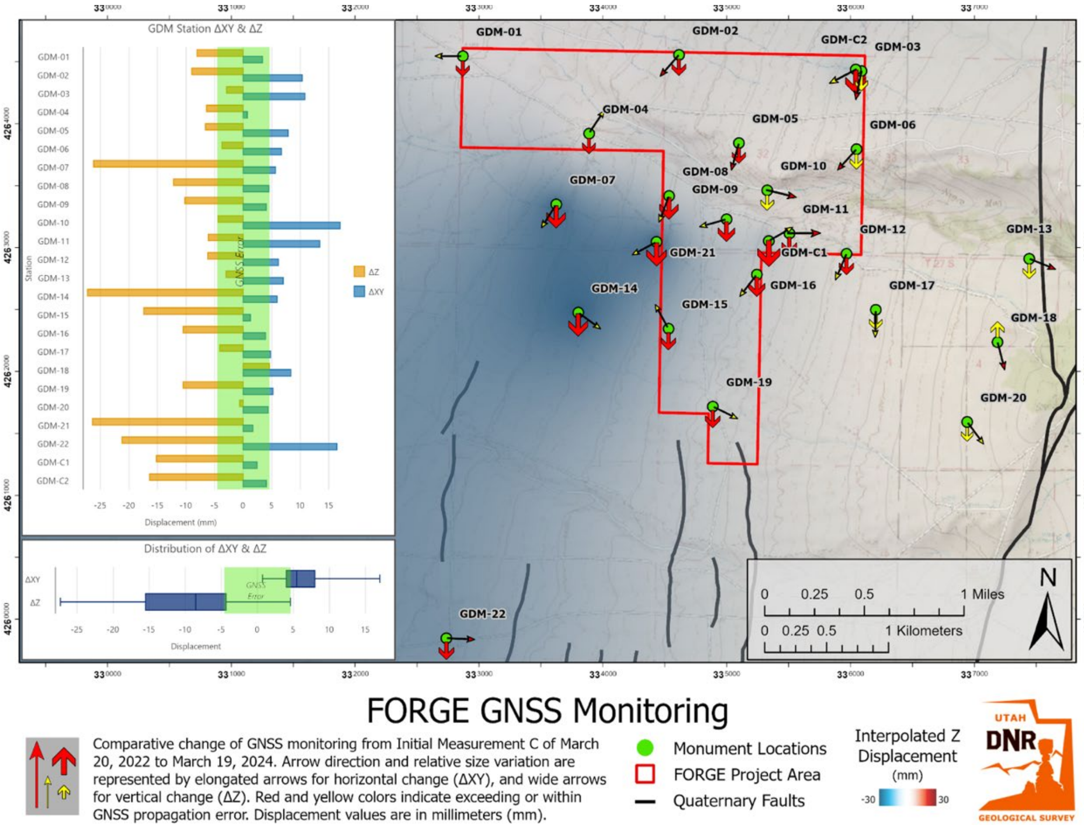


Figure B.4-1. *Vector map and vertical surface displacement interpolation of monuments measured between Monitoring Campaigns Initial C (March 13, 2022) and 21 (March 19, 2024). Displacement surface color scale bar in mm located to lower right.*

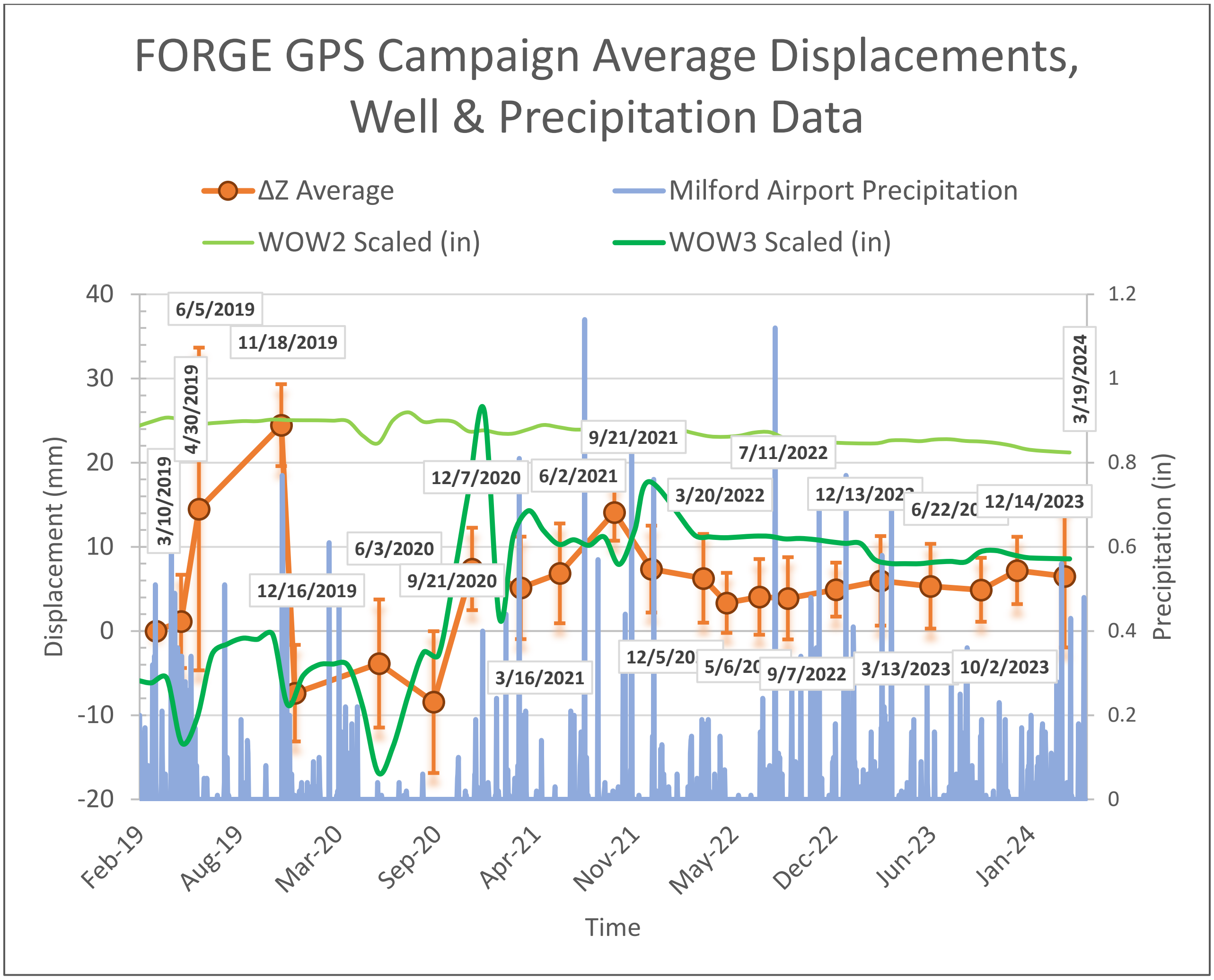


Figure B.4-2. *Time series graph showing average vertical displacements of all monuments compared to precipitation at the Milford Municipal Airport and the groundwater levels of wells WOW2 and WOW3.*

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 Utah FORGE wells (Figure B.4-3). Furthermore, from a simple forward model (Mogi, 1958), assuming an inflated sphere buried in a half space with uniform elastic properties, vertical displacements for a range of scenarios can be calculated. Six separate cases were considered (Table B.4-1)

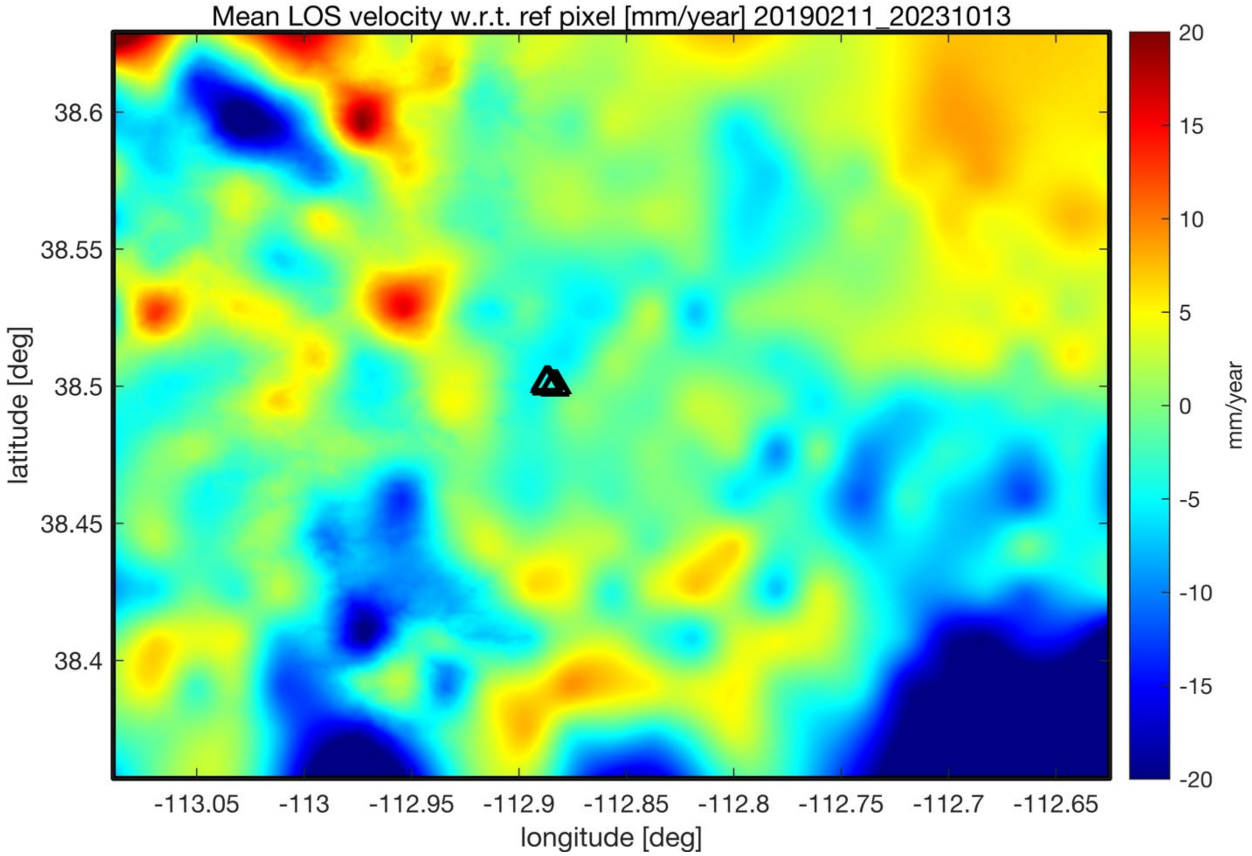


Figure B.4-3. *Map of mean rate of radar line of sight (LOS) displacement averaged over the time interval [2019/02/11 through 2023/10/13]. X and Y coordinates are longitude and longitude in degrees, respectively. Triangles indicate locations of wells 58-32, 68-32, and 78-32.*

Table B.4-1. *Values of parameters in Mogi model.*

Case	Depth (m)	**Δ** Volume (m^3)	Equiv. seismic moment M_0 (N.m)*	Equiv. seismic magnitude Mw
1	3334	3.8E+02	1.1E+13	2.7
2	3334	1.8E+04	5.3E+14	3.8
3	3334	3.8E+05	1.1E+16	4.7
4	3334	3.8E+06	1.1E+17	5.3
5	3334	3.8E+07	1.1E+18	6.0
6	500	1.8E+04	5.3E+14	3.8

* assuming geometric potency (slip x area) equal to volume change ΔV and shear modulus of 30 GPa.

The first two cases approximate the stimulations in July 2023 and April 2024. As shown by solid curves in Figure B.4-4, the simulated ground motion forms small bulge of uplift. The maximum values of vertical displacement are 8 micrometer and 4 micrometer, respectively. These values are considerably smaller than the detection limit of 10 millimeter for InSAR.

Three hypothetical cases are also considered with large modeled injection volumes (dotted curves). In Case 3, the vertical displacement u_z of 8 mm approaches the detection limit of 10 mm. Cases 4 and 5 consider injection volumes of the same order of magnitude (in absolute value) of annual rate of net production at a commercial operation; pumping at 500 GPM for 1 year is approximately equivalent to $\Delta V \sim 10^6$ m^3. The values of $\boldsymbol{u}_z$ in Cases 4 and 5 are 80 mm and 800 mm, respectively. In other words, if injection at the same rate as during the 2023 Utah FORGE tests were to continue for a year with no production, then the surface displacement would be measurable by InSAR.

To illustrate the non-linear trade-off between depth d and volume change ΔV, another hypothetical case with a shallow depth d=500 m and ΔV=18,000 m^3 (just as in Case 2) was considered. This Case 6 would produce 20 mm of vertical displacement at the surface (dark blue dotted curve).

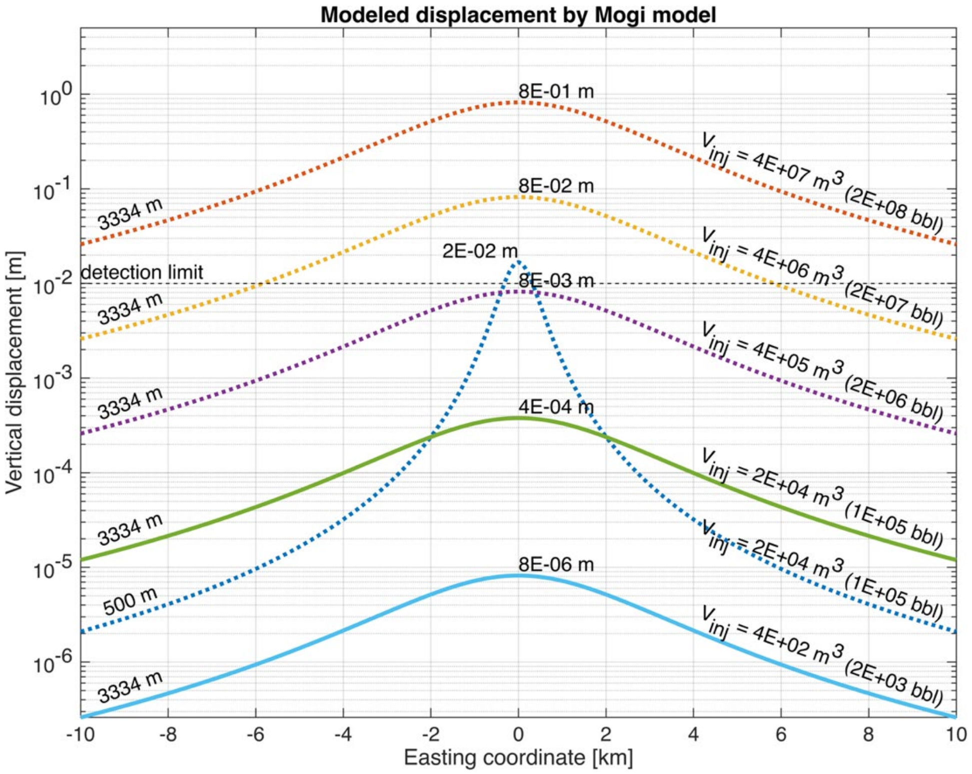


Figure B.4-4. *Plot of vertical displacement in meters calculated from the Mogi model for injected volumes approximating the stimulations in July 2023 (light blue solid line) and April 2024 (green solid line) as well as three hypothetical cases (purple, yellow, red) with different values of volume change (labels on right hand side). The dark blue curve shows a hypothetical case with a shallow depth (labels at left).*

Repeat gravity surveys of the GPS monuments by the Utah Geological Survey shows time series variation of -20 to +400 uGal (Figure B.4-5), 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.

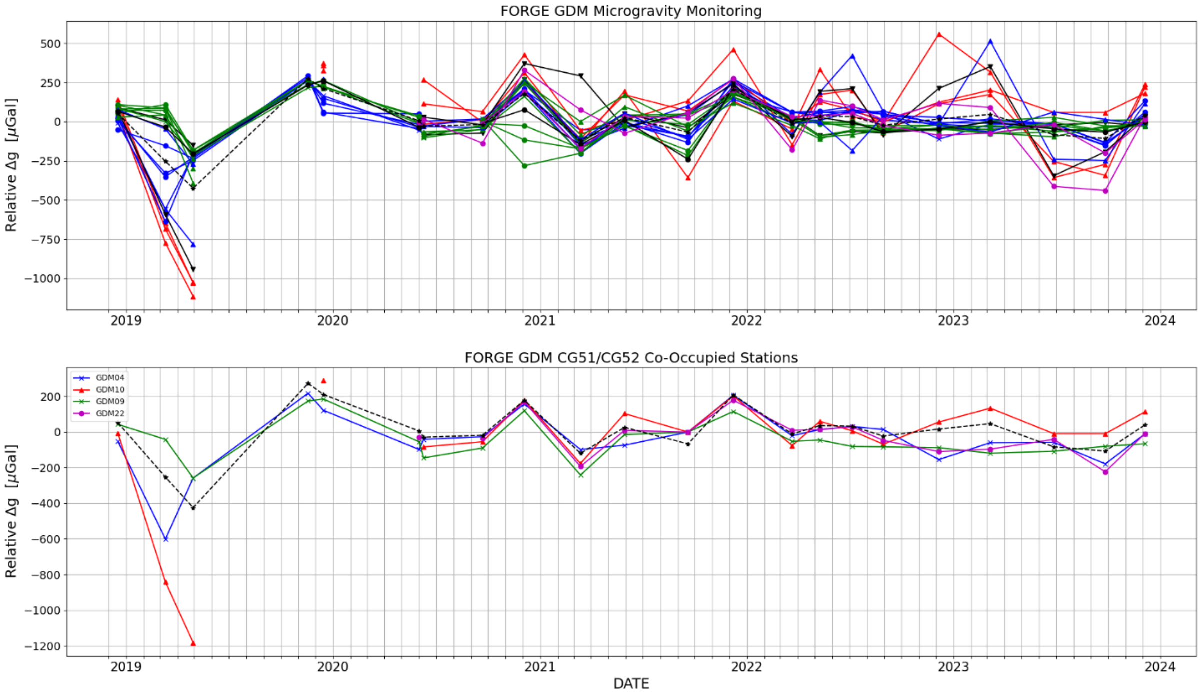
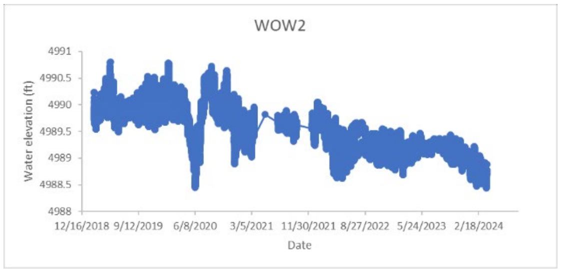


Figure B.4-5. *Plot of gravity station results from December 2018 to December 2023. Top panel shows the observed gravity changes in µGal; bottom panel shows the trends of the local field tie points (GDM10, GDM22) and daily loop base stations (GDM04, GDM09). Dashed lines show the average trend for all stations. Assigned colors based on earlier groupings according to qualitative signal trends.*

Groundwater levels are monitored in two shallow wells, WOW2 and WOW3, which are the only accessible ones available in the vicinity of Utah FORGE. Over the last year, WOW2 showed gradual water level decline of 0.5 feet, whereas the water level in WOW3 remained static (Figure B.4-6). The drilling of a new water well on the Utah FORGE site, 58B-32, provides an additional monitoring point, and during pump testing in February, 2024, there was no indication of water-level change in either WOW2 or WOW3.



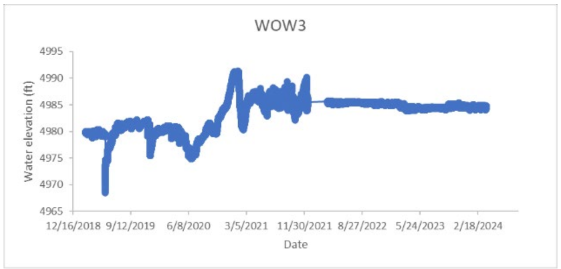


Figure B.4-6. *Continuous water levels for the WOW2 and WOW3 monitoring sites*

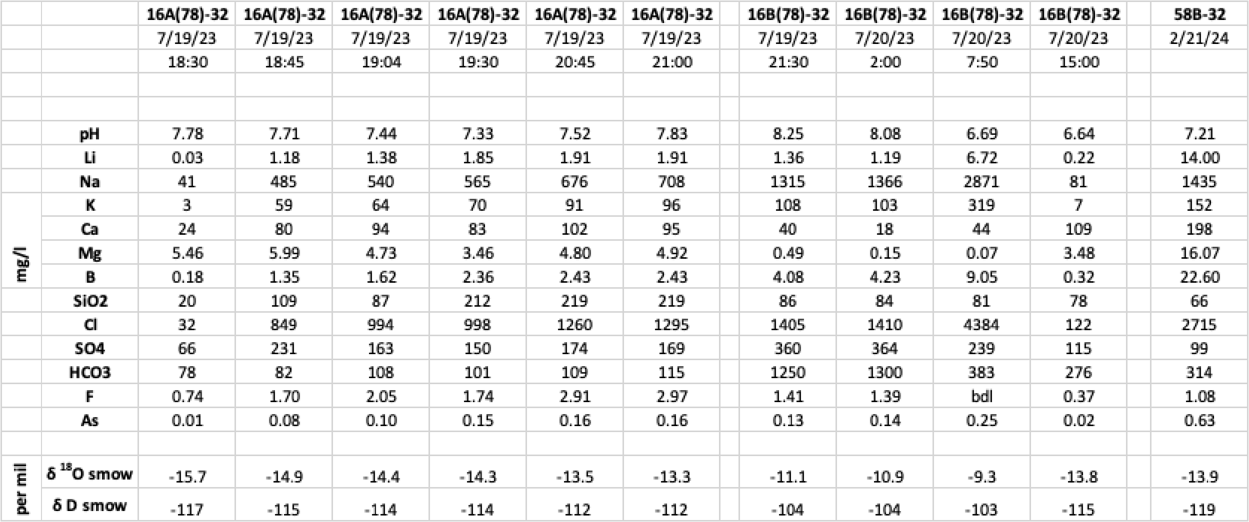
Geochemistry of Waters

Chemical analyses for produced fluids were obtained from the short term circulation test between wells 16A(78)-32 and 16B(78)-32 on July 19-20, 2023, and completion of groundwater supply well 58B-32 in February, 2024 (Table B.4-2). The 16A(78)-32 data represent a phase of injection flowback which lasted between 4:15 and 9:09 pm on July 19, 2023, prior to injection-production circulation testing. These data are interesting because they provide results that resemble the injection flowback testing carried out in April 17 through 22, 2022. Specifically, the injected water is nearly fresh water as represented by the sample obtained at 18:30, which never left the well, whereas the subsequent waters show progressive increase in total dissolved salts (e.g., Cl increases from 849 to 1295 mg/kg). Similarly, oxygen and hydrogen isotopes show progressive enrichments, which provisionally are believed to be related to fluid-mineral interactions occurring in the stimulated EGS reservoir. The 16B(78)-32 data represent production fluids collected between 21:30 July 19 and 15:00 July 20, 2023. Significant is the sample obtained at 7:50 on July 20, 2023, which shows a significant increase in total dissolved salts with 4384 mg/kg Cl; this is also the most isotopically enriched waters of the samples analyzed.

A water sample collected February 21, 2024 provides characterization of the groundwater aquifer intersected by 58B-32 that represents the subsurface hydrothermal outflow from Roosevelt Hot Springs. This well is the supply well for future injected fluids, including the fluids used in the April 2024 stimulation-circulation test. The chemical analysis is similar to the compositional data collected for an aquifer sample obtained from 78-32 in 2019.

A comparison of representative water compositions of produced and flowback waters, including the early production fluid from Roosevelt Hot Springs, is shown in Figure B.4-7. There are two aspects worth highlighting.

Table B.4-2. *Analytical results for flowback and produced waters from wells 16A(78)-32, 16B(78)-32, and 58B-32.*



		16A(78)-32	16A(78)-32	16A(78)-32	16A(78)-32	16A(78)-32	16A(78)-32		16B(78)-32	16B(78)-32	16B(78)-32	16B(78)-32		58B-32
		7/19/23	7/19/23	7/19/23	7/19/23	7/19/23	7/19/23		7/19/23	7/20/23	7/20/23	7/20/23		2/21/24
		18:30	18:45	19:04	19:30	20:45	21:00		21:30	2:00	7:50	15:00		
	pH	7.78	7.71	7.44	7.33	7.52	7.83		8.25	8.08	6.69	6.64		7.21
	Li	0.03	1.18	1.38	1.85	1.91	1.91		1.36	1.19	6.72	0.22		14.00
	Na	41	485	540	565	676	708		1315	1366	2871	81		1435
mg/l	**K**	3	59	64	70	91	96		108	103	319	7		152
	Ca	24	80	94	83	102	95		40	18	44	109		198
	Mg	5.46	5.99	4.73	3.46	4.80	4.92		0.49	0.15	0.07	3.48		16.07
	B	0.18	1.35	1.62	2.36	2.43	2.43		4.08	4.23	9.05	0.32		22.60
	SiO2	20	109	87	212	219	219		86	84	81	78		66
	Cl	32	849	994	998	1260	1295		1405	1410	4384	122		2715
	SO4	66	231	163	150	174	169		360	364	239	115		99
	HCO3	78	82	108	101	109	115		1250	1300	383	276		314
	F	0.74	1.70	2.05	1.74	2.91	2.97		1.41	1.39	bdl	0.37		1.08
	As	0.01	0.08	0.10	0.15	0.16	0.16		0.13	0.14	0.25	0.02		0.63
per mil	**$\delta^{18}O$ smow**	-15.7	-14.9	-14.4	-14.3	-13.5	-13.3		-11.1	-10.9	-9.3	-13.8		-13.9
	δ D smow	-117	-115	-114	-114	-112	-112		-104	-104	-103	-115		-119

First, the produced water from 16B(78)-32 (7/20/23) resembles the chemical and isotopic compositions of end-member flowback waters from the first three stimulated stages in 16A(78)-32, July 17-21, 2023. This is evidence of connectivity and breakthrough during the July, 2023 circulation testing, but more importantly provides provisional indication of the likely EGS reservoir fluid composition. These four waters also bear resemblance to the produced water from Roosevelt Hot Springs (14-2 RHS), except for the silica concentration and the oxygen and hydrogen isotope compositions.

Second, the 58B-78 and 78-32 waters represent the hydrothermal outflow from Roosevelt Hot Springs, and when compared with 14-2 RHS, effects of dilution are discernible as is a significant increase in calcium. The latter has a bearing on calcite deposition induced by heating during injection, which based on thermodynamic calculations would occur between 50° and 100°C. The implication is that calcite anti-scalants will be required for long-term circulation plans to prevent blockages from forming in the EGS reservoir.

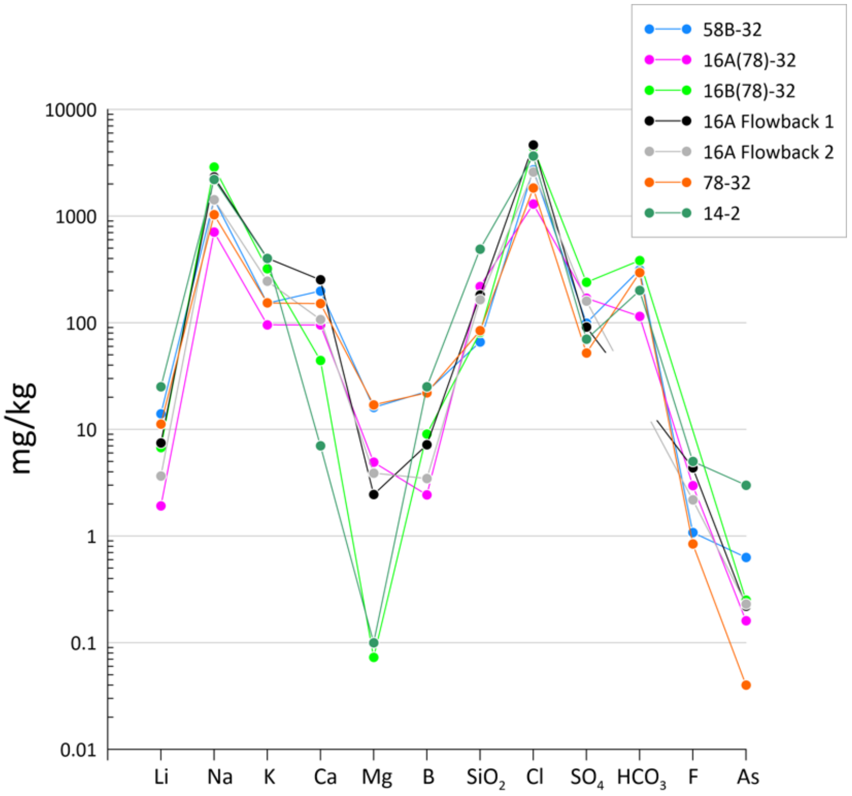


Figure B.4-7. *Spidergram plots of flowback and produced waters that have interacted with the stimulated reservoir (16A(78)-32, 16B(78)-32, 16A Flowback 1 & 2) or derive from Roosevelt Hot Springs (58B-32, 78-32, 14-2).*

Geology of the EGS Reservoir

The Utah FORGE EGS reservoir occurs in the underlying basement where granitoid and metamorphic rocks form a mixed lithologic assemblage (Figure B.4-8). The granitoid ranges from true granite to diorite in composition, whereas the metamorphic rock is predominantly made of orthogneiss. Because they are mineralogically and compositionally similar, felsic granitoid and gneiss are difficult to distinguish in drill cuttings as deformation fabrics and foliation are difficult to detect. Differentiation relies on occurrences of metamorphic sillimanite or garnet, which occur in low abundances (< 1wt%). Notably, core samples of orthogneiss with penetrative deformation fabrics do not contain these metamorphic phases. Provisionally, the shallowest occurrence of orthogneiss occurs at ~2,300 m depth in wells 16A(78)-32, 56-32 and 78B-32 (Figure B.4-8). From petrographic analyses of cuttings, the intervals of orthogneiss range from ~10 m to >100 m length, being separated by intervals of felsic granitoid.

Preexisting fractures are important, as when stimulated, they act as permeable pathways for injected and circulating fluid. Fracture zones are also the locus of alteration and open-space filling mineralization. The geophysical log responses to fracture zones include abundant fracture planes in FMI logs, relatively long sonic travel times, increased porosity and resistivity, and a decrease in density. Fracturing is most common in the upper basement and decreases with depth. Some of the more pronounced fracture zones occur at lithologic contacts between the granitoid and shallowest orthogneiss in wells 16A(78)-32 and 56-32, and a thin schist in well 16A(78)-32. Fractures in these zones are dominantly interpreted to be unmineralized and show significant variability in orientation.

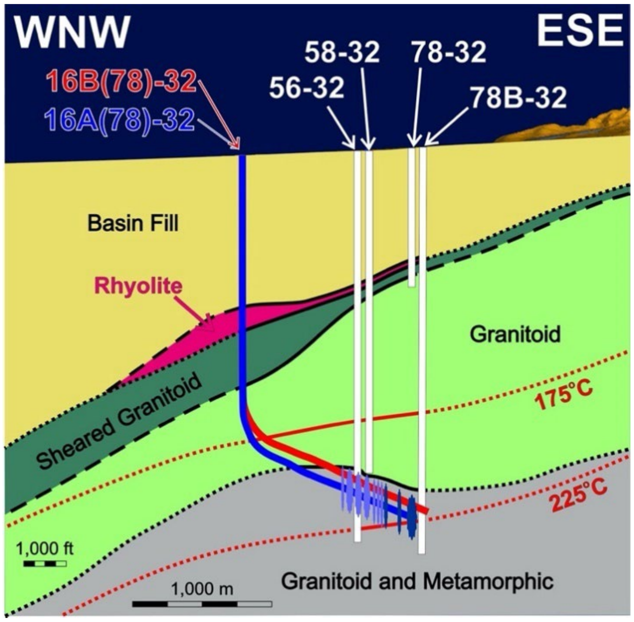


Figure B.4-8. *Geological cross section showing the stimulated intervals (dark blue=2022; light blue=2024) in wells 16A(78)-32 and 16B(78)-32 and the EGS reservoir beneath Utah FORGE.*

Overall hydrothermal alteration and vein mineralization are weakly developed, consistent with the low permeabilities of the basement rocks; however, where sheared and fractured, alteration and open-space mineralization intensify. Another control on emplacement of secondary minerals is temperature, and the hottest formed phases comprise epidote, which is widely distributed in trace amounts throughout the granitoid and metamorphic rocks, actinolite, which occurs locally as needle-like inclusions in epidote, and rare albite. Clay and carbonate minerals are the most common secondary phases, and clay minerals form at cooler temperatures. Clays, including kaolinite, chlorite, illite and interlayered chlorite/smectite, and illite/smectite, appear to mainly form via replacement of preexisting phases, but they were also deposited in fractures, locally. Fe- and Mg-carbonates minerals are the most abundant open-space filling, occurring as both euhedral rhombs encapsulated in fine-grained quartz ± illite and in late monomineralic veins.

The occurrences of two minor soluble phases in the form of anhydrite and halite are also important. Anhydrite is widely distributed and likely restricted to fracture and pore fillings, whereas only one occurrence of halite intergrown with interlayered illite/smectite has been identified (Figure B.4-9). Nonetheless, flowback waters resulting from injection experiments in 16A(78)-32, occurring in April, 2022, showed sharp increases Cl, SO_4, Na, K, and Ca, suggesting that such soluble minerals are widespread and have capacity to transform the compositions of modern EGS fluids over very short time-scales.

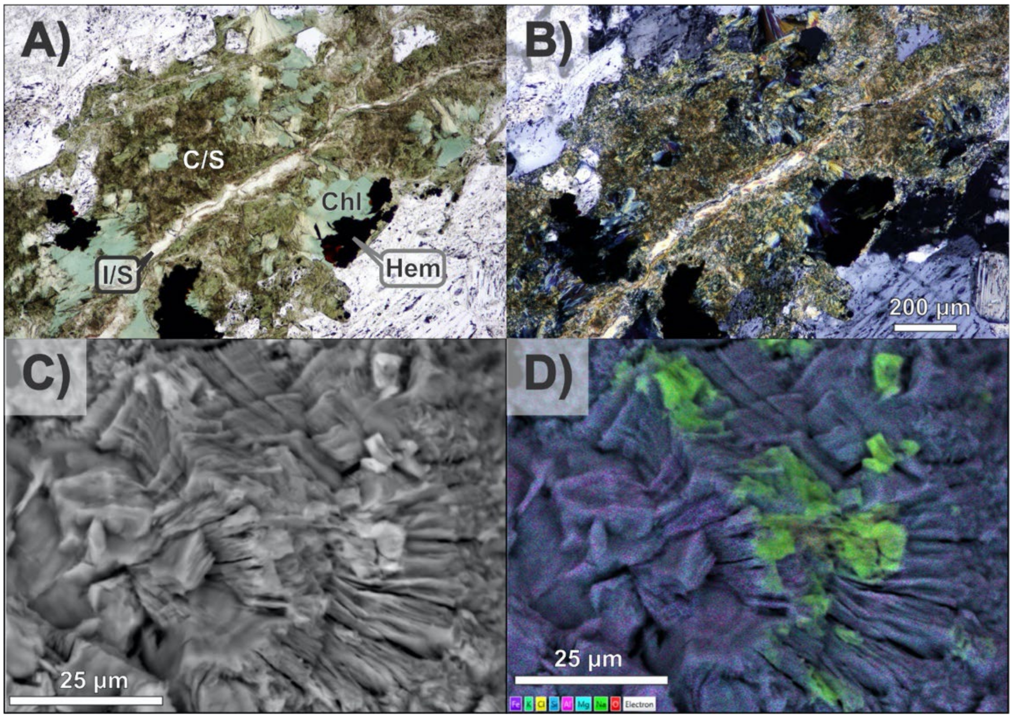


Figure B.4-9. *Photomicrographs, SEM back scatter electron (SEM-BSE) image, and an energy dispersive spectroscopy (SEM-EDS) elemental map of a vein cutting core form well 16A(78)-32 at 1,783 m. A & B) Photomicrographs of the vein (in thin section) filled by chlorite (Chl), interlayered chlorite/smectite (C/S) and hematite (Hem). A late fracture cuts the vein filled by lighter colored interlayered illite/smectite (I/S) and halite. A = plane polarized light; B = crossed polarized light. C) SEM-BSE photomicrograph of intergrown interlayered illite/smectite and halite (lighter gray) on a rough, broken surface. D) SEM-EDS elemental map overlain on the SEM-BSE image shown in panel C in which halite crystals are green and interlayered illite/smectite is blue.*

B.5 SEISMIC MONITORING

Overall goals: The Recipient will continue to collect seismicity data from surface and borehole seismometers. Collection will continue throughout the lifetime of the project and will be re-evaluated on an annual basis for efficacy in tracking seismicity and in ensuring appropriate tracking of event magnitudes and ground shaking from a hazard and mitigation perspective. Data from the permanent network will be telemetered in near-real-time and be made available to the public through the EarthScope Data Management Center (DMC). Data from temporary deployments (e.g., industry geophone strings, distributed acoustic sensors, and geophone arrays) will be archived in a timely fashion for access by the community. The results of existing data will be incorporated into the seismic catalog, the earth model, and used to update the Induced Seismicity Mitigation Plan (ISMP) on an annual basis or more frequently as required.

Maintenance of the Seismic Network and Telecommunications Hub

Data flow from the local seismic network is 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 was stored on-site backfilled into the system and was added to the data archive. Specific activities are detailed below.

From April through June 2023, the cell modem feedline at FSB3 was replaced due to water ingress. Stations FSB4,5,6 and FOR7,8 were down due to a 4-day loss of utility power in the trailer at wellhead 58-32. A recently graduated Master's student determined the horizontal channel orientations for all Utah FORGE stations using surface waves from teleseismic earthquakes. The details of this analysis were part of Patrick Bradshaw’s thesis work and are summarized in a report available on the Geothermal Data Repository (GDR). Table B.5-1 summarizes the findings (Bradshaw et al., 2023). As a result of his work, broadband stations FOR5 and FOR8 were reoriented to true north, as they were off by 16.5 and 8 degrees east, respectively.

Table B.5-1. *Shallow Borehole Horizontal Channel Orientation*

Station	Azimuth of Channel 1 Relative to North
FORK	-105
FSB1	103
FSB2	-118
FSB3	-24

FSB4	141
FSB5	-45
FSB6	-42

From July through September, 2023, the primary fieldwork was to mitigate effects of excessive heat on seismic sensors and radios used for telemetry. The sensor cover at site FOR2 was buried to better thermally insulate the sensors. New mounts were designed for the radios and many were repositioned out of direct sunlight. Additionally, equipment targeted for continuous monitoring of borehole PSS geophones was retrieved and tested for repurposing. Engineers also worked with GES and Utah FORGE staff in testing refurbished PSS tools and in developing telemetry infrastructure for communication between the pads.

At the end of December, there were power issues and an unusual GPS glitch that resulted in a real-time data outage. The Utah FORGE site was visited December 28 and most stations were brought back then. Two stations were remotely cycled and data flow resumed December 31. No data was lost and all data has been archived. Due to construction at the Blundell Power Plant facilities, we have temporarily pulled station FORB. When construction is finished the station will be reinstalled.

Since January 2024, we have made several site visits for maintenance issues. Notably, we upgraded the broadband sensors and data logger at station FORU to newer and more modern equipment (Trillium compact posthole sensor and Centaur data logger). We also had to change the telemetry coming from station FOR7 from radio to cell modem. When the water tanks were installed on pad 58-32 they blocked the line-of-site path. There were also power issues on the 58-32 pad that required a visit to manually restart the data collection nodes.

Local Seismic Monitoring for Hazard Assessment:

Seismic Network Updates

The seismic network has been largely stable this year. Although station FORB has been temporarily removed due to construction at the Blundell Power Plant. When possible, the station will be reinstalled. All Utah FORGE data continues to flow to UUSS in near-real-time where it is integrated into the Advanced National Seismic System Quake Monitoring System (AQMS). Data also flows into a separate Utah FORGE-specific operational module based on *qseek* (Isken et al., 2024) for automatically detecting and locating FORGE-related seismic events M > -1.

For borehole monitoring Geo Energie Suisse (GES) continued working with Avalon to refurbish and correct design flaws in the PSS tools. In October 2023, these tools were deployed into 58-32. The work was overseen by a GES engineer and Ben Dyer. There were initial problems with connecting the boots. A specialized tool was designed and built to solve this problem. Of the two tools that were sent one had only vertical channels working. The second tool was deployed and detected several local earthquakes. It was determined that the assembly of the tools was not adequately quality-controlled. Based on the experiment, it was concluded that PSS tools would be a good option for the 2024 stimulation with the revised cable head design and having the GES engineer on-site to inspect the tools before deployment.

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, 2023 through April 30, 2024, 1346 earthquakes (M -1.51 to 2.56) have been located (Figure B.5-1 and Figure B.5-2). 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; Petersen and Pankow, 2023; Zandt et al., 1982). The seismicity close to the Blundell power plant tends to be shallow and we hypothesize it is a byproduct of Blundell production activities. Additionally, there is an earthquake 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 earthquakes in and around the Utah FORGE footprint are associated with the 2023 circulation test, the 2024 stimulations, and the 2024 Cape Station stimulations.

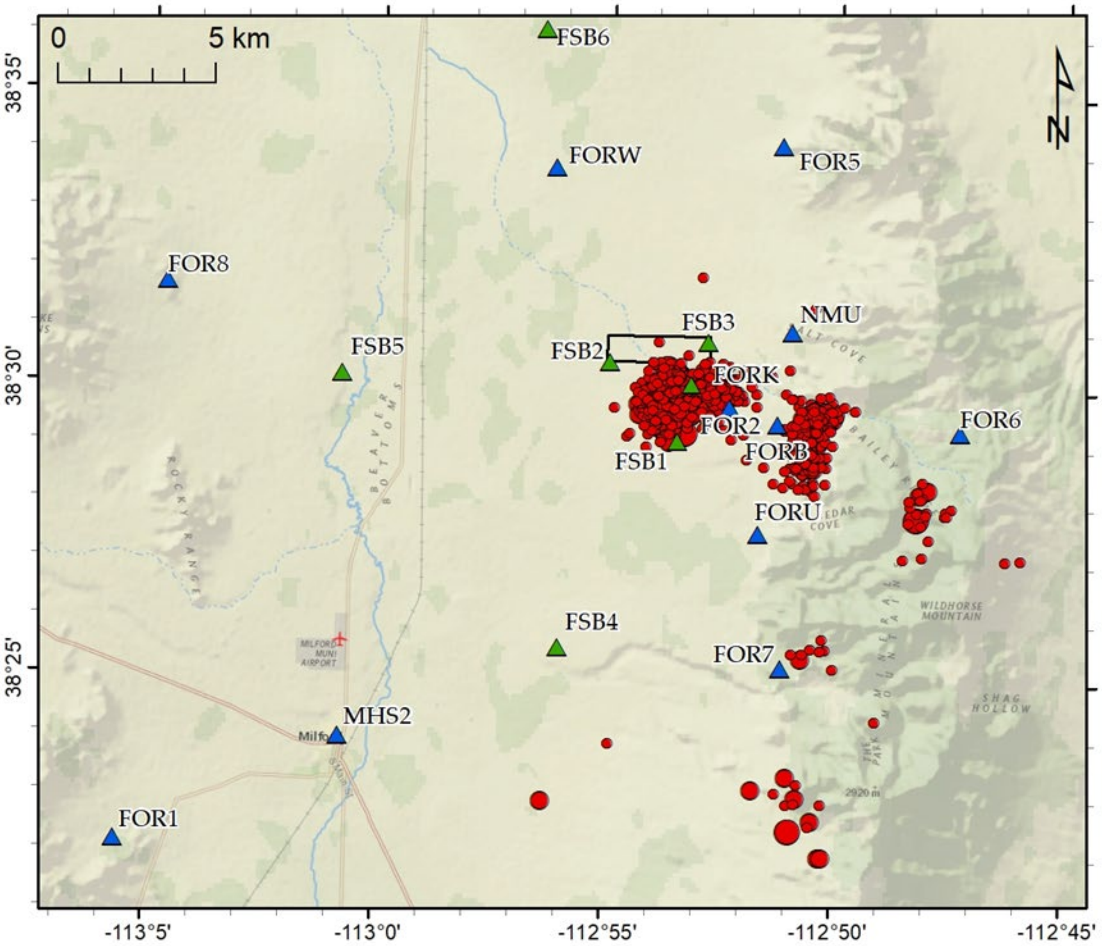


Figure B.5-1. *Seismicity in the proximity of the Utah FORGE site for the time period April 1, 2023 through April 30, 2024 recorded as part of the Utah FORGE project. Triangles are seismic stations. Red circles seismic events (size scaled by magnitude). The largest event clusters from west to east are related to Utah FORGE/Cape Station, Blundell and Mineral Mountains swarm activity, respectively.*

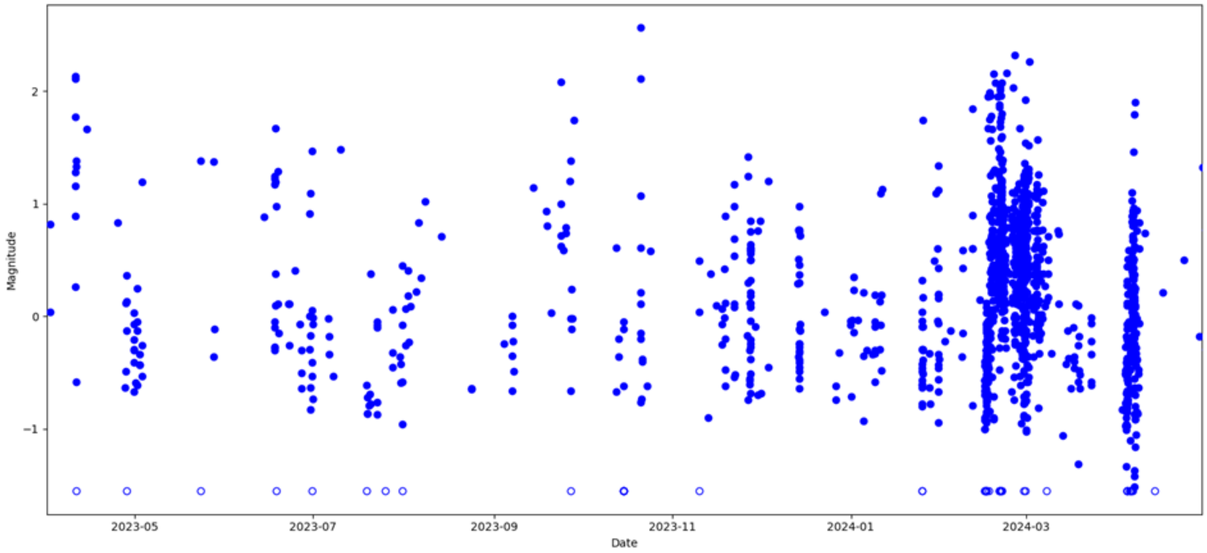


Figure B.5-2. *Magnitude time history for seismicity located in proximity to the Utah FORGE site recorded as part of the Utah FORGE project. Increased earthquake activities in February 2024 and April 2024 are attributed to the stimulations at Cape Station and Utah FORGE. Open circles indicate very small events without magnitude estimates. Same time period as in Figure B.5-1.*

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

The primary activity at Utah FORGE over the last year was a circulation test conducted between wells 16A(78)-32 and 16B(78)-32 from the initial three stages completed in 16A(78)-32, and the additional stimulation stages completed in both 16A(78)-32 and 16B(78)-32 (herein, abbreviated 16A-32 and 16B-32). The objective of the seismic monitoring was to identify the location of microseismicity relative to the reservoir volume outlined by the microseismic events induced during the stimulations of 2022. Specifically, we identify where within the reservoir the microseismic activity occurs and if the microseismicity is located on the edges of the previously stimulated reservoir. Additional work includes testing whether past seismic zones are re-activated. It also became necessary to discriminate seismic activity that originates within Utah FORGE from seismic activity that occurred within the Fervo Cape Station reservoir. For all activities at Utah FORGE, the Traffic Light System (TLS) as detailed in the Induced Seismic Mitigation Plan is in play. The TLS remained at green for both the Utah FORGE circulation and stimulation. However, the status was moved to amber several times during the Cape Station stimulations, without any implications for the Utah FORGE project that was not injecting during February 2024

Two separate catalogs detailing microseismic activity from the circulation and stimulations have been developed. The first uses the surface and shallow-borehole sensors and the second uses seismic instrumentation of deep boreholes. Surface geophone and infrasound arrays were also deployed to monitor the 2024 stimulation. Several presentations, conference papers, data publications, and peer-reviewed articles (Table 2) discuss the details of the monitoring and follow-up activities.

Three-dimensional Velocity Model

Efforts for optimizing the usage of surface monitoring networks require a detailed seismic velocity model. Due to the dipping undulating boundary between the granitic basement and the sedimentary basin below the Utah FORGE site, a 3D velocity model is critical for reliably predicting theoretical seismic travel times used in microseismic event locations using surface networks. We compiled all available information regarding seismic velocities from existing studies and reports in the study area to create a new composite 3D velocity model for Utah FORGE (Finger et al., 2024).

The model combines the quasi-3D S-wave velocity structure from Zhang and Pankow (2021) with borehole-derived vp/vs profiles (Lellouche et al., 2020) and a local 3D reflection study (Podgorny et al., 2018; Miller et al., 2019). The 3D model was calibrated with theoretical arrivals and manual seismic phase picks on the permanent Utah FORGE network and on nodal geophones that were temporally deployed during the stimulations in April 2022 (Whidden et al., 2023). The composite 3D velocity model drastically improves the fit between observed and theoretical travel times compared to the simplified two-layer 1D velocity model used for the regional catalog of UUSS (Figure B.5-3).

The 3D model was published via the GDR (Finger et al., 2024) to be used by the research community.

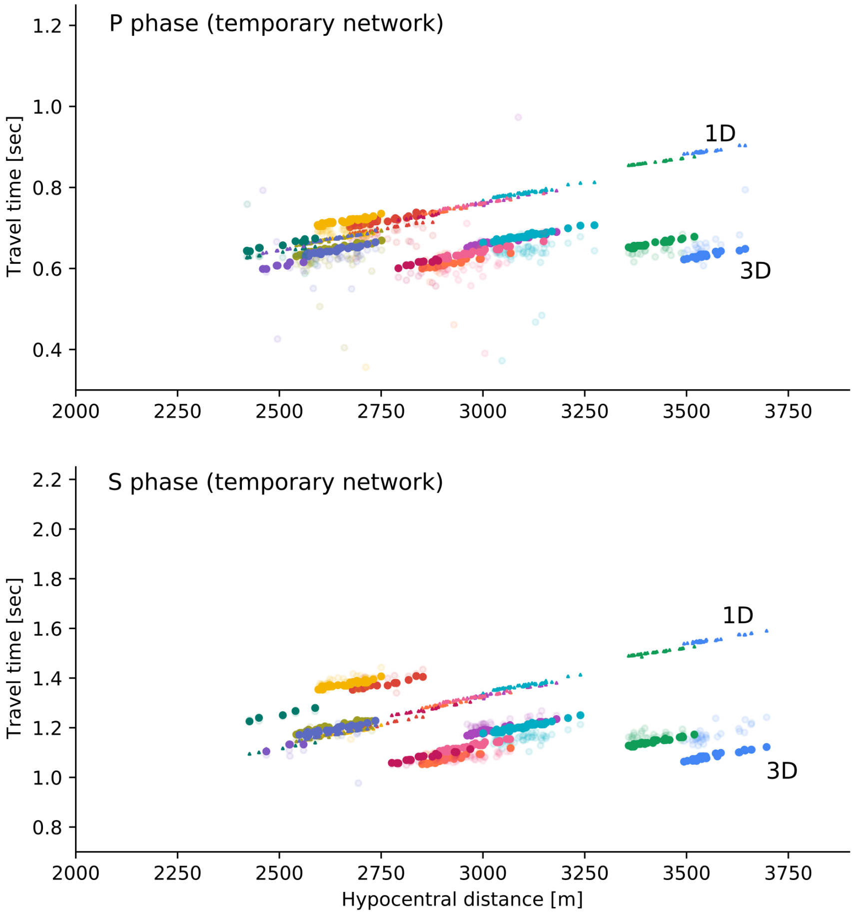


Figure B.5-3. *Comparison of modeled theoretical travel times for the new composite 3D velocity model and the simplified regional 1D model with travel time picks on seismic receivers distributed around the Utah FORGE site. The 3D model provides a much better fit between the observed travel times (pale colors in the background) at the surface and the theoretical travel times calculated based on the high-precision event locations from Dyer et al., 2023.*

2023 Drilling and Circulation Monitoring

Surface Network Reservoir Monitoring

Between April and August 2023, an enhanced automatic earthquake detection workflow relying on a subset of only five surface and shallow-borehole stations closest to the injections (UU.FSB1, UU.FSB2, UU.FSB3, UU.FORK, UU.FOR2) provided a more detailed picture of seismicity during the drilling of the production borehole 16B-32 and the following circulation test. The enhanced detection workflow lowers the detection threshold compared to the regional catalog produced by UUSS, revealing minor seismic activity induced during the drilling and increased induced seismic activity during the circulation test (Figure B.5-4). Unlike during the stimulation experiments in 2022, there was no complementary downhole geophone monitoring. Thus, the (near-)surface monitoring is the only comprehensive dataset that could provide reliable microseismic event locations for the entire period of the circulation tests.

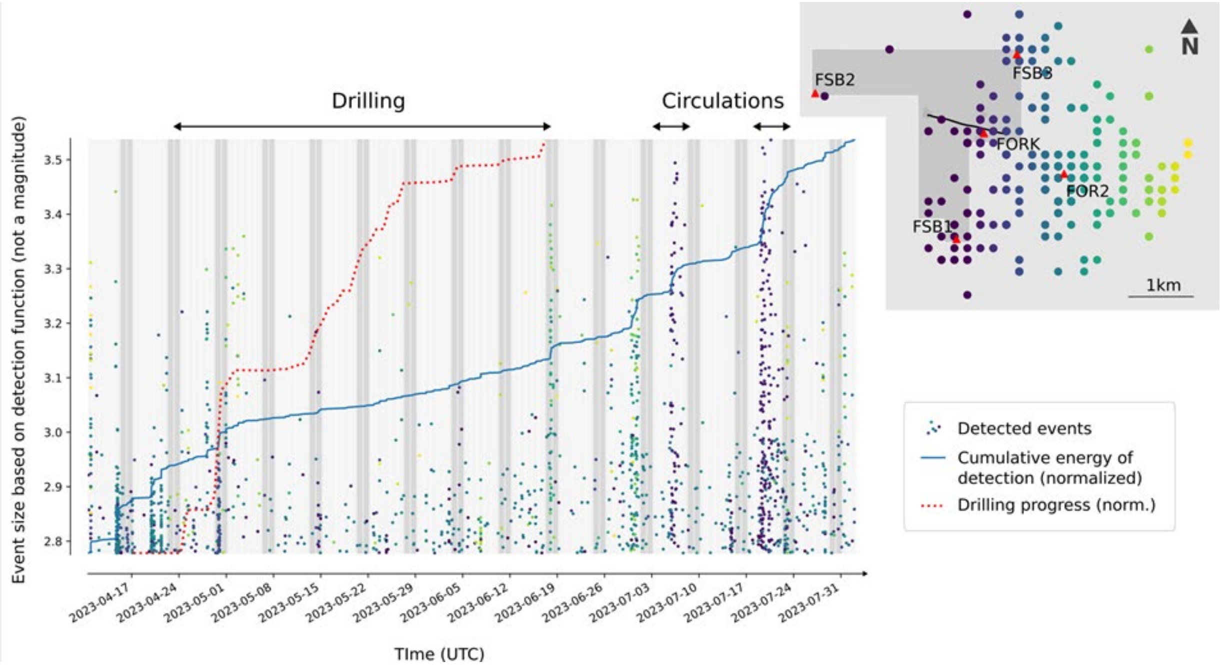


Figure B.5-4*. Enhanced earthquake detection between April and August 2023. The detected events are colored by longitude to separate events below the Utah FORGE site (purple) and natural seismicity (green to yellow) to the east, close to Blundell or in the Mineral Mountains. For convenience, gray bars in the background of the timeline divide it into weeks without any implications for the seismic activity.*

Inherently, the detection capability and the resolution of (near-)surface networks are more limited compared to downhole monitoring networks due to the larger distance to the geothermal reservoir and a noisier sensor environment. To overcome the reduced resolution of the surface seismic network, a joint workflow of full-waveform-based enhanced detections and relative relocations was applied to the circulation experiments in 2023 and the stimulations in 2022. Subsequently, we match the results for the stimulations with the high-quality locations of the 2022 downhole catalog of Dyer et al. (2023), to obtain absolute locations. The locations of over 500 events induced during the circulations in 2023 map the further growth of the hydraulic fracture opened during stage 3 of the 2022 stimulation (Figure B.5-5). The maximum magnitude of M0.45 induced during the circulation test is similar to the maximum magnitude of M0.5 induced during the stimulations in 2022. Details on the applied method that could be used for cost-efficient surface monitoring of geothermal reservoirs are described in Niemz et al. (2024).

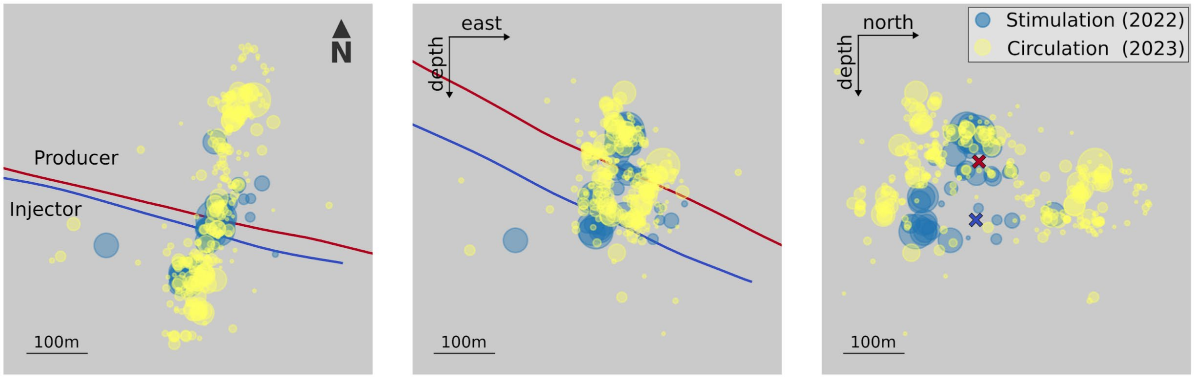


Figure B.5-5. *Relocation results of injection-induced seismicity as observed by the UUSS surface network during the circulation test in 2023. Circles scaled by event magnitude (Mmax 0.5). The map view (left panel) and the two depth sections (center and right) show the locations of seismicity related to the two experiments. The projected trajectory of the injection well is shown in blue. The production well is red. The circulation seismicity frames the previous seismic cloud and shows a pronounced migration toward the north and south (from Niemz et al., 2024).*

The shallow borehole (1000 ft/300 m) station UU.FORK proved exceptionally valuable in detecting seismic activity during the circulation test. It was the only station able to record all the events with a sufficient signal-to-noise ratio, thereby providing reliable relative magnitudes for the studied events (Niemz et al., 2024). The superior quality of the data recorded at the station FORK compared to the other stations results from the effective noise reduction of the shallow borehole installation (Figure B.5-6). Such installations successfully combine reduced drilling costs compared to deep borehole installations and noise reduction compared to surface sensors.

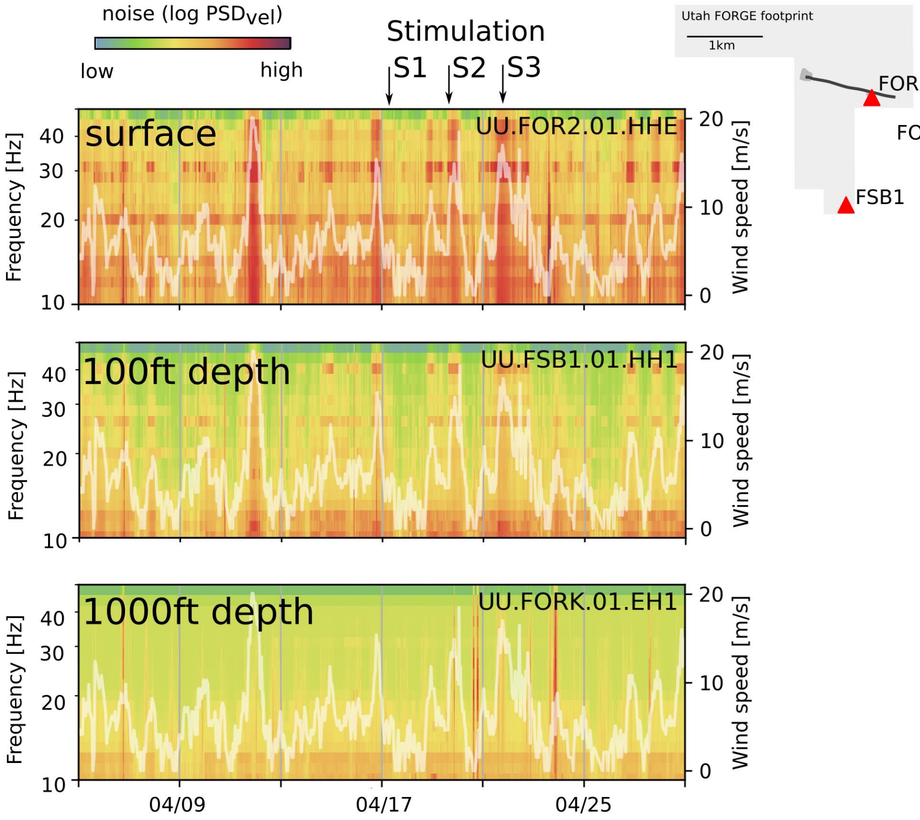


Figure B.5-6. *High winds (white line), common at Utah FORGE, can contaminate seismic records by introducing high background noise. Such noise contaminations affected the ability to detect low-magnitude microseismic events, e.g., during the stimulation stages in April 2022 (S1, S2, S3). The influence of surface noise induced by high winds is reduced significantly with the increasing installation depth of the sensors in a borehole. The wind and other noise sources vanish at a depth of 1000 ft, and local signals become more apparent.*

The circulation-induced seismicity at Utah FORGE and the microseismic catalog from Niemz et al. (2024) were used as a test case and benchmark for the newly developed detection and locations algorithm *qseek* (Isken et al., 2024). *qseek* improves the full-waveform-based detection workflow by combining machine-learning-informed phase detection with robust migration and stacking techniques. With the support of 3D velocity models, *qseek* maximizes the information gained from surface monitoring.

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

GES processed the 16B-32 DAS data acquired by Neubrex during the second part of the July 16A-32 to 16B-32 circulation tests (circulation stages 3 and 4) to identify microseismicity. The DAS cable was not available before this time. The microseismic activity occurred over a period of around 48 hours during which time more than 2200 microseismic events were identified.

Each of these events was auto-located to determine the measured depth along 16B-32 and the offset of the event from the well. Note, a 3D location of these events is not possible using the linear array of the 16B-32 DAS data.

These 2D event locations determined from the DAS are consistent with the 3D distribution of the Stage 3 events of the April 2022 stimulation. No events were identified in the region of the April 2022 stimulation Stages 1 and 2. The circulation events were located at offsets of up to 900 ft from 16B-32. For events occurring close to well 16B-32 during the circulation, it was also notable that the moveouts of the P and S waves recorded on the DAS cable fitted the predicted moveouts very closely. The seismic velocities (P and S) of the granite used for the calculation of predicted moveouts were derived from the perforation shots in April 2022. A typical event is shown in Figure B.5-7 where the measured depth range of the fiber is 7477-10108 ft. Many of the event gathers show apparent reflections originating at 16B-32. A wavefield migration of the S wave was attempted but did not stack well as the 3D event locations are not known.

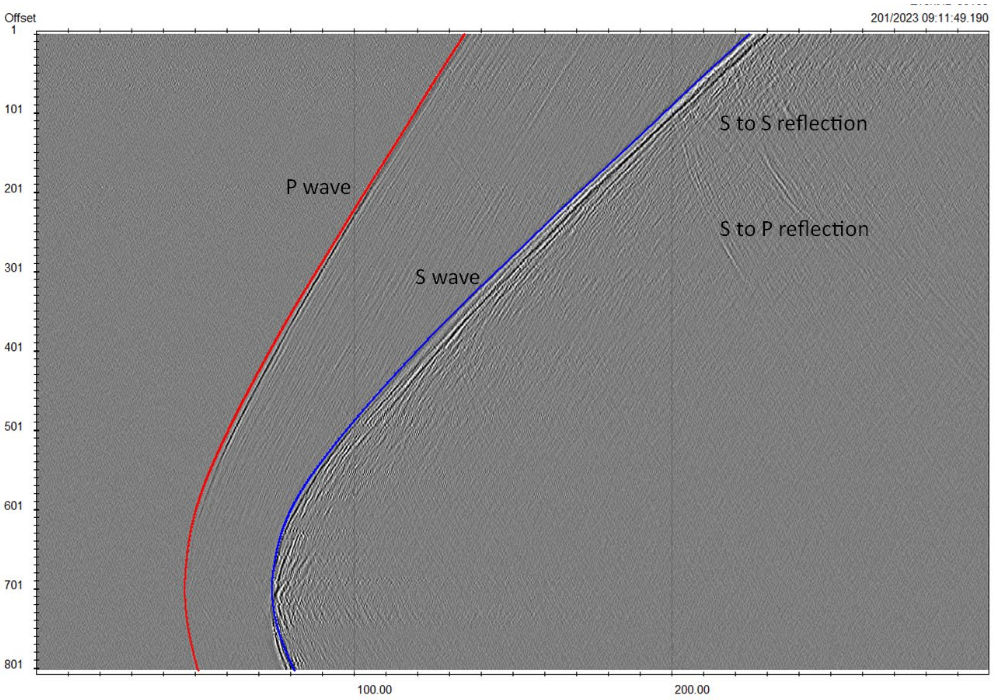


Figure B.5-7. *Circulation microseismic event recorded on the 16B-32 DAS measured depth range of the fiber is 7477-10108 ft. The red and blue arrivals were determined from the auto-location and are a close fit to the actual arrivals, demonstrating the suitability of the velocity model to the data. Many of the event gathers show apparent reflections originating at 16B-32.*

2024 Stimulation Monitoring

Surface Network Reservoir Monitoring

During the stimulation in April 2024, the enhanced detection and location workflow based on the *qseek* algorithm ran automatically in quasi-real time, with a delay of 2-10 minutes. The detection workflow was used as a secondary system for the authoritative TLS threshold regarding the number of events with magnitudes larger than M1. Between April 3 and April 24, ~8,000 events above M -2 were detected, thereof ~200 above M0. About 95% of all events were induced before April 10 during the larger-volume stimulations of the injection borehole 16A-32 (Figure B.5-8). We calculated preliminary relative relocations using the same approach as for the circulation-induced seismicity in 2023 (see circulation section above, Niemz et al., 2024). The first events were induced in the volume of the stimulation stage 3 (April 2022). As expected, events occurred further up the deviated injection well (Figure B.5-9) as the sequence of staged injection intervals moved up the well.

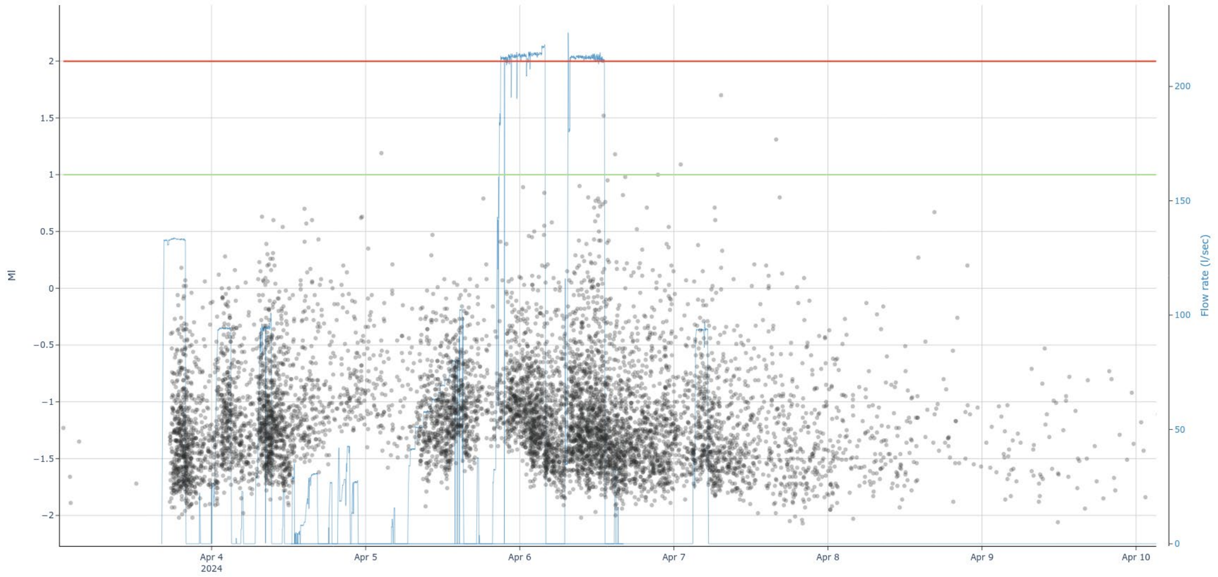


Figure B.5-8. *The seismic event detections from the secondary quasi-realtime seismic monitoring system during the stimulation in April 2024 show the correlation between the seismic event rate and the injection activity. The blue line in the background represents the slurry flow rate. The maximum induced magnitude was below the TLS threshold of M2 (red horizontal line), and the injections did not pass the TLS threshold of 10 events above M1 (green horizontal line) in 24 hours.*

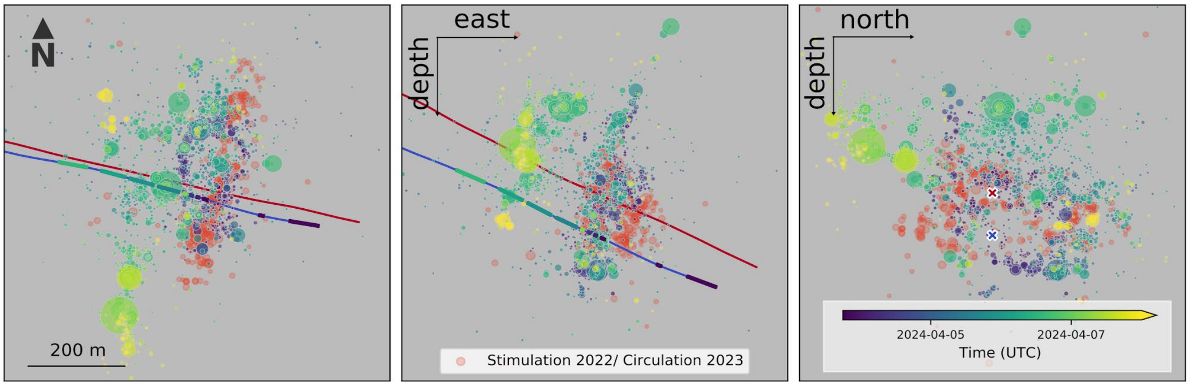


Figure B.5-9. *Preliminary relative event locations for the 2024 stimulations based on the surface and shallow-borehole stations at Utah FORGE. Only microseismic events with magnitudes larger than M-1 induced during the stimulations in April 2024 are shown here. Events are color-coded by their origin time (violet to yellow) and scaled by their magnitude. Stimulation 2022 and circulation 2023 catalog from Niemz et al., 2024.*

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

GES produced a real-time catalog during all stages of the April 2024 stimulations (Figure B.5-10). The monitoring integrated data from the 16B-32 DAS, Fervo Delano 1 DAS, an 8-level Avalon geochain in 78B-32, and a three-component Avalon PSS tool in 56-32. A 12-level Schlumberger geophone string was placed in 58-32, but was not synchronized or integrated with the larger, deep-well receiver array. Further, the Schlumberger string was pulled from 58-32 after the upper completion stages of 16A-32 made connection with 58-32, causing the wellbore to flow. Thus, for most of the stimulations, there was no monitoring from 58-32. However, access to the Fervo Delano 1 DAS mitigated the loss of coverage and location precision. Prior to the last two stages of the stimulation of 16B-32, a wireline DAS extending from the surface to a depth of 7342.5 ft was deployed in 58-32. The signal quality from the 58-32 wireline DAS is comparable to the signal quality for the detections seen on the 16B-32 behind-casing DAS. Figure B.5-10 shows the preliminary catalog determined by GES for the stimulation. The first-order observations are similar to the observations from the surface catalog. The seismicity began in the zone from the 2022 stimulation and then followed the staged stimulation phases uphole.

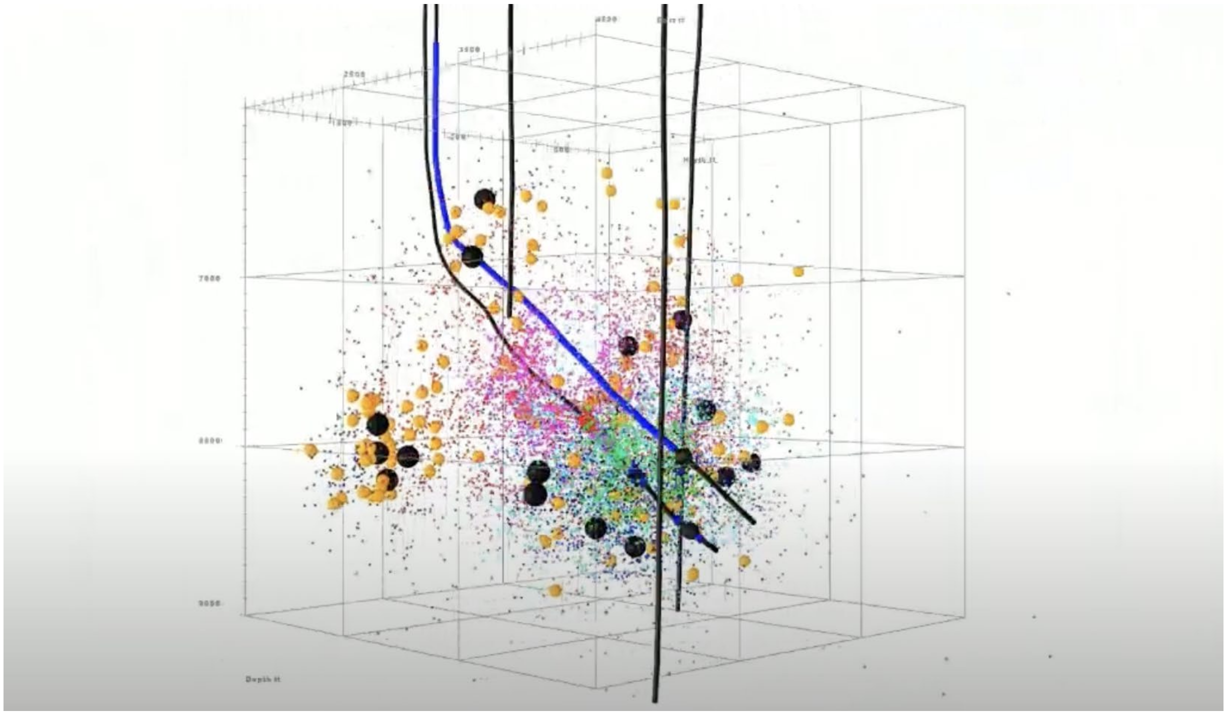


Figure B.5-10. *GES preliminary catalog for the 2024 stimulations. Orange symbols 0.6 < M < 1 and black M > 1.*

Cape Station Monitoring

The stimulations at Cape Station were used as another test case for the improved detection and location algorithm *qseek,* using only the surface and shallow-borehole network. The algorithm performed very well. It detected and located over 50,000 microseismic events above M-2 between mid-Februrary and the beginning of March (Figure B.5-11). The locations of ~2,800 events above M0 revealed a clear clustering of seismic activity in multiple plane-like structures (Figure B.5-12).

GES also used the Cape Station stimulation to test the integration of the 16B-32 DAS data into the Divine software in real-time. In addition to the 16B-32 DAS data, GES integrated DAS data from Fervo's Delano 1 well and data from the PSS geophone in 78B-32. Their preliminary catalog has locations for just over 7100 events M -0.7 to M 2. Similar to the results from the surface network, the deep-well detected seismicity clusters into multiple plane-like structures.

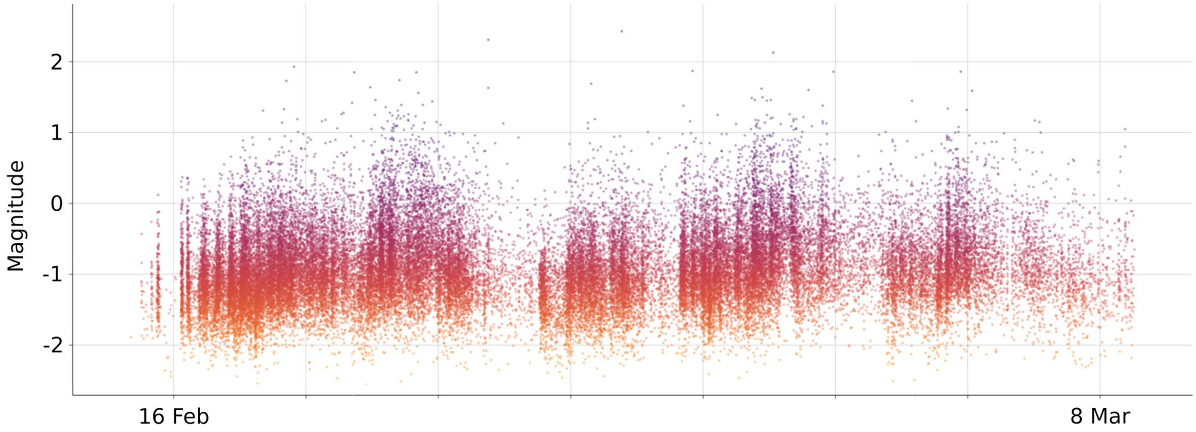


Figure B.5-11. *Seismic event detection during the stimulations at Cape Station between mid-February 2024 and the beginning of March 2024. The enhanced detections are based solely on the UUSS (near-)surface station network. The produced catalog contains over 50,000 events above M-2.*

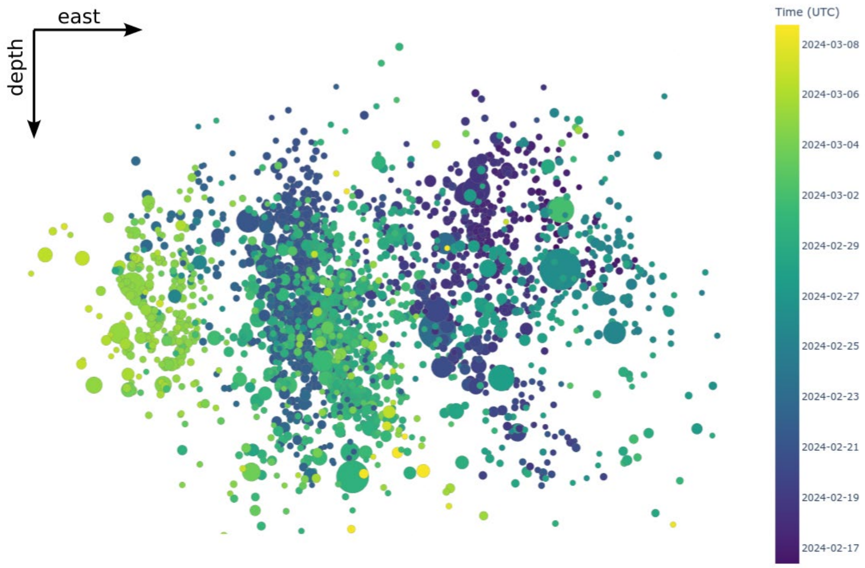


Figure B.5-12. *The advanced detection and location workflow qseek clearly shows planar features within the reservoir of Cape Station. The automated event locations shown here only include events above M0.*

Temporary Monitoring Arrays

The assessment of detection and location capabilities of deep boreholes, shallow boreholes, and surface stations in the local network, as well as how to optimize the involved workflow, is one focus of the broad monitoring setup at Utah FORGE. In a previous reporting period, we set up a complementary temporary network of nodal geophones during the stimulation in April 2022. We explored the advantages of a patch layout combining 16 collocated nodal geophones in patches distributed around Utah FORGE for noise reduction and to increase the database for surface event locations and the azimuthal coverage for planned focal mechanism studies. Initial efforts are documented in Whidden et al. (2023) and presented at the IUGG meeting (Niemz et al., 2023).

In May 2023, additional test deployments of nodal geophones were conducted to assess noise reductions for different instrumental burial depths and to optimize the spacing between nodal geophones for direct stacking of the data within each patch.

Fully burying the nodes at a depth of only 10 cm significantly reduced wind-induced noise that is abundant in a valley with occasionally high wind speeds. Additionally, we found that smaller node spacings, such as 10 m, well below the previously used 30m, have the potential to obtain more coherent waveforms while still suppressing very local noise sources during the stacking. At 30m grid spacing, the direct stacking of seismic signals containing both P and S is hindered by considerable differences in S-P travel times across the patch depending on the frequency content and the hypocentral distance.

To compare the data quality of the nodal stack directly with that of permanent network stations, we installed patches next to UU.FSB1 and UU.FSB2 during the stimulation at Cape Station in February 2024, exploiting the similarity in location and the frequency content of the induced events from Cape Station relative to the events induced by the stimulations at Utah FORGE.

The findings from the test deployments in 2023 and 2024 were integrated into the temporary nodal deployment of 16 patches of 9 nodal geophones during the stimulations in April 2024.

Update Induced Seismicity Plan (ISMP)

The Induced Seismic Monitoring Plan was not formally updated this year. Elements that are updated separately include updated seismicity maps. These are available in real-time and as static quarterly maps at https://quake.utah.edu/forge-map. Updated Seismic Monitoring Plans are generated and submitted for review before each activity at Utah FORGE. The plan for the upcoming stimulation was submitted and approved. It was previously identified that an updated probabilistic seismic hazard analysis (PSHA) was going to depend on findings in the recently released 2023 U.S. Geological Survey National Seismic Hazard Maps. The publications documenting these changes have been recently published, and we are evaluating potential changes before moving toward a new PSHA.

Collaborate and Coordinate Seismic Experiments

In addition to the work related to operational seismic monitoring, the seismic team works with other groups to coordinate seismic activities. During this year, we have met with Fervo seismologists to discuss sharing access to the DAS cables, coordinating access on permitted lands, and sharing information on seismic events and seismic products. We have worked with colleagues from LBNL regarding real-time monitoring and coordinating magnitude scales. We have worked with Rice University to coordinate temporary geophone experiments and when their seismic orbital vibrator sources (SOVs) can be run to not interfere with other seismic monitoring. Finally, we coordinated with the Geothermica DEEP project to test new models for Adaptive Traffic Light Systems (ATLS). Scientists from ETH were on-site for the stimulation. Real-time data was fed into a SeisComp data processing system and fed into three separate ATLS models. For all these projects, we had multiple meetings with each group.

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 (Petersen and Pankow, 2023). Based on the monitoring reinforcing 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.

A new 3D seismic velocity (Finger et al., 2023) model has been generated and fine-tuned using reservoir seismicity. This new velocity model is key for determining locations using the (near-) surface stations and will facilitate earthquake location efforts in the future. The combination of the new velocity model and a sophisticated detection and location algorithm (*qseek*, Isken et al., 2024) allows for detections down to M -1.5 using just the (near-)surface seismic stations. When the initial locations are relocated using relative location techniques, the resulting seismicity patterns are very similar to what is determined using deep borehole instrumentation.

The 2023 circulation was successfully monitored using just the (near-) surface stations (Niemz et al., 2024). Preliminary results from the 2024 stimulation again show the value of only a limited number of near-surface seismic stations for operational seismic monitoring when taking advantage of advanced full-waveform techniques. The resulting high-precision reservoir catalog shows many of the same features as the borehole seismic network. Such near-surface installations are most certainly an option to explore for long-term monitoring of EGS.

GES successfully integrated DAS data with geophone data to generate a high-precision downhole catalog. Judging from the wide use of their previous 2022 stimulation catalog in the EGS research community, the catalog will become a starting point for many future studies on induced seismicity and reservoir mechanics.

The Traffic Light System did not move out of the green zone for either the Utah FORGE circulation test or the stimulations. However, Utah FORGE was moved to Amber as a result of stimulation seismicity generated in the Cape Station reservoir. Having two geothermal reservoirs so close together is complicating seismic monitoring, which has implications for enacting protocols associated with the TLS.

B.6 UTAH FORGE MODELING

Introduction

The Utah FORGE Reference DFN has been updated to reflect the additional data collected and analyzed since the last major revision in 2021. A clustering algorithm was used on acoustic log data for each of the current five deep wells in order to identify changing rock types or mechanical properties. This exercise provided rationale for including several new discrete features into the DFN model. The rock type classification along the well bores shows the significant heterogeneity of the reservoir rock where plutonic granitoids intermingle with metamorphic rock (Figure B.6-1, B.6-2 and B.6-3). Simple boundaries between major rock types were not established, instead, the evidence points to sheared zones or mixed melting at lithologic boundaries. While the four fracture sets identified in the 2021 revision remain, the overall fracture intensity in the DFN has increased and the relative proportions of each set in the new, larger model region have been adjusted.

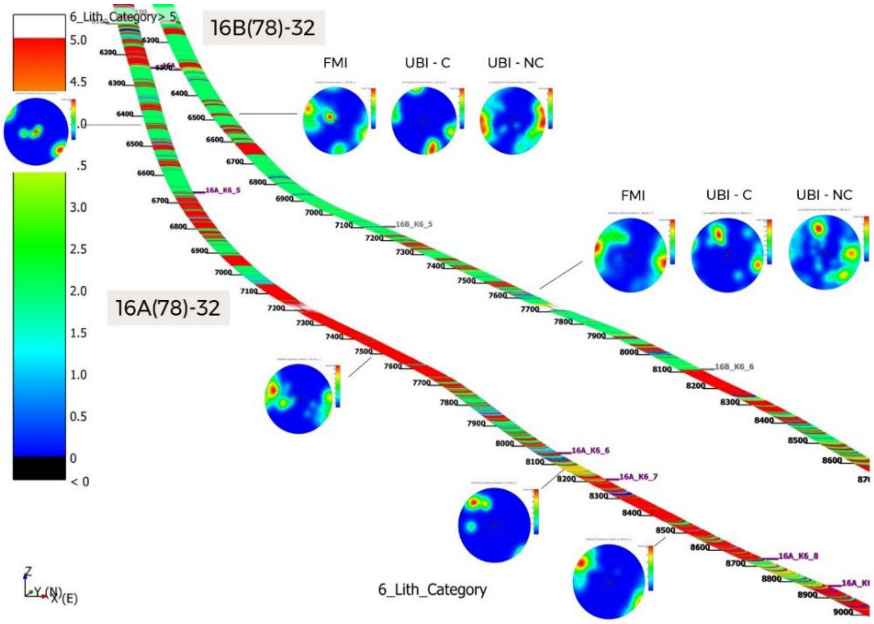


__Figure B.6-1.__ Fracture pole orientations plotted in upper hemisphere stereonets for the upper deviated sections of wells 16A(78)-32 and 16B(78)-32. Wells are colored by cluster label number using k=6.

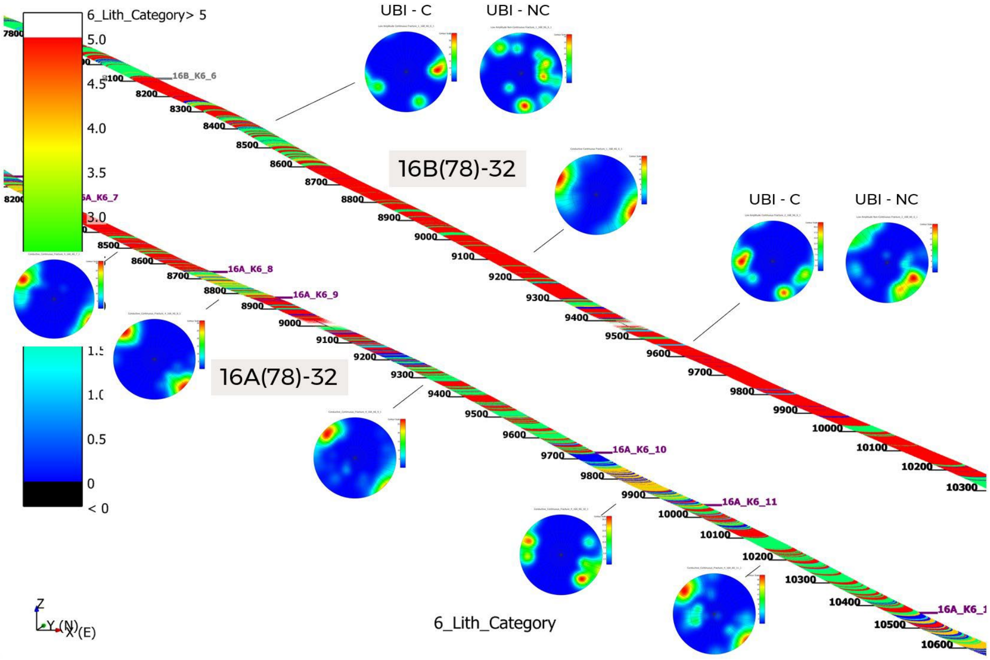


__Figure B.6-2.__ Fracture pole orientations plotted in upper hemisphere stereonets for the middle deviated sections of wells 16A(78)-32 and 16B(78)-32. Wells are colored by cluster label number using k=6.

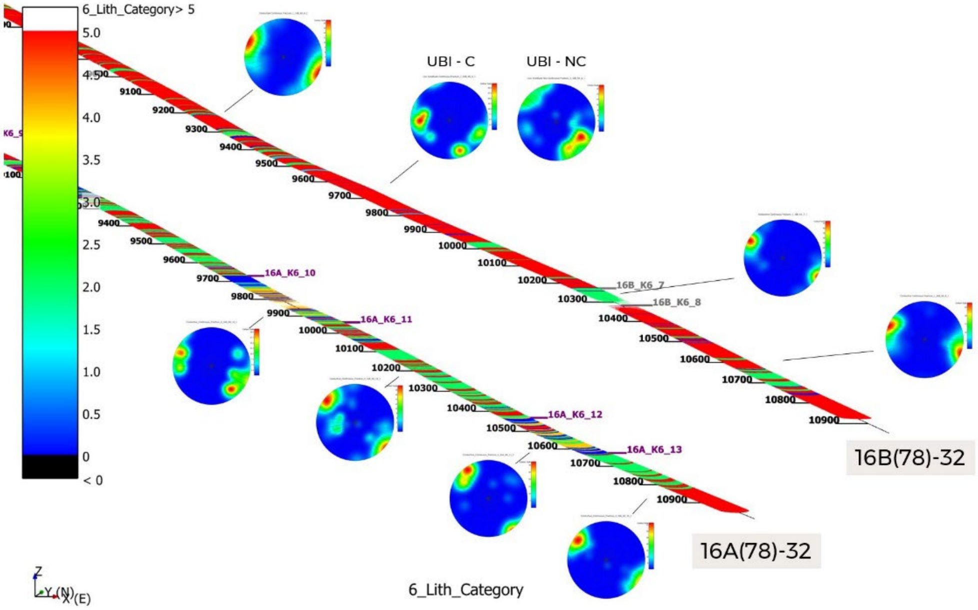


__Figure B.6-3.__ Fracture pole orientations plotted in upper hemisphere stereonets for the deepest deviated sections of wells 16A(78)-32 and 16B(78)-32. Wells are colored by cluster label number using k=6.

The additional data provided by two deep wells at the Utah FORGE site have highlighted the complexity of the natural fracture orientations and intensity. The updated Reference DFN includes adjusted fracture set orientations and intensities and many new discrete features representing significant faults or fracture zones (Figure B.6-4). There has been excellent progress with identifying significant faults or fracture zones that can be added to the DFN as discrete features effort and several features have now been identified in each well bore which are now included in the Reference DFN. Combining the fracture interpretations from the resistivity logs with the cluster analysis performed on the acoustic logs is proving to be a valuable process. We are now using the rock type cluster results to identify some of the most significant, high-porosity features that have been located from the resistivity logs, which solves part of this issue. Further work with some underutilized fracture aperture estimates available from the fracture identification process also allow a ranking to be made of the identified fractures, so that those having the largest measured apertures values can be included in the DFN.

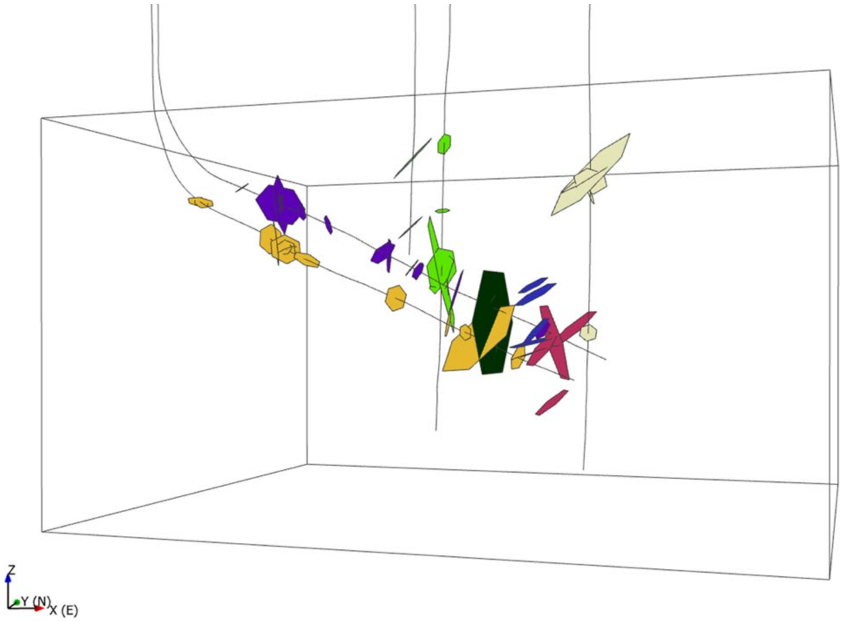


Figure B.6-4. *Discrete fracture sets included in the Reference DFN.*

In all the numerical models used for the back analysis of the 2022 stimulations, the same DFN geometrical realization and strength (weak, frictional and permeable) were assumed. For all three stages, the stimulation is a combination of slipping of pre-existing joints and propagation of hydraulic fractures. The extents of the slipped joints and hydraulic fractures for Stage 1 and Stage 2 are smaller than for Stage 3, which is due to the larger fluid viscosity in Stage 3. The fluid viscosity used in Stage 3 is 100 cP, while it is 2 cP in Stages 1 and 2. Larger fluid viscosity yields higher pressure, which results in more hydraulic fracture propagation and more slipping joints. The extents of DFN with apertures enhanced for Stage 1 and Stage 2 are larger than Stage 3 (Figure B.6-5), and the fracture aperture magnitude is smaller than Stage 3. That is consistent with the expectation that higher viscosity fluid yields larger fracture aperture and less leak-off.

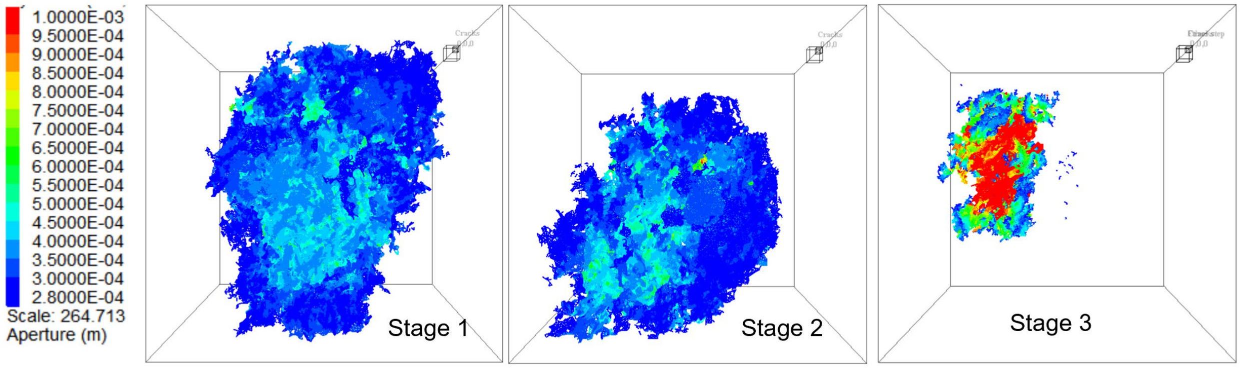


Figure B.6-5. *Hydraulic apertures of fractures at the end of pumping in the models of three stages. Only the DFN fractures with hydraulic aperture increased during the pumping are shown. The fractures with aperture less than 2.8E-4 m (maximum initial aperture) are not shown because their apertures are not increased due to fluid pumping.*

For all the three stages, the extents of microseismicity events from the numerical model match those from the field. Stage 1 was conducted at a 200 ft openhole section, and there are large uncertainties in the fracture initiation location. Also, the planned injection point is different from the actual perforation location for Stages 2 and 3. Therefore, the goal of the comparison is not to match the exact locations of the microseismic events but to match the extent of the cloud of events. The b value of the filed data for all the three stages ranges from 2.2 to 2.4. The b value from the numerical models also ranges from 2.3 to 2.4. This indicates that the numerical models well represent the mechanism in the field. The height of microseismicity cloud of Stage 3 is much larger than that of Stage 1 and Stage 2. The reason is that the Stage 3 is hydraulic fracture dominated due to large fluid viscosity while for Stages 1 and 2 fluid leakoff into DFN is dominant.

The numerical models for three stages use the same DFN geometrical realization and DFN strength. The DFN fractures in the models are assumed to have 37o friction angle, zero cohesion and zero tensile strength. The numerical models predict that rock response to stimulation by fluid injection in all three stages includes combination of hydraulic fracturing and stimulation of DFN. DFN leakoff seems to dominate response in Stages 1 and 2, which is expected considering use of slick water. Stage 3, which was stimulated with xlink fluid, is dominated by hydraulic fracturing. For Stage 1, the simulated net pressure matches well the field data. For Stages 2 and 3, the simulated net pressure matches the field data at later injection times (greater than 80 minutes). Injection pressure histories (for these stages that use cased completion with perforation clusters) are not matched well in early period probably because of complex evolving geometries and processes in well near field that are not included in this model.

The extents of the simulated microseismicity events and b value match the field recorded data for all the three stages. Stage 3 has the largest height of microseismic cloud due to large fluid viscosity.

Examination of near wellbore fracturing found that the strength of the cement sheath strongly influences the near-wellbore fracture behaviors. With a relatively lower cement strength, more complex fractures were formed with fracture paths twisting and curving, leading to increased resistance to fluid flow and pressure built up during fracture propagation. Such near-wellbore tortuosity can reduce the communication path between the wellbore and the near reservoir. This is even more critical if proppants are planned in the future designs at the Utah FORGE Site. Cement sheath with higher fracture toughness is recommended to prevent potential proppant bridging and premature screenouts.

The near wellbore simulation results also showed that the existence of the DFN intersecting the wellbore section at a favorable angle (i.e., close to the plane of the minimum in-situ stress) can effectively reduce the breakdown pressure. This is consistent with the design concept for Stages 2 and 3 at Utah FORGE Site, which was to ensure that perforations intersected with the natural fractures. In the simulated case with the DFN, a decrease of ~ 20% in peak net pressure was observed, which helped facilitate breakdown in the high-strength reservoir, as well as much less severity of near-wellbore tortuosity owing to the pathway formed by pre-existing fractures. The simulation results also showed that the existence of the DFN intersecting the wellbore section at a favorable angle (i.e., close to the plane of the minimum in-situ stress) can effectively reduce the breakdown pressure. This is consistent with the design concept for Stages 2 and 3 at Utah FORGE Site, which was to ensure that perforations intersected with the natural fractures. In the simulated case with the DFN, a decrease of ~ 20% in peak net pressure was observed, which helped facilitate breakdown in the high-strength reservoir, as well as much less severity of near-wellbore tortuosity owing to the pathway formed by pre-existing fractures.

Flow conformance in long-term circulation is critical to EGS performance. For Utah FORGE, analytical model results show that once approximately 30-40 perforations are reached, excluding exit perforations did not significantly alter the flow distribution within the wells/reservoir. For the parallel well design (as 16A-16B were drilled), a lower permeability value of 1x10-14 m2 yielded a nearly perfect flow distribution percentage across all fractures, however, this permeability value yielded unrealistically high pressure drops. Even though in the parallel case the flow distribution percentage was nearly perfect for the lower permeability value of 1x10-14 m2, the pressure drop values suggest this permeability value is not feasible for a good EGS design. CFD model results for the three-fracture model show the flow distribution percentage with the open hole fracture at the toe getting approximately 90% of the flow and the other two fractures sharing the remaining 10% of the flow relatively equally. This is a reasonable estimate as to how the EGS would perform as the CFD model includes gravity, temperature and pressure boundary conditions.

The calculated fracture permeability is less than ~1x10-11 m2 for most simulation cases which is useful for further applications of this model. Further applications of this model will incorporate real rock fractures in the current fracture zones that were simplified to pipes. This flow channel representing the fracture zones is a worst-case scenario as the actual rock fractures will behave much differently and have a lower permeability value.

Based on based on a review of the July circulation tests, reevaluation of the original Utah FORGE numerical models was undertaken (Figures B.6-6 and 7). In this work several of the conceptual models were numerically tested to evaluate the fracture properties. Key findings from the low flow rate injections are that there is a large, highly permeable fracture network surrounding the injection zone with most of the fluid flowing into fractures that are weakly connected to the production well. This zone is represented in our models using spatially varying permeability and porosity. To match both the well head pressure and outflow rate, the matrix porous flow properties had to be increased by about 10x that of the background matrix material properties, and most importantly, a DFN (with fracture reactivation) was required to match the observed data. Simple planer fractures were inadequate to mimic the observed behavior.

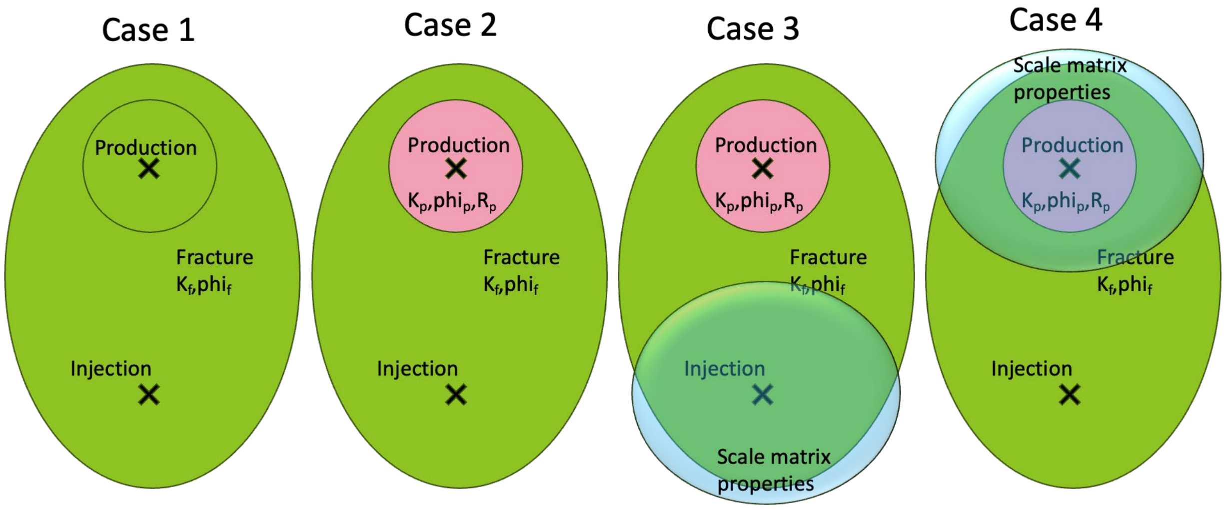


Figure B.6-6. *Four fracture characterizations simulated in this work. Case 1 uses a single set of properties for all regions of the fracture network. Case 2 has a single set of properties for the injection region and fracture regions with a lowered permeability around the production zone. Case 3 is similar to case 2 with an additional region of higher permeability extending into the matrix around the production well. Case 4 is similar to Case 2 with an additional region of higher permeability extending into the matrix around the injection well. The production region has* R_p*=10 meters and the matrix scaled region has R=100 meters.*

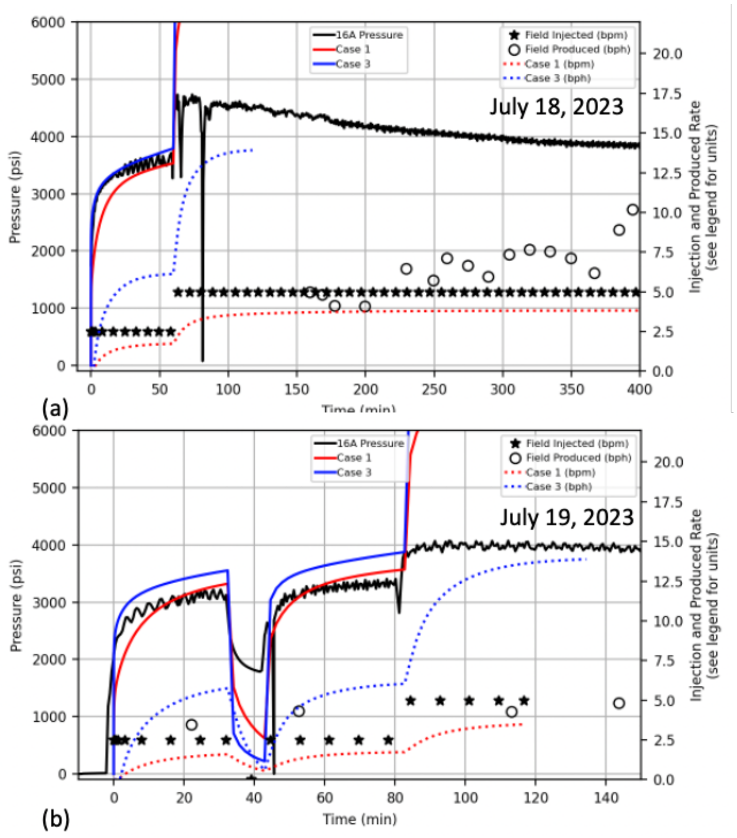


Figure B.6-7. *Experimental field data (black data) and simulation results (colored data) for the (a) July 18 and (b) July 19, 2023 circulation test. The left axis and solid lines show pressure data where both simulations match the early time field data. The dashed lines and markers show injection and production data. Note the units of the constant property dashed line in blue is in barrels per minute (bpm) and the spatially varying properties are in barrels per hour (bph).*

B.7 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.7-1, B.7-2). 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 30 to 33 months, with good progress and significant achievements as summarized below.

Table B.7-1. *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.7-2. *2020-1 R&D Award Prime Recipients & Project Titles.*

Topic-ID	***Title***	***Recipient***	***Period***
1-2551	*Development of Multi-Stage Fracturing System and Wellbore Tractor*	*Colorado School of Mines*	*10/1/2021-9/30/2024*
1-2410	*Development of a Smart Completion & Stimulation Solution*	*Welltec*	*10/1/2021-9/30/2024*
1-2409	*Zonal Isolation Solution for Geothermal Wells*	*PetroQuip*	*10/1/2021-9/30/2024*
2-2439	*A Multi-Component Approach to Characterizing In-Situ Stress*	*Battelle*	*10/1/2021-9/30/2024*

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*
2-2404	*Application of Advanced Techniques for Determination of Reservoir-Scale Stress State*	*Univ. Oklahoma*	*10/1/2021-9/30/2024*
3-2418	*Wellbore fracture imaging using inflow detection measurements*	*Stanford Univ.*	*10/1/2021-9/30/2024*
3-2535	*Joint electromagnetic/seismic/InSAR imaging*	*Lawrence Berkeley National Lab*	*12/1/2021-9/30/2024*
3-2417	*Fiber-optic geophysical monitoring of reservoir evolution at Utah FORGE*	*Rice Univ.*	*10/1/2021-9/30/2024*
3-2514	*A Strain Sensing Array to Characterize Deformation at Utah FORGE*	*Clemson Univ.*	*10/1/2021-9/30/2024*
4-2492	*Design and implementation of innovative stimulation treatments to maximize energy recovery efficiency*	*Univ. Texas Austin*	*10/1/2021-9/30/2024*
4-2541	*Optimization and validation of a plug-and-perf stimulation treatment design at Utah FORGE*	*Fervo*	*10/1/2021-6/30/2024*
5-2419	*Seismicity-permeability relationships probed via nonlinear acoustic imaging- of fractures in shear*	*Penn State Univ.*	*10/1/2021-9/30/2024*
5-2615	*Experimental determination and modeling-informed analysis of thermo- poromechanical response of fractured rock*	*Univ. Oklahoma*	*10/1/2021-9/30/2024*
5-2565	*Evolution of permeability and strength recovery of shear fractures under hydrothermal conditions*	*US Geological Survey*	*10/1/2021-9/30/2024*
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*
5-2557	*Role of fluid and temperature in fracture mechanics and coupled THMC processes*	*Purdue Univ.*	*10/1/2021-9/30/2024*

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

The following summaries outline projects, detailing objectives, activities, and achievements. For comprehensive information, including figures and tables, please refer to Supplemental reports.

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.

A project website was created and preliminarily populated to publicize the project, tools developed and process applications GeoThermOPTIMAL | Colorado School of Mines. Additional material will be added to support disclosures at the DOE's upcoming NREL IGF with start-up GTO Technologies.

Completed seal drag friction tests - Eighteen independent seal drag configuration tests were completed and provided a repeatable low seal drag force – 388 lbf.

Completed Collet load testing, first with an analog load cell, then with flow loop testing. The Collet would always "catch" the Ball at 8 bbl/min or less. The Ball would always "pass" at 11-12 bbl/min. Highly repeatable over four (4) days of testing. No ball erosion or deformation.

Acquired system components with 200C rating for system testing. Designed and built high temp seal testing fixture for qualification of sliding seals to be used in the actuator. Manufacturing tractor drive assembly with motor controller testing. Completed actuator testing controlled by master controller for shifting tool and anchor. Motor drive issues resolved with controller and motor company on the hydraulic drive. Fabricating and testing sub-assemblies for final assembly. Completed and tested actuator system pull test to 20,000 lbs F.

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.

During the last reporting period, additional testing has been undergoing, an additional Fracture Initiation Device (FID) test with horizontal pattern was successfully completed on the rock at 7,500 psi, the test report will be included in the library.

Multiple parts for the final assemblies have been manufactured for the field trial, still waiting confirmation of base pipe properties, connections and well diagram to complete assemblies for the field trial in the Utah FORGE site.

Another highlight was the completion of the second cycle on the long-scale test was successfully performed, the test was performed continuously for two weeks, during which the setup was heated to a temperature of 220°C, and pressure was kept at 3,000 PSI at the packer and annulus. In this period, the pressure was successfully increased to 6,000 PSI three times while maintaining the temperature at 220°C.

For the testing setup an additional compressor was attached to the pumps in order to maintain the pressure in the long-scale setup; and a new chiller was installed in the setup, the cooling system for the coils and heating unit was separated for better performance. A separate circulation pump was installed for the coils, and the heating unit was cooled with the help of the chiller.

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.

- Engineering Design Specification Document (EDSD) completed and submitted for both products. Locking Bridge Plug (LBP), Landing Profile (LP), and the Open-Hole Packer (OHP).
- Completed Design Review for all products.
- Completed documentation showing the manufacturing and inspection of all test tools and fixtures.
- The LBP/LP project was then completed with the successful installation in Well 16B early in April. The LBP held the required 7500 pressure differential after being set.
- The OHP project was completed with a test at 7500 psi and 450°F. The packer held the pressure differential from above then below, then started leaking when the differential was reversed again. We think all leaks were internal on piston seals not the large element seal.

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.

The core-based stress methods have led to mutually-consistent estimates of minimum and maximum horizontal stress for well 16A(78)-32. These core-based data also provide a training set for a Machine Learning model that has been deployed to interpret sonic log data for well 16A(78)-32. The minimum stress gradient is found to be 0.61-0.74 psi/ft and consistent with uniform tectonic strain of 150 microstrain in the Granitoid and tectonic strain that is around 50% higher in the Gneiss than in the Granitoid. The maximum stress is found to be 0.90-1.01 psi/ft in the granitoid and 1.32 psi/ft in the Gneiss and consistent with tectonic strain around 300 microstrain through the Granitoid and over 900 microstrain in the Gneiss.

The in-situ stress testing approach completed seven mini-frac tests within the upper (vertical or nearly vertical) section of the 16B(78)-32 wellbore. SH_{min} was estimated to range from 0.6 to 0.94 psi/ft and SH_{max} was estimated to range from 0.6 to 2.43 psi/ft, where the ranges reflect an adjustment made to account for cooling effects (the lower bound value corresponds to the unadjusted values for SH_{min} and SH_{max}). Vertical stress was estimated to be 1.08 psi/ft. Modeling work is ongoing to assess the validity of the thermal adjustment factor.

The wellbore stress modeling has indicated the striking result the pre-cooling can induce starter cracks and furthermore can, in some cases, change the preferred orientation of hydraulic fracture initiation. This result is being tested in block experiments through another FORGE-funded project and the concept opens the door for engineering near-wellbore hydraulic fracture geometry through strategic application of precooling.

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.

The project is divided into three modeling tasks and one experimental one, with the goal of identifying the link between in situ stress conditions and the resulting hydraulic fractures to improve the in situ stress characterization.

For the modeling effort, the team has employed the GEOS simulation framework to model the DFITs conducted at well 58-32. The influence of various simulation parameters has been investigated. Additionally, to model the nucleation and propagation of hydraulic fractures in the near wellbore region, a novel phase field formulation was devised, capable of incorporating rock strengths, and thus properly capture both nucleation and propagation. This approach was the subject of a publication, and it is currently being employed to model the experiments conducted at the University of Pittsburgh as part of the experimental task of the project. Finally, a model of the stimulation performed at well 16A was built and calibrated against field data.

For the experimental task, the team at the university of Pittsburgh, has designed and built an experimental apparatus for conducting true-triaxial hydraulic fracturing tests on high-temperature analogue Utah FORGE granites under conditions mimicking the Utah FORGE site. The setup allows for various stress applications and rapid temperature changes, enhancing the understanding and validation of in-situ stress estimations. The integration of computer vision with traditional fracture observation methods and advanced materials analysis further enriches the analysis capabilities. So far, the PITT team has effectively conducted several hydraulic fracturing tests in both normal and reverse faulting stress conditions.

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 the Utah FORGE site, namely 78B-32, 56-32, and 58-32, and the inclined injection well 16A(78)-32 have been established based on the drilling-induced fractures (DIFs) and breakouts observed from borehole image logs (FMI and/or UBI logs), and stress polygon. We integrated the multiple approaches and data sources (DIFs, breakouts, stress polygon, Kirsch, FM, etc.) to constrain the wellbore stress model. A new inversion technique relying on the trace angle of fractures at the wellbore wall has been used which seems to better constrain the SH magnitude.

In relation to the focal mechanism work, previously we developed criteria to identify problematic channels and applied notch filter to correct the waveforms. We applied these corrections to pre-process waveforms, and developed ML approaches to automatically measure polarity and amplitude ratios and obtained solutions for about 700 events using downhole geophone arrays. We now note some spatial coherency in the distribution and further evaluate the results. We reexamined the patterns for previously obtained reverse faulting events, and found that those were affected by Sv/P amplitude ratio and the take off angle calculation with the HASH package based on manual examination of selected events with surface nodal recordings. We added a new station (shallow borehole, UU.FORK) and updated the results using improved amplitude ratio measurement: P amplitude (sum of the P amplitude on the vertical and radial components) and Sh amplitude (maximum S wave amplitude on the ZRT components). The previous measurement was based on individual components, which could be affected by location uncertainty and geophone orientation uncertainty. We used the MTFIT algorithm, and compared solutions from the “iterative” and “McMc” algorithms. We obtained solution for 492 events during stage 3 based on two borehole wells and UU.FORK, and only select the 269 events that have “kagan” angle (difference of nodal planes between two algorithms) within 35 degrees from the two algorithms for stress inversion.

- Wellbore stress data has been established based on various data sources such as axial and transverse DIF, breakouts, and DFIT. The DFIs have been analyzed using 3 different techniques which yield consistent results.
- Fault plane solution and focal mechanisms analysis has been carried out.
- Some stress heterogeneity and pore pressure mapping has been carried out for stage 1-3 obtained and is ongoing for other stages.
- Developed and tested machine-learning pickers for phase arrival and polarity.
- Developed automated workflow to perform polarity, amplitude ratio measurements, and focal mechanism inversion.
- Assembled event waveforms from two downhole wells and one borehole station from LBNL for over 22,000 events during stage 3 in 2022.
- Obtained stress orientations based on focal mechanism solutions of about 700 microseismic events.

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.

The recent developments of the chloride tool focused on the field scale in preparation for the field test at the Utah FORGE site. A high-temperature Chemical Buffer Amplifier (CBA) board was designed to operate at 260°C, and an alternative system microcontroller from Analog Devices is being explored for data transmission at 200°C. The tool assembly includes a PTS sensor package, a wire guide component, and an electronics housing for data transmission through a 7-conductor feedthrough. Numerical simulations at the field scale were conducted under downhole conditions (225°C and 5000 psia) and showed no significant change in fluid flow behavior compared to laboratory conditions. Further simulations focused on the design of the field-scale tool housing. Simulations assessed ten different positions relative to the feed zone height. The simulations suggested that the best signal recordings occurred at the beginning of the tool's Run in Hole (RIH) motion when the lower part of the housing met the feed zone.

Several improvements were also made to the laboratory apparatus, which involved addressing the electrical noise issue affecting the voltage readings of the laboratory-scale chloride tool. Changing the reservoir pump from AC to DC and wrapping various electronic sources with Faraday fabric have greatly dampened the interference noise in the voltage readings. Additionally, the routing mechanism of the tool running system was reconfigured to improve the tool movements and enhance deployment control.

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.

Most accomplishments for Project 3-2535 this last year revolved around preparing the Vertical Electromagnetic Profiling (VEMP) system ready for deployment at Utah FORGE to make three-component magnetic field measurements in well 78B-32 and possibly other observation wells. Most modifications on the VEMP tool were completed with two remaining tasks being the installation of an orientation magnetometer and an external temperature measurement. A paper that was submitted to “Geophysical Prospecting” for publication went through two rounds of revisions, based on reviewers’ recommendations, and is currently prepared for resubmission, at which point it is assumed acceptable for publication. Though not directly funded by Utah FORGE, 14000 ft of high temperature logging cable, donated by the USGS to LBNL, was spooled onto LBNL’s High Temperature logging truck for deploying the VEMP tool in the observation wells. This step included testing of the VEMP downhole acquisition system to prove transmissivity of signal up the cable. To provide an electromagnetic source field for the measurements, a downhole electrode was built that will electrically energize the vertical section of well 16A and /or 16B. To deploy this in one or both of the stimulation wells, our smaller ‘Bread Van’ logging truck was respooled with 4000 ft of high temperature seven-conductor logging cable. Last, we continued to update and improve our InSAR data processing workflow and have been able to get noise levels below 5mm. Unfortunately, even with this low noise level we were unable to detect surface deformation that was correlated to the previous stimulation.

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.

During the past year, the FOGMORE (Fiber Optic Geophysical Monitoring of Reservoir Evolution) team has made significant strides in establishing our monitoring capabilities at the Utah FORGE site. During the summer of 2023, we installed a unique fiber-optic cable behind casing during the drilling of well 16B which, combined with DAS acquisition, provided a detailed record of microseismic activity during the subsequent circulation test. These events were relocated to generate a detailed map of fractures that were reactivated during the circulation test. A fascinating observation made from these events were coherent microseismic reflections generated by previously unmapped structural features within the EGS reservoir; these features were isolated and migrated to build a detailed image of compliant units near wells 16A and B. Results from the 2023 FOGMORE effort have been submitted as three parallel extended abstracts to IMAGE 2024. During the fall of 2023 and spring of 2024, our team surveyed, permitted, and installed an array of semi-permanent seismic sources to enable real-time DAS-VSP imaging during stimulation activities. These sources, now commissioned and tested, are currently being utilized to monitor the state of the fracture network geometry over time. A last significant activity has been refinement of a detailed site THM model which will be used to guide monitoring activity during the April 2024 stimulation.

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: Phase I strainmeters deployed in the alluvium were operational throughout the year, and the noise level continued to be roughly one order of magnitude greater than strainmeters deployed in rock at other sites. Four new strainmeters were built using two different strainmeter designs with a goal of reducing noise by using longer gauges to average out local perturbations. Two strainmeters were deployed in February 2024 using a new grout formulation. These Phase IIa instruments are in permanent compression with early data showing tide-like behavior. The six strainmeters in the Phase I and IIa arrays have been operational during the April 2024 stimulation, and processing the strain data will be initiated after the stimulation is complete. Raw data from Phase I strainmeters is available on the IRIS DMC under network code 2J. 'earthscopestraintools', a software package for strain data analysis was developed in collaboration with EarthScope Consortium. A split-sleeve strainmeter was heated to between 200°C and 300°C while being loaded every hour in the laboratory. The strainmeter successfully measured strains caused by the applied loads for six months at geothermal reservoir temperatures. We developed and analyzed a concept to describe the strain from well stimulation caused by two end-member deformation sources; (1) one to a few discrete fractures represented as a displacement discontinuity, and (2) a zone of multiple distributed fractures represented as a region of transformation strain (e.g. poroelastic, thermoelastic strain). These analyses show how strain data could be used to discriminate discrete from distributed fractures created during stimulation.

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. Simulations were run to model fracture propagation in the 16A well. The results clearly show that the hydraulic fractures are approximately planar with some deviations and branches due to natural fractures. Provided fracture designs for the planned stimulation treatments in well 2024. The complete fiber system was successfully installed in mid-2023, is fully operational and was utilized to gather data during the stimulation treatment in April 2024.

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: We have completed reactivation experiments on critically stressed fractures by incrementing pore fluid pressures until failure. Experiments have specifically examined the role of pre-existing shear stress on the anticipated maximum seismic moment returned upon reactivation. Experiments have been for both (i) slowly incremented fluid pressures and resulting low flow rates maintaining steady-state and uniform pressure distributions on the reactivated fracture (Figure 1) and show that seismic moment (M) is related to injected volume (ΔV) and fault pre-stress (c) as $M = \frac{c}{1-c} G \Delta V$ with seismic moment growing with increasing critical stress (c) approaching failure (c=1).

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.

- Poroelastic properties of some Utah FORGE rocks have been successfully determined at room temperature.
- Poroelastic properties of some Utah FORGE rocks have been successfully determined at temperature of up to 185 C.
- Lab-scale microfrac test design and conducted and the impact of cooling observed.
- Temperature dependent crack closure has been observed impacting interpretation of the temperature dependent poroelastic properties. Tests at higher temperatures are planned for assessment and verification of the results.
- Plans are to continue with remainder of the project to include poroelastic properties at higher temperatures using Utah FORGE rocks with different textures.

Micro-frac tests completed. Reopening and closure were studied at room temperature and higher, and the results were analyzed. Stiffness/compliance signatures is not observed in the case of the coarse-grained Texas Pearl granite. The “tangent” method provides reliable results. The impact of cooling on ISIP, reopening and closure pressure have been captured. observed.

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: We have conducted experiments examining the rates and mechanisms of evolving frictional strength, permeability, and aperture in fractures at temperatures up to 300 °C. Single fracture convergence experiments have focused on determining the rates and conditions at which interface (fracture) convergence occurs. Recent experiments have used electrical resistance measurements in the plane of the interface (fracture) to directly monitor the harmonic average aperture. In initial room temperature tests electrical resistance measurements resolve micron-scale elastic changes in interface aperture in response to changes in effective stress of a few MPa. These results suggest that convergence can be measured at any effective stress level. Hydrothermal shear deformation tests have examined the evolution of both frictional strength and fluid flow. These experiments have shown that the evolution of fracture properties at hydrothermal conditions is complex, resulting from multiple interacting processes that depend on both temperature and the timescale of the observation. Shear deformation experiments have also been conducted to examine the effects of natural fracture roughness. Aligned scans of rough fracture surfaces are being used to generate relationships for fracture aperture versus contact area as a function of degree-of-closure and current magnitude of slip. We find that profiled surface computations overpredict observed flow rates. Correcting for this initial deviation, our mechanistic model follows the evolution of aperture as asperities are compacted and dissolved implicit with diffusion from the asperity region. Small increases to reaction rates are required to match permeability degradation. We are building a library of correlations to our experimental 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: Completed 56 double-direct shear experiments Utah-FORGE derived gouge, gneiss, and granitoids at elevated temperature to characterize rate-state material properties. Results indicate granitoids are velocity-neutral and transition to weakening with pore pressure, shear strain and velocity. Completed four triaxial direct shear experiments measuring mechanical strength, deformation, hydraulic conductivity, surface evolution, and rock-water reactivity at temperatures between 180-210°C. Experimental results show artificially created slickensides, low shear dilation angles (3 to 5°), high shear strength (8±3 MPa), friction angles between 32 to 48°, and low shear stimulated hydraulic aperture (0.020 mm). Hydraulic aperture decreases to 0.006 mm after stress cycle. Performed three core-flooding experiments between 100-200°C circulating analog Milford Golf Course water through one "natural" and two planar fractures. Measured pressure, fracture topography, permeability, and chemical evolution. Results show decreased fracture permeability across 3 experiments indicating rapid and sustained reaction. Developed workflow to provide posterior probability density functions for the stress magnitudes and direction based on core, log, well test, and drilling data from p5894 experimental data and regional stress data. Completed three reactive transport simulations with differing volume fractions of primary minerals (calcium, sodium, silica, and chloride) in GEOS. Completed dozens of THM models in GEOS to estimate pressure and stress evolution related to 16A Stage 3 stimulation. Modeled the MEQ response to 16A Stage 3 stimulation in RSQSim using THM pressure and stress from GEOS reservoir simulation. Preliminary results show good agreement between observed and simulated MEQ catalogs in terms of number of events, magnitude range, spatial distribution, and statistical measures.

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: We developed and implemented dynamic frictional fracture elastodynamics in 2D and 3D with a rate-and-state friction model and a continuum damage-breakage capability into the INL MOOSE code. Our framework is well-suited for data fusion from field sites and experiments to simulate, for example, damage and acoustic emission/induced seismicity during stimulation. The code has been quantitatively verified with borehole breakout problems from existing experimental data in the literature that included dry conditions, pore pressure effects, and thermal effects. The results show good agreement with experimental observations and expected trends. In addition, we explored fluid injection into a complex fault network problem coupled with a continuum damage-breakage model to understand the rupture propagation along the fault network and damage accumulation in the bulk. The full wavefield was also computed to characterize slip and opening of pre-existing faults and nucleation as well as growth of new surfaces. Currently, the code sits on a GitHub repository and is in the process of being integrated into INL MOOSE code. We also advanced a rate-and-state friction model by accounting for the effects of variations in bulk permeability, injection rate, and frictional properties on slip physics. With the integration of tri-axial experimental data from wellbore breakout testing and mechanics-driven theoretical model, the newly updated MOOSE/FALCON simulator will provide a tool for optimal reservoir design at the Utah FORGE site to enable identification of key parameters for heat recovery and quantification of coupled THMC processes that govern fracture evolution.

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.

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, 2024, quarterly reports (October 1-December, 31, 2023) reports had been submitted and evaluated. Health Indicators for the R&D projects were finalized in February 2024 after consultation with all the Topic and R&D Leads. All projects were assessed to possess a green health indicator regarding their scope and schedule, except for two instances where a yellow health indicator was assigned. Of these two cases, one was promptly rectified upon the submission of an overdue report, while Utah FORGE provided guidance to address the issues in the other case, which is currently in the process of resolution. In terms of expenditure, most projects were deemed to have a green health indicator. However, five (5) projects were marked as non-compliant due to either incorrect or missing reports. Additionally, one project received a yellow indicator, and another received a red indicator. All issues of non-compliance have since been resolved. The project with a yellow indicator has been provided with guidance to address its issues and is currently undergoing resolution. The project marked with a red indicator refused to provide complete financial information. As of this report, Utah FORGE is actively working to resolve this matter. Each project's Principal Investigator was promptly informed of any deficiencies identified, and appropriate corrective actions were either taken or are currently underway to address them.

Utah FORGE has granted contract continuance where applicable. As of March 31, 2024, seven projects have been approved to progress to budget year three, while ten projects are in year two, with five of them undergoing No Cost Extensions awaiting progress to advance to year three. Utah FORGE remains diligently engaged in monitoring each R&D project to uphold their respective schedules.

Apart from monitoring the progress of the R&D projects' milestone achievements, the R&D Leads also participated in 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 STAT and 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, 2024, thirty-one (31) Go/No-Go Stage Gates were successfully approved (Table B.7-3).

Table B.7-3. *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*
3-2417 Rice	*2*	*Fiber Deployment Plan & AFE: (Q1/Yr2) The deployment plan and AFE will be submitted to DOE and the Utah FORGE Team for review and approval.*	*4/5/2023*
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 Utah 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*
3-2417 Rice	*2*	*Short-Run Cable Evaluation*	*2/28/2023*
3-2417 Rice	*4*	*Permitting for SOV Sources*	*2/28/2023*
3-2418 Stanford	*1*	*Phase 1 (confirmation/adjustment of tool and interpretation methods for Utah FORGE reservoir conditions - 225°C, 5000 psia, 24 hours tool exposure) a Go/No-Go decision will be made based on the confirmation that the tool itself and the interpretation methods will be functional in Utah FORGE wells.*	*5/23/2023*
5-2565 USGS	*1*	*Healing models expanded to hydrothermal conditions*	*4/21/23*

5-2565 USGS	*2*	*THMC simulation structure coupled with phreeqcRM*	*4/21/23*
4-2492 UT Austin	*1*	*Provide a detailed perforation cluster design and hydraulic fracture designs for different stages of the stimulation.*	*8/4/2023*
5-2419 Penn State	*1*	*Refine protocols to synthesize NAI-friction-permeability observations.*	*8/22/2023*
5-2419 Penn State	*2*	*Define magnitude -versus- injected-fluid-volume relations as a function of these variables – i.e.,* $M–\Delta V/s = f(\sigma', p, c, T, \Delta V/s, \lambda)$.	*8/22/2023*
2-2410 Welltec	*1*	*Successful demonstration of system ability to operate under the expected downhole conditions. Experimental workflow validated system performance in different conditions (rock stresses, parameters, annular isolation length). Design and procurement of the full-scale test set-up*	*8/30/2023*
3-2417 Rice	*5*	*NEPA Approval for Monitoring System Installation at Utah FORGE Site*	*4/4/2024*
5-2428 LLNL	*1*	*Complete at least four triaxial direct-shear experiments at elevated temperatures (>100 ◦C) by the end of Performance Period 1. Additionally, complete measurements of Coulomb failure, rate-state friction properties, and permeability evolution and conduct initial uncertainty quantification for these experimental results*	*11/8/2023*
2-2439 Battelle	*3*	*Decision on agreement between model and analytical benchmarks for near wellbore stresses within 5%.*	*1/12/24*
2-2446 LLNL	*1*	*Deliver results from THM modeling and interpretations of DFIT/minifrac and submit to GDR.*	*2/5/2024*
4-2492 UT Austin	*2*	*The recipient will present the deployment plan and NEPA approval to Utah FORGE for approval, prior to procuring any equipment.*	*3/5/2024*
5-2615 OU	*2*	*Acquisition of measurements from Tasks 5 and 6 (i.e., the set of poroelastic properties of fractured rock) have been made under high temperature (90-150ºC), and impacts of thermo-poromechanical effects in micro-frac tests and modeling are illustrated.*	*4/3/2024*

1-2409 PetroQuip	*2*	*Decision will be made based on the test results obtained by PQES in Task 4, evaluating the likelihood that the OHP tool as designed will be functional in Utah FORGE wells.*	*4/1/2024*
3-2514 Clemson	*4*	*Approval to deploy two strainmeters for Phase IIa.*	*3/27/2024*
2-2404 OU	*2*	*Successful preparation of deformation jacket. Drilling induced cracks catalogued for analysis. Existing and new stress data compiled and preliminary wellbore stress function developed.*	*4/5/2024*

On September 7th and 8th 2023, the Utah FORGE R&D team hosted the 2023 R&D Annual Workshop. This virtual event included the active participation of all current R&D awardees, the STAT review panel, the Utah FORGE team, and an impressive turnout of more than 100 external participants, all connecting via Zoom.

Over the course of the two-day workshop, each R&D awardee was allocated a dedicated hour to present their project's progress and engage in a thorough discussion with the review panel. When time allowed, some inquiries from the broader audience were addressed. All presentations were meticulously recorded and have been made accessible on the Geothermal Data Repository (GDR) and linked to the respective project wiki pages (https://openei.org/wiki/R%26D_Projects).

The Utah FORGE R&D team coordinated this event, assuming responsibilities such as identifying and confirming attendee availability, crafting comprehensive report and presentation templates, structuring the workshop schedule and logistics, configuring the webinar platform, and facilitating the smooth flow of presentations and Q&A sessions. Their meticulous execution of this plan culminated in a highly successful and productive workshop.

For 2024, the Annual Workshop is provisionally scheduled for August for both the 2020-1 and 2022-2 awardees, 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 STAT 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, 2024.

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 2024. 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.7-4).

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.7-1). These full applications transitioned into the STAT review process, overseen by the STAT Chair and monitored by the Utah FORGE R&D and Finance/Accounting teams.

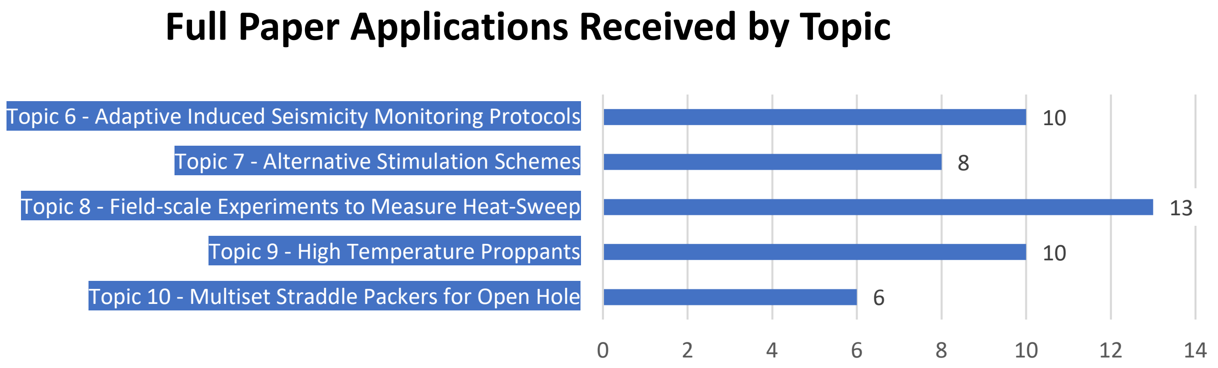
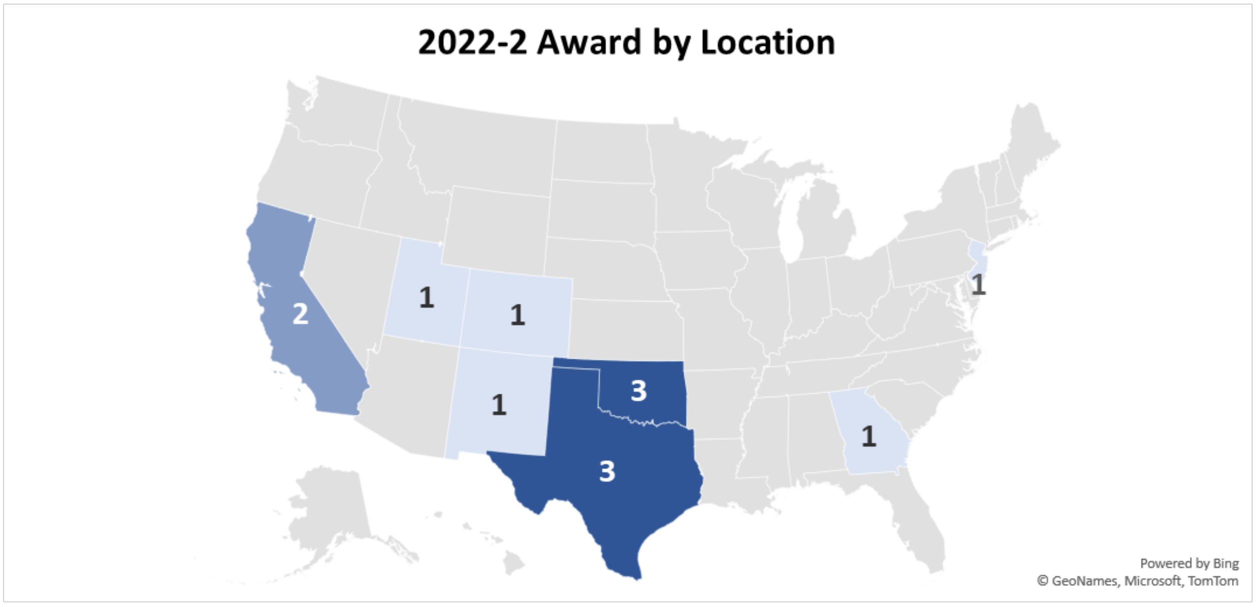


Figure B.7-1. *Solicitation 2022-2 Full Paper Application Statistics*

In June 2023, the STAT review for Solicitation 2022-2 concluded, and they offered recommendations to the Steering Committee for assessment. The Steering Committee meetings were completed, and their recommendations were subsequently forwarded to the Federal Review Panel, which will evaluate and provide recommendations to Utah FORGE. While not directly engaged in the Federal Review Panel phase of the Solicitation 2022-2 process, the Utah FORGE R&D team actively supported STAT, the Steering Committee, and Federal Review Panel by furnishing merit review reports, conflict-of-interest (COI) information, budget analysis and recommended adjustments, and insights for work scope and contract negotiation strategies.

In October 2023, the Federal Review Panel completed their evaluation, granting final approval to Utah FORGE to commence award negotiations with the selected awardees. Notably, thirteen (13) projects progressed to the awardee negotiation phase for Solicitation 2022-2

In December 2024, the collaborative efforts of the Utah FORGE R&D team and the Finance and Contracts team marked the initiation of award negotiations for Solicitation 2022-2. All thirteen (13) initial negotiation meetings were conducted, providing each awardee with feedback on necessary adjustments to their scope and schedule to align with the intent of the topic area and overall goals of Utah FORGE. The awardees, who come from a diverse range of institutions and geographic locations, foster collaboration and innovation from a multitude of vantage points (refer to Figure B.7-2). Additionally, seven groups are oriented towards fieldwork objectives, while six are dedicated entirely to laboratory-based endeavors refer to (Figure B.7-3).



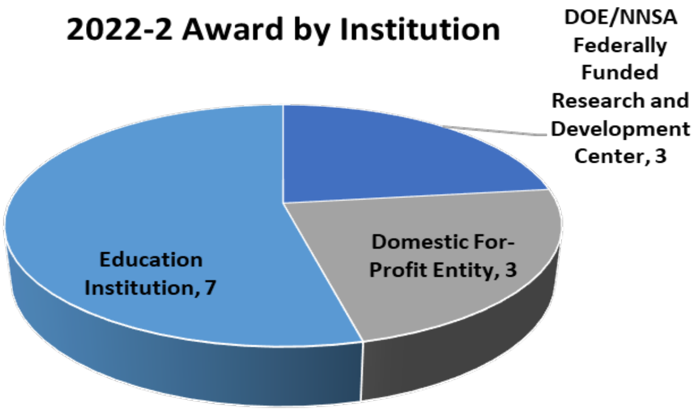


Figure B.7-2. *2022-2 Awards by Location and Institution*

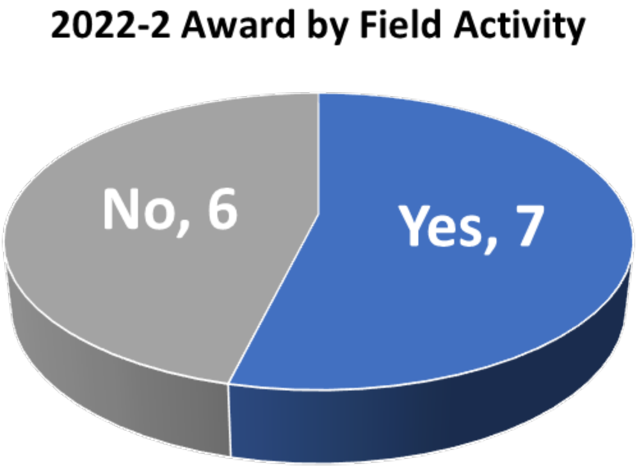


Figure B.7-3. *2022-2 Planned Field Activity*

As of May 2024, nine out of the thirteen awardees have been fully contracted and are actively engaged, with the final four in the process of finalization. The 2022-2 Solicitation comprises a portfolio of 13 projects that covers 5 topic areas (Tables B.7-4, B.7-5).

Table B.7-4. *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.*

Table B.7-5. *2022-2 R&D Award Prime Recipients & Project Titles.*

Topic-ID	*Title*	*Recipient*	*Period*	*DOE cost*	*Total Value*
6-3629	*Cutting-edge application of machine learning, geomechanics, and seismology for real-time decision-making tools during stimulation*	*University of Utah*	*4/1/2024- 3/31/2027*	*$995,085*	*$995,085*
*6-3656**	*Real-Time Robust Adaptive Traffic Light System and Reservoir Engineering with Machine-Learning-Based Seismicity Forecasting and Data-Driven Ground Motion Prediction*	*Lawrence Berkeley National Laboratory*	*4/1/2024- 3/31/2027*	*$1,000,657*	*$1,000,657*
6-3712	*Probabilistic Estimation of Seismic Response Using Physics-Informed Recurrent Neural Networks*	*Global Technology Connection, Inc.*	*4/1/2024- 3/31/2026*	*$1,053,511*	*$1,154,334*
7-3639	*Design and Implementation of a Novel Multi-frac Stimulation Concept in Utah FORGE*	*University of Oklahoma*	*4/1/2024- 3/31/2027*	*$757,151*	*$774,941*
*7-3691**	*Chemical Stimulation Concepts for the Utah FORGE EGS Reservoir Using In-Situ Generated Acid and Chelating Agents at Low, Neutral, and High pH.*	*National Renewable Energy Laboratory*	*4/1/2024- 3/31/2027*	*$3,000,300*	*$3,325,024*
8-3617	*Integrating Tracer Huff-Puff Tests and Geomechanical Analysis to Measure Evolution of the Fracture Network in EGS Reservoirs*	*California State University, Long Beach*	*4/1/2024- 3/31/2027*	*$2,274,607*	*$2,335,876*

8-3637	*ID2 - Integrated Diagnostics for Interpretation of Doublet Heat-Sweep Efficiency*	*Texas Tech University*	*4/1/2024- 3/31/2027*	*$2,945,001*	*$3,102,011*
*8-3707**	*A Novel Linear Sensing Array and Machine Learning Approach for Determining Geothermal Heat Sweep Efficiency*	*Sandia National Lab*	*4/1/2024- 3/31/2027*	*$3,777,487*	*$3,777,487*
9-3635	*High-Temperature Testing of Proppants for EGS and Simulation of Electromagnetic Fracture Mapping Using Electrically-Conductive Proppants*	*Stevens Institute of Technology*	*4/1/2024- 3/31/2027*	*$1,521,587*	*$1,521,587*
9-3664	*Development and Testing of Tagged Proppant for Fracture Conductivity Enhancement and Reservoir Characterization in EGS*	*University of Oklahoma*	*4/1/2024- 3/31/2027*	*$1,587,031*	*$1,601,031*
9-3706	*High Temperature Proppants and Zeolite Markers: Designing, Characterizing & Optimizing Proppant and Flow Monitoring Materials for a Utah FORGE Engineered Geothermal System*	*Oklahoma State University*	*4/1/2024- 3/31/2027*	*$3,017,943*	*$3,017,943*
10-3726	*Geothermal Multiset Straddle (GMS) for High-Temperature Applications*	*Welltec*	*4/1/2024- 3/31/2027*	*$4,340,910*	*$4,830,711*

10-3627	*Thermo Re-Settable Straddle System*	*PetroQuip*	*4/1/2024-3/31/2027*	*$5,319,086*	*$6,648,858*

**Awaiting contract finalization*

Solicitation 2022-12 Project Summaries of Objectives, Activities, and Achievements

6-3629 University of Utah: *Cutting-edge Application of Machine Learning, Geomechanics, and Seismology for Real-time Decision-making Tools During Stimulation*

Objectives: The overall project objective is to develop a real-time decision-making platform. The proposed platform will enable immediate data analysis and seismic event detection, location and moment magnitude calculations.

Activities: Characterize the fundamental seismology and geomechanics of the emerging Utah FORGE site. Developing a compliance technology for real-time data acquisition, screening and analysis. Upgrade and develop a tool for geomechanical risk assessment.

6-3656 Lawrence Berkeley National Laboratory: *Real-Time Robust Adaptive Traffic Light System and Reservoir Engineering with Machine-Learning-Based Seismicity Forecasting and Data-Driven Ground Motion Prediction*

Objectives: Integrating seismicity forecasting and ground motion (GM) modeling with recent seismic observation and machine-learning (ML) approaches. Will develop real- time physics-informed ML-based seismicity forecasting and GM prediction methods for adaptive traffic light system (ATLS) and best practices at EGS to mitigate and control induced seismicity.

Activities: Develop ML-based seismicity forecasting and GM prediction methods and test with field data. Demonstrate developed technologies of the seismicity forecasting and GM prediction methods to Utah FORGE stimulation data for real-time risk assessment and reservoir engineering.

6-3712 Global Technology Connection, Inc.: *Probabilistic Estimation of Seismic Response Using Physics-Informed Recurrent Neural Networks*

Objectives: Build analysis software that predicts the seismic response at the Utah FORGE site based on the hydraulic stimulations (past and present) and the site's geophysical structure.

Activities: Field data curation, processing, and interpretation. Reservoir simulation, validation against field data, and parametric studies. Machine learning based predictors for seismic response at the Utah FORGE site using field and simulation data, with capabilities to incorporate future field data.

***7-3639 University of Oklahoma:** Design and Implementation of a Novel Multi-frac Stimulation Concept in Utah FORGE*

Objectives: Design and implement an advanced reservoir stimulation concept in Utah FORGE for eventual application to future U.S. EGS.

Activities: Stimulation design and analysis, stimulation recommendations and implementation and data synthesis, and post-stimulation monitoring, modeling/analysis.

***7-3691 National Renewable Energy Laboratory:** Chemical Stimulation Concepts for the Utah FORGE EGS Reservoir Using In-Situ Generated Acid and Chelating Agents at Low, Neutral, and High pH.*

Objectives: Develop an effective chemical stimulation protocol for the Utah FORGE EGS reservoir that can be repeated elsewhere.

Activities: Modeling reservoir dynamics to inform development of a chemical stimulation program and testing mineral dissolution and permeability effects of combined acid and chelating agents. Testing will occur in the laboratory using analogous reservoir core samples at similar PT reservoir conditions, and in-situ during field demonstration in the Utah FORGE EGS reservoir.

***8-3617 California State University, Long Beach:** Integrating Tracer Huff-Puff Tests and Geomechanical Analysis to Measure Evolution of the Fracture Network in EGS Reservoirs*

Objectives: Demonstrate a new approach to estimating heat exchange areas and thermal breakthrough in EGS reservoirs using single-well testing.

Activities: Design, procurement, and installation and forward modeling for experiments at Utah FORGE site. Execution of experiments, data assimilation in THMC model, and documentation of results, cost-analysis, and workflow.

***8-3637 Texas Tech University:** ID2 - Integrated Diagnostics for Interpretation of Doublet Heat-Sweep Efficiency*

Objectives: Characterize the heat sweep efficiency of the injector-producer doublet at Utah FORGE using novel distributed fiber optic sensing and chemical tracer technologies.

Activities: Laboratory experiments to qualify candidate chemical tracers. Execute the field experiments by establishing circulation between the injector and producer at various injection rates and pressures.

8-3707 Sandia National Lab: *A Novel Linear Sensing Array and Machine Learning Approach for Determining Geothermal Heat Sweep Efficiency*

Objectives: Create a downhole linear sensor array (LSA) and data modeling and analysis (DMA) methodology that will provide higher fidelity estimates of sub-surface fracture structure.

Activities: Tool development, testing & field deployment.

9-3635 Stevens Institute of Technology: *High-Temperature Testing of Proppants for EGS and Simulation of Electromagnetic Fracture Mapping Using Electrically-Conductive Proppants*

Objectives: Perform well-controlled laboratory experiments to test the high-temperature performance of electrically-conductive (EC) and non-EC proppants in maintaining fracture's hydraulic and electrical conductivities and to understand and quantify the thermal-hydrological-mechanical-chemical (THMC) mechanisms that regulate the observed behaviors. Explore the use of EC proppants and fluids in assisting enhanced geothermal system (EGS) proppant/fracture imaging via borehole electromagnetic (EM) measurements.

Activities: Comprehensive experiments to measure hydraulic and electrical conductivities. Hydraulic fracturing and proppant transport simulations. Develop forward and inverse EM modeling for fracture and EC proppant imaging.

9-3664 University of Oklahoma: *Development and Testing of Tagged Proppant for Fracture Conductivity Enhancement and Reservoir Characterization in EGS*

Objectives: Develop and test new types of proppants that can be used in geothermal conditions of at least of 250 ˚C and differential pressures of 35-70 MPa.

Activities: Material selection, manufacturing, and testing for strength, durability, and conductivity measurements of proppant packs in granite fractures at high temperatures and pressures similar to those in Utah FORGE.

9-3706 Oklahoma State University: *High Temperature Proppants and Zeolite Markers: Designing, Characterizing & Optimizing Proppant and Flow Monitoring Materials for a Utah FORGE Engineered Geothermal System*

Objectives: Identify, design, characterize and optimize proppant performance in EGS reservoirs.

Activities: Develop enhanced propping materials, especially graphene-coated proppants. Laboratory testing of new, legacy, and Utah FORGE-developed proppant materials. THMC modeling of laboratory tests for interpretation and underlying coupled processes at proppant-fracture surface contacts and proppant filled fractures. Integrating the measured proppant properties into the model.

10-3726 Welltec: *Geothermal Multiset Straddle (GMS) for High-Temperature Applications*

Objectives: Develop an open hole multi-set retrievable straddle isolation system capable to withstand geothermal downhole conditions for the effective stimulation of the well.

Activities: Tool development, testing & field deployment.

10-3627 PetroQuip: *Thermo Re-Settable Straddle System*

Objectives: Develop and test open hole straddle packers suitable for use in EGS wells with rugose profiles at operational temperatures at or greater than 225^{o}C and an operational life of at least two weeks

Activities: Tool development, testing & field deployment.

B.8 COMMUNICATIONS AND OUTREACH

During Phase 3B Year 2, Outreach and Communication activities continued to expand to engage new audiences and improve their interactions with Utah FORGE. Our efforts realized measurable success during this period, as illustrated in Table B.8-1. To support our efforts, the Outreach and Communication team continued to work closely with interns from the from the College of Humanities, the College of Social and Behavioral Science and the College of Fine Arts, Department of Art and Art History, as well as welcoming a new intern from the College of Engineering, Department of Chemical Engineering.

Along with continued face-to-face meetings at conferences, in classrooms, and at public events, electronic media, including the Utah FORGE website, continued to be extensively used. They are the primary means of communication to the largest audiences.

Website

During Phase B Year 2, the website was redesigned to improve navigation and enhance the user experience. The newly re-designed site was launched in March 2024. A survey to gauge visitors' thoughts about the website will be launched following the reporting period.

The website continued to gain significant traction year-over-year, with just under 95,000 page views during Phase 3B Year 2, an increase of nearly 42-percent over Phase 3B Year 1, which saw just over 67,000 page views. Growth occurred in three of the four most visited pages. The Solicitations page saw an approximately 50-percent drop from the prior year, however Solicitation 2022-2 was released during Phase B Year 1, causing the page to experience greater traffic than normal. It should be noted that compared with Phase 3A Year 2, which also lacked a released solicitation, the page was visited nearly three times more.

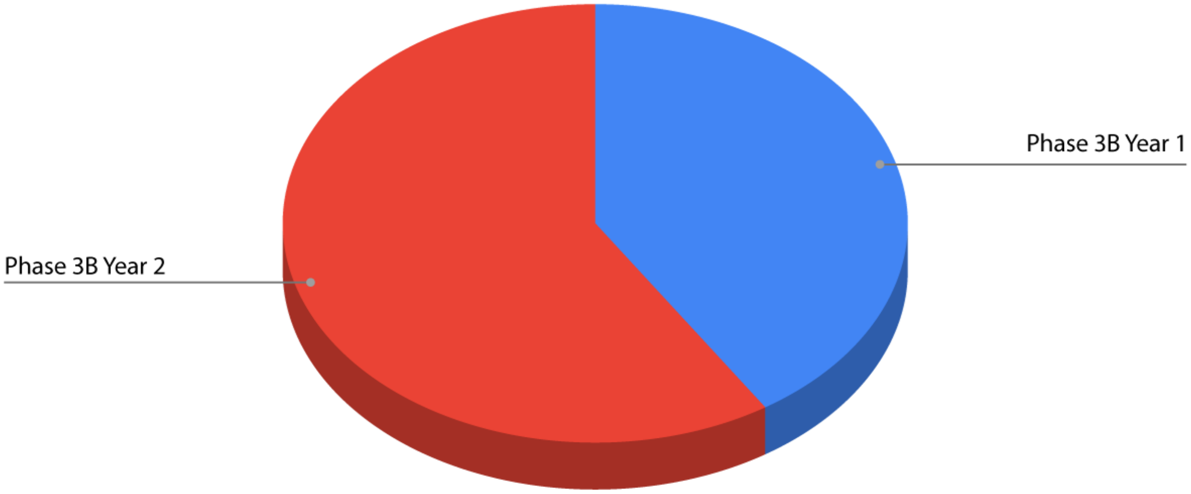


Figure B.8-1. *All page views Phase 3B Year 2 compared to Phase 3B Year 1.*

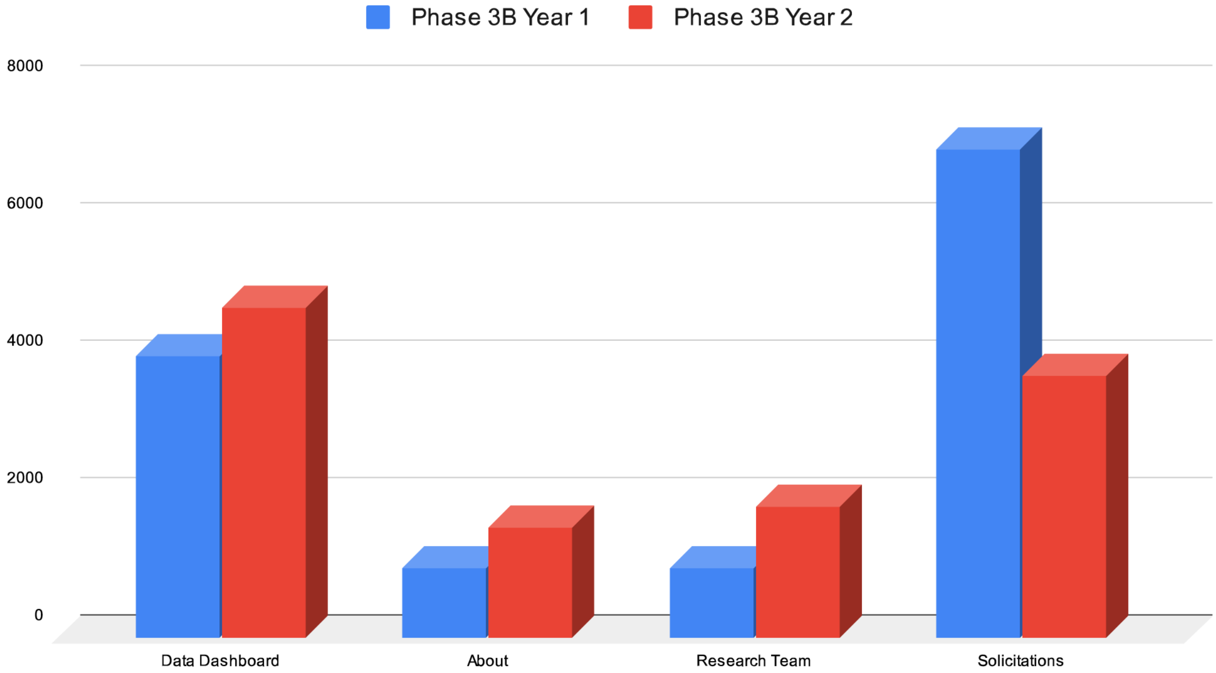


Figure B.8-2. *Top page views Phase 3A Year 2 compared to Phase 3B Year 1.*

Social Media

During the Phase B Year2, there were 293 social media announcements posted on Utah FORGE's social media platforms: Facebook (90), X (102), LinkedIn (90), and YouTube (11) with a total of 4721 followers across all four platforms (329 on Facebook, 814 on Twitter, 3022 on LinkedIn and 556 on YouTube) compared to just 1959 followers in Phase 3B Year 1, an increase over 140%. LinkedIn alone saw an increase of nearly 1000 followers year-over-year. Moreover, LinkedIn and X crested 140,000 combined impressions, while content on YouTube enjoyed nearly 2,700 views. Additionally, Instagram was added to the platform bundle, however it is currently in the pilot stage.

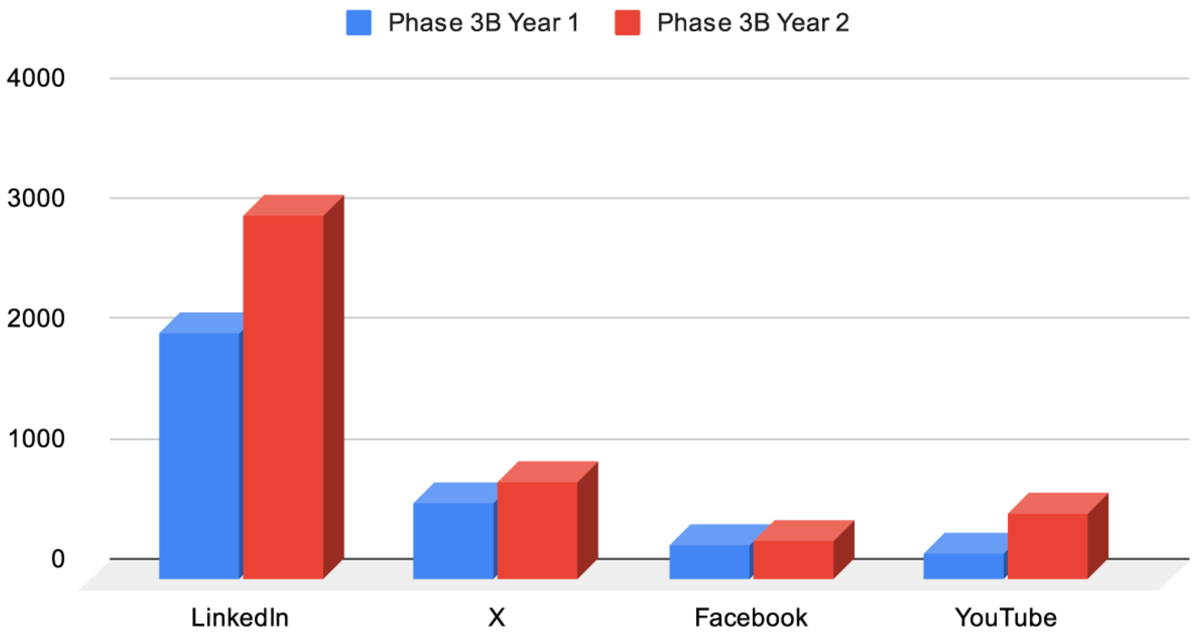


Figure B.8-3. *Growth in Social Media Posts.*

E-Mail Distribution Subscribers

During Phase 3B Year 2, the email subscription list continued to grow. 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 specific subscription exists within the distribution list. In total, the number of subscribers nearly tripled to 3022 from the 1026 in Phase 3B Year 1. There were 40 emails during the period.

Furthermore, according to Campaign Monitor, successful email marketing campaigns result in open rates of 15-25%; Utah FORGE's open rate in Phase 3B Year 2 was an impressive 51%, while the click through rate for the period averaged 12% - 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, such as successful site activities; additionally, journalists writing about geothermal topics have included Utah FORGE in articles based on existing familiarity of the project; and a media day was also held, during which members of the local press were able to tour the site. These efforts resulted in 67 media stories, on par with last year's number of 65 stories.

Media stories were run in general consumer publications such as *The Salt Lake Tribune* and *The Deseret News*; national- level outlets such as National Public Radio, *Wired Magazine* and *Forbes*; industry publications like Think GeoEnergy, Energy Central, and *Drilling Contractor*. Additionally, stories also appeared in the University of Utah publications @TheU and *U Magazine* and in the local Beaver-area newspaper, *The Beaver County Journal*, as well as on local radio and television.

Story topics included the potential offered by geothermal energy and EGS, the drilling of the production well, the Acting Assistant Secretary's visit to the University of Utah and the project site, 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 5.3 million readers of its print edition and nearly 78 million monthly unique visitors to its online version; *Wired* enjoys a combined online and print monthly readership of 30 million, and *The Deseret News* and *The Salt Lake Tribune*, both of which are primarily on-line outlets with limited print days, enjoy a combined monthly page views of over 12 million.

Scientific Outreach

Research findings were presented at scientific conferences throughout Phase 3B Year 2. Over 75 posters, papers and talks were presented at a variety of conferences, seminars, and webinars. Among the conferences and meetings at which presentations were made were the Seismological Society of America's Annual Meeting, the World Geothermal Congress, AGU Fall Conference, ARMA 57th US Rock Mechanics / Geomechanics Symposium, and the Stanford Geothermal Workshop, at which seventeen Utah FORGE presentations were made.

Field Trips

Utah FORGE personnel conducted ten field trips for over 50 individuals. Among those attending the field trips were Deputy Assistant Secretary David Turk, Acting Assistant Deputy Secretary Alejandro Moreno, Geothermal Technology Office Director Lauren Boyd, Utah Governor Spencer Cox, Colorado Governor Jared Polis, Beaver County Commissioners, students from the University of Utah S.J. Quinney School of Law, and members of the media.

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, one webinar and two videos were produced and promoted. The webinar by Dr. John McLennan highlighted the stimulation of a high temperature granitic reservoir and has been viewed by 40 individuals. The first video focused on VIPs who have visited Utah FORGE, while the second highlighted community support of the project. Together they have been viewed over 500 times.

Please refer to table B.8-1 for a full list of Outreach and Communication products.

Modeling and Simulation Community Updates

A total of five Modeling and Simulation Community Updates were hosted. They have had over 2,000 combined post-meeting views. A special subscription created in Phase 3B Year 1 now boasts over 160 registered attendees.

Brochures and Printed Materials

As part of the website redesign, the media kit was updated. Posters highlighting community outreach were updated and placed in display cases in Caboose Park in Milford, Utah. It should be noted that Utah FORGE purchased a new display case for the park. Handouts and other informational materials were updated to reflect the most recent project activities and accomplishments.

Surveys

Collaborating with our colleagues Dr. Sara Yeo of the University of Utah Department of Communication and Dr. Meaghan McKasy of the Utah Valley University Department of Communication, a follow-up survey measuring people’s understanding of geothermal energy and Enhanced Geothermal Systems was created. It was distributed by an outside third party to respondents in all 50 U.S. states. The survey focuses on the respondents’ reactions to terms such as “microseismicity”, “seismicity”, and “earthquakes” and other terms. It seeks responses from all 50 U.S. states. The analysis will be conducted in the next reporting period.

Outreach to Elected and Other Officials

Elected officials and regulators were briefed on the current activities of Utah FORGE through both in-person meetings and email updates. Additionally, meetings with County officials, City officials, Congressional staff members, and individual Utah state legislators were held. Dr. Moore presented to the Utah state Legislature’s Public Utilities, Energy and Technology (PUET) Interim Committee, and the Rural Caucus. Well over 100 stakeholders have been briefed, including U.S. Representative Celeste Maloy, staff members of U.S. Senators Mike Lee and Mitt Romney, Utah state Representative Carl Albrecht and Utah state Senators Evan Vickers and Nate Blouin, Commissioners of Beaver County and Carbon County, and Councilmembers from Beaver City, Milford, and Minersville.

Moreover, elected officials visited the Utah FORGE site. In May, Associated Principal Deputy Secretary Alejandro Moreno and other Department of Energy officials spent two days learning about Utah FORGE and touring the site. His tour included presentations about Utah FORGE and our collaboration with the University of Utah’s College of Education and Department of Communication, a tour of the site, and a stop at the Milford Public Library, where the attendees viewed real-time seismic monitoring via the University of Utah Seismograph Stations on a computer provided by Utah FORGE, and viewed geothermal posters created by fifth and sixth graders from the local elementary school as part of a contest run by the Outreach team, which is discussed in detail below.

K-12 Education

Phase 3B Year 2 saw increased interactions with students and teachers alike. Again, with support from Enel Clean Energy, the Outreach and Communication team conducted two contests. For 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. The students then participated in hands-on science experiments using a thermal camera, a Peltier module, and hand "boilers" - these experiments allowed the students to see "firsthand" the concepts of heat transfer that they had learned about in the lecture.

Following the classroom visits, the students wrote about a geothermal topic and illustrated a poster. Due to school scheduling issues, the winners were selected and received their prizes in May, following this reporting period. All of the posters will be displayed in the city library corresponding to the school's location.

The second contest was a statewide song parody. Information about the contest and its rules, along with geothermal resources, were sent to teachers via the Utah Science Teachers Association monthly newsletter. Additionally, nearly 1000 teachers in every middle, junior and high school in the state received the same information directly from Utah FORGE. For the contest, students created a short song video, parodying a popular song, but with the lyrics changed to incorporate geothermal energy terms and ideas. As with the elementary school poster contest, class scheduling issues prevented the winners of this year's song parody contest from receiving their prizes during this reporting period.

However, the previous song parody contest held during the 2022-2023 academic year, experienced similar deadline conflicts with annual reporting. Per last year's report, an accounting of that contest will be presented now. The contest was open to sixth to twelfth graders across the state. The winning team was from Beaver High School; the runners were from Milford High School (Beaver County); and honorable mentions winners came from Minersville Elementary School (Beaver County), Hidden Valley Middle School (Salt Lake County), and Elk Meadows Elementary School (Salt Lake County).

Of note, upon learning of their victory, the two girls from Beaver High immediately began to jump up and down while hugging each other. Additionally, at Minersville Elementary School, the school administration held an all-class assembly to recognize the team as they received their honorable mention awards.

The Outreach and Communication team hosted a booth during the annual conference of the Utah Science Teaching Association. This is a professional development organization for science teachers of all grades throughout the state. At the booth, attendees received information about geothermal energy, the Utah and the Science and Engineering Education (SEEd) Standards-based lesson plans developed by the University of Utah's College of Education in conjunction with Utah FORGE, other resources available to them, and the song parody contest. Over 160 science teachers visited the booth.

On September 17 and 18, members of the Utah FORGE Outreach and Communication team, joined by student interns and a 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. Attendees could also win various prizes (discussed below). STEM Fest included two days of school groups and an evening for families. Organizers estimated the event saw some 14,000 participants – an increase of almost 10% year-over-year.

Previously, 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. Adding to the resource, our College of Education colleagues provided a professional development opportunity for teachers via an online workshop, during which attendees learned about geothermal energy, geoscience in Utah and using the Science and Engineering Education (SEEd) Standards lesson plans in their classrooms. As part of the workshop, Dr. Stuart Simmons presented on geothermal energy. The virtual workshop was held twice, on November 2 and November 16, 2023, with a total of 20 participants.

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. At every meeting, the commissioners and councilmen have expressed their continuing support for the project.

The Outreach and Communication team also hosted booths during the Midvale Harvest Days Festival (Salt Lake County) and the University of Utah’s Welcome Week.

During Harvest Days, individuals visiting the Utah FORGE booth learned about geothermal energy in general and about EGS and Utah FORGE’s research specifically. A core sample was displayed and handouts about the project were available. Branded pens and candy were available to anyone who wished, and children could take a plastic see through envelope containing a small piece of granite, an explanatory note, and a magnifying glass.

The Utah FORGE booth at the University of Utah’s Welcome Week was open from 10:00 a.m. to 2:00 p.m. August 21-23. Members of the Utah FORGE Outreach and Communication team, including interns, were at the booth providing information about geothermal energy, its use on campus, EGS and Utah FORGE's research. Core samples and a sample drill bit were displayed, handouts about the project were available, as were stickers.

Rain on the second day of the event forced the activities indoors, which limited foot traffic. Over the three days, 200 visitors stopped at the Utah FORGE booth, including the President of the University of Utah, Taylor Randall, who came by on the first day of the event (Monday, August 21). Randall, who is very supportive of the project, took time to meet the Utah FORGE interns, and to express his appreciation for their efforts.

Members of the Utah FORGE Outreach and Communication team again 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. Between 400-450 individuals stopped at the booth.

This year, Utah FORGE was asked to participate in the pre-fair field trip for the local elementary school students. Classes rotated between four different "stops" for 20 minutes. With such a brief time to interact, the Outreach and Communication team utilized a thermal camera and ice cubes to show heat transfer on the children's bodies. The team interacted with over 700 students.

At most community events, visitors to Utah FORGE booths have the opportunity to win a prize. They can either spin a wheel of fortune to receive the prize corresponding to the space the wheel's "stopper" has landed, or they can win the prize of their choice by answering a geothermal-related trivia question. The questions were intentionally "easy." Examples include: "Which national park is known for geothermal features?", "Wind, solar and geothermal energy are all what type of energy resource?" and "True or False: geothermal energy can harm the environment."

Prizes at the various events included inflatable beach balls, "hard hat" stress balls, bubbles, light-up "pop tubes" and geometric spinners.

These games have proven to be very popular with children and adults alike. Not only are they a successful way to encourage engagement, they also provide an important opportunity to educate visitors to the booths. Some visitors engaged in good-natured competitions with their friends, or brought others to the booth so they could try to answer a question.

Utah FORGE was included in the first "Innovators Needed" display as part of the newest exhibit at the Natural History Museum of Utah, which enjoys some 250,000 visitors annually. The exhibit, titled A Climate of Hope, focuses on steps underway to address climate change. A ribbon cutting for the exhibit's opening day was held on November 11, 2023, which was attended by well over 250 people. The launch coincided with the annual museum's "behind the scenes" day for members – making it one of the busiest attendance days of the year.

Finally, a Virtual Visitor Center was designed and populated with content. Users are able to visit various different stops at the Utah FORGE site and the surrounding area. Stops include: The Utah FORGE wells, the Mineral Mountains, the solar farms, hog farms, windmills, Blundell Geothermal Plant, Opal Mound, Roosevelt Hot Springs, and Milford City. Visitors can read information about each entity, see photos of it, and, in some cases, view short videos. The Virtual Visitor Center is also equipped for a virtual reality experience, allowing users to "be on" the rig and well pad as work is being conducted around them. It is designed for desktop, mobile and handheld devices. It will be launched shortly after this reporting period.

Milestones

Of an ambitious fourteen milestones, twelve were achieved during the reporting period:

Technical Outreach			
Submit Geothermal Rising abstract on best outreach and engagement practices	Submit Geothermal Rising presentation on best practices	Host booth at Geothermal Rising	Present paper on best practices for community outreach at Geothermal Rising
Community Outreach			
Host Governor Spencer Cox and Governor Jared Polis at the site	Produce and promote a VIP video	Produce and promote a community support video	Host a media day at the Utah FORGE site
Education		Digital	
Implement a state-wide song parody contest	Participate in and promote the Natural History Museum of Utah's "A Climate of Hope" exhibit's opening day	Run digital billboards about the project on the University of Utah's campus	Redesign and launch the Utah FORGE website

The two milestones not completed: new hands-on teaching module and a K-12 webinar outlining expressions of geothermal energy are currently in progress.

Table B.8-1: *Phase 3A and Phase 3B list of communication products with links*

Full Videos	*8*	*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* *8. Thank You Beaver County*
Short Videos / Video Clips	*6*	*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* *6. VIPs Visit the Utah FORGE Team*
Modeling and Simulation Forum	*28*	*Modeling and Simulation Forum*
Webinars	*14*	*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* 14. *Stimulation of a High Temperature Granitic Reservoir at the Utah FORGE site*
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	*190*	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*

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143. *July 10, 2023, Think GeoEnergy, Utah FORGE project confirms connectivity of EGS reservoir*

144. *July 14, 2023, @TheU, Geothermal at the U: past, present and future*

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147. *August 28, 2023, The Baltimore Sun, There's a Cast Source of Clean Energy Beneath Our Feet. And a Race to Tap it.*

148. *August 28, 2023, VigourTimes, Emerging Geothermal Solutions Arise from Fracking Innovation*

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		168. January 2024, The American Oil & Gas Reporter, Geothermal Needs Oil Field Expertise
		169. January 8, 2024, MIT Technology Review, Enhanced geothermal systems: 10 Breakthrough Technologies 2024
		170. February 5, 2024, Forbes, Clean Alternate Energies: Geothermal Breakthrough Emerges from Shale Revolution (Originally ran January 17)
		171. February 13, 2024, ThinkGeoEnergy, Fervo reports improved drilling times at Cape Station geothermal project, Utah
		172. February 23, 2024, The Deseret News, Geothermal regulations, permitting need overhaul, Curtis says
		173. February 29, 2024, The Sonoma County Gazette, Harnessing the Earth's warmth in Sonoma County
		174. March 5, 2024, Think GeoEnergy, Utah FORGE goes beyond drilling with geothermal education efforts
		175. March 7, 2024, KUER, California is betting on southwest Utah's geothermal energy. Will Utah keep up?
		176. March 9, 2024. The Salt Lake Tribune, Fracking for heat: Utah could become home to world's largest enhanced geothermal plant
		177. March 13, 2004, Think GeoEnergy, Pro-geothermal policies being pushed in the US at federal, state levels
		178. March 16. 2024, The Deseret News, Utah energy: What's here and what's coming for consumers
		179. March 19, 2024, Think GeoEnergy, U.S. DOE publishes report on Commercial Liftoff of Next-Generation Geothermal
		180. March 20, 2024, The Salt Lake Tribune, Opinion: Geothermal energy deserves the red carpet, not red tape

		181. March 25, 2024, Canary Media, Geothermal is the hottest thing in clean energy. Here's why *182. March 27, 2024, The Beaver County Journal, Commission Corner* *183. March 27, 2024, ETV News, Carbon Emery Economic Development Committee Continues to Work to Improve Economics* *184. April 1, 2024, JPT, A Grand Challenge Update on Geothermal Energy* *185. April 2, 2024, Power Magazine, Delving Deeper: New Optimism for Enhanced Geothermal Systems* *186. April 11, 2024 Phys, Rock permeability, microquakes link may be a boon for geothermal energy* *187. April 13, 2024, Globe Echo, New Discovery: Rock Permeability and Microquakes Could Boost Geothermal Energy* *188. April 17, 2024, Utah Business, Fervo forges ahead with world's largest "next-generation" geothermal project in Beaver County* *189. April 17, 2024, HARTENERGY, US Geothermal Sector Gears Up for Commercial Liftoff* *190. April 26, 2024, Think GeoEnergy, Lecture recoding on EGS by Prof. Roland Horne available online*

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 Exchange Council (ALEC) Annual Conference	Dr. Ben Barker and Christopher Katis	Overview of Utah FORGE
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 Utah Chemical Engineering Graduate Seminar*	*Dr. Joseph Moore*	*Creating Enhanced Geothermal System Reservoirs*
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*	*Dr. Joseph Moore*	*An Overview of the Utah FORGE Project*

	(IUGS) Energy Transition Series		
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 Engineering*	*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 Energy Utilization in Latin America.*	*Dr. Joseph Moore*	*An Overview of the Utah Frontier Observatory for Research in Geothermal Energy (FORGE)*

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, 2022	*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*	*Dr. John McLennan*	*Drilling, Reservoir Characterization and Fracturing at the Utah FORGE Site*

	Geomechanics Symposium		
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 M*EQs
		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)*
Apr. 18, 2023	*Seismological Society of America's Annual Meeting*	*Dr. Kristine Pankow*	*De-risking Deep Geothermal Projects: Geophysical Monitoring and Forecast Modeling Advances*
Apr. 19, 2023	*Seismological Society of America's Annual Meeting*	*Dr. Kristine Pankow*	*Towards Best Practices for Egs Seismic Monitoring: Insights Gained at Utah FORGE*
Apr. 23, 2023	*European Geosciences Union General Assembly*	*G. Petersen, K, Whidden, K. Pankow*	*40 years of seismic swarms in the BR-CP transition zone in Central Utah*
Apr. 27, 2023	*Clean Energy for America*	*Dr. Joseph Moore*	*Geothermal 101: Making a Zero-Carbon Energy Future a Reality.*
May 17, 2023	*Wilkes Climate Summit*	*Dr. Joseph Moore*	*Utilizing Geothermal Energy*
May 22, 2023	*Leadership Academy*	*Dr. Joseph Moore*	*An Overview of Geothermal Energy*
May 24, 2023	*Geothermal Transition Summit, North America*	*Dr. Clay Jones*	*Enhanced Geothermal Systems Overview*

May 24, 2023	*Visit by Assistant Secretary of Energy Alejandro Moreno*	*Dr. Joseph Moore*	*An Overview of Utah FORGE*
June 1, 2023	*EGI: Spring Webinar Series*	*Dr. John McLennan*	*Stimulation of a High Temperature Granitic Reservoir at the Utah FORGE Site*
June 23, 2023	*Schlumberger Borehole Seismic Special Interest Group*	*Dr. Kristine Pankow*	*An Overview of Seismic Monitoring at Utah FORGE*
June 27, 2023	*ARMA 57th US Rock Mechanics / Geomechanics Symposium*	*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*
June 27, 2023	*ARMA 57th US Rock Mechanics / Geomechanics Symposium*	*Dr. Meng Cao*	*Creation of a Data-Calibrated Discrete Fracture Network of the Utah FORGE Site*
June 27, 2023	*ARMA 57th US Rock Mechanics / Geomechanics Symposium*	*Dr. Hongkyu Yoon*	*Subsurface Characterization Using Bayesian Deep Generative Prior-Based Inverse Modeling for the Utah FORGE Enhanced Geothermal System*
July 6, 2023	*Annual Geothermica DEEP Meeting*	*Dr. Kristine Pankow*	*Seismic monitoring at Utah FORGE: What we have learned and what is next*
July 6, 2023	*Annual Geothermica DEEP Meeting*	*Peter Niemz*	*Potentials and limitations of nodal patches for cost-efficient monitoring of EGS-induced seismicity*
July 12, 2023	*Uintah Oil and Gas Collaborative*	*Alan Walker*	*An Overview of Utah FORGE*
July 15, 2023	*2023 International Union of Geodesy and Geophysics General Assembly*	*Peter Niemz*	*Exploring the potential of surface monitoring networks for induced seismicity in the Utah FORGE geothermal project*

Aug. 9, 2023	*Utah House and Senate Public Utilities, Energy and Technology interim committee*	*Dr. Joseph Moore*	*The Future of Geothermal Energy in Utah*
Aug. 24, 2023	*University of Utah's Gardner Policy Institute's Energy Advisory Council*	*Alan Walker*	*An Overview of Utah FORGE*
Aug. 24, 2023	*Rotary International, Sugarhouse Chapter*	*Alan Walker*	*An Overview of Utah FORGE*
Sept. 7, 2023	*University of Utah's Energy & Geoscience Institute's Annual Technical Conference*	*Dr. John McLennan*	*An Overview of Utah FORGE*
Sept. 8, 2023	*University of Utah's Energy & Geoscience Institute's Annual Technical Conference*	*Dr. John McLennan*	*Panel: The Role of Renewable Energy and Energy Storage in Meeting US Energy Needs*
Sep. 13, 2023	*Colorado School of Mines*	*Dr. Kristine Pankow*	*Seismic Monitoring at Utah FORGE*
Sep. 16, 2023	*World Geotherm Congress*	*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*
Sep 16, 2023	*World Geotherm Congress*	*Dr. Ben Dyer et. al.*	*Innovative microseismic monitoring tools and configurations for geothermal applications*
Sep. 17, 2023	*Chinese Geological Survey*	*Dr. Joseph Moore*	*An Overview of Utah FORGE*
Sep. 18, 2023	*EGI Annual Technical Conference*	*Dr. Kristine Pankow*	*Seismic Monitoring at Utah FORGE: What we have learned and what is next*

Oct. 17, 2023	*National Association of State Energy Officials*	*Dr. Joseph Moore*	*Geothermal Energy: The Heat Beneath Our Feet*
Oct. 18, 2023	*Colorado Energy Commission*	*Dr. John McLennan*	*An Overview of Utah FORGE and Enhanced Geothermal Systems*
Oct. 25, 2023	*Brigham Young University Business Class*	*Dr. Joseph Moore*	*An Overview of Geothermal Energy and Utah FORGE*
Nov. 2, 2023	*International Geomechanics Symposium*	*Dr. John McLennan*	*Geothermal Energy: An Opportunity – Any Temperature, Any Time, Any Where*
Nov. 8, 2023	*Colorado Department of Natural Resources*	*Dr. Joseph Moore*	*An Update on Utah FORGE (as part of site tour)*
Nov. 8, 2023	*Eavor*	*Dr. Joseph Moore*	*An Update on Utah FORGE (as part of site tour)*
Nov. 14, 2023	*SPE/GR Workshop: Geothermal and Oil & Gas – Mutual Challenges and Solutions*	*Dr. John McLennan*	*Insights from Drilling, Completion, and Circulation at the Utah FORGE Complex*
Nov. 16, 2023	*University of Utah College of Education Canvas Workshop*	*Dr. Stuart Simmons*	*A Geoscience and Geothermal Energy Overview*
Nov. 29, 2023	*Geothermal Energy Machinery and System (GEMS) Workshop*	*Dr. Joseph Moore*	*Utah FORGE: A Steppingstone to EGS Development*
Nov. 29, 2023	*Geothermal Energy Machinery and System (GEMS) Workshop*	*Dr. Joseph Moore*	*An Academic Panel Discussing Geothermal Energy*
Dec. 6, 2023	*China Geological Survey*	*Dr. Joseph Moore*	*An Overview of Utah FORGE (as part of site tour)*
Dec. 11, 2023	*United Kingdom Science & Innovation Network*	*Dr. Joseph Moore*	*An Overview of Utah FORGE*

Dec. 15, 2023	*AGU Fall Meeting*	*Peter Niemz*	*Advancing Surface Monitoring for Enhanced Geothermal Systems: Insights for the Utah FORGE Project*
Dec. 15, 2023	*AGU Fall Meeting*	*G. Petersen, K. Whidden, K. Pankow*	*Interactions of regional tectonics, local faults, and hydrothermal features; Seismic swarms in central Utah*
Jan. 11, 2024	*British Consulate-General: UK Energy Security*	*Dr. Joseph Moore*	*An Overview of Geothermal Energy and Utah FORGE*
Jan. 11, 2024	*Schlumberger Geothermal Webinar Series*	*Erik Borchardt and Andy Wray*	*A Fracture Characterization Case Study from Utah FORGE*
Feb. 12-14, 2024	*Stanford Geothermal Workshop*	*Dr. Joseph Moore*	*Update on 2023 Activities at FORGE*
		Dr. Pengju Xing	*Analysis of Circulation Tests and Well Connections at Utah FORGE*
		Dr. Branko Damjanac	*Coupled Hydro-Mechanical Back-Analysis of Circulation Program at FORGE in July of 2023*
		Dr. Aleta Finnila	*Updated Reference Discrete Fracture Network Model at Utah FORGE*
		Sarah Sausan	*Updates on the Development of Chloride-based Wireline Tool for Measuring Feed Zone Inflow in Enhanced Geothermal Systems (EGS) Wells*
		Dr. Stuart Simmons	*The Interplay of Impermeable Crystalline Basement Rocks, Tectonic Fracturing and Magmatic Intrusion in the Development of Geothermal Resources at Utah FORGE and Roosevelt Hot Springs*

		Wei Fu	*Near-Wellbore DEM Model of Hydraulic Fracture Initiation for Utah FORGE Site,*
		Dr. Robert Podgorney	*Numerically Testing Conceptual Models of the Utah FORGE Reservoir Using July 2024 Circulation Test Data*
		Dr. Ahmad Ghassemi	*The Role of Thermo-Poroelastic Effects on Transverse Fractures in the Utah FORGE Well 16-A*
		Dr. Zhi Yi	*The Updated Wellbore Stress Models for Utah FORGE*
		Andres Baena Velasquez	*Design and Experimental Validation of Unique Geothermal Downhole Valve for FORGE Project*
		Aileen Zebrowski	*Characterization of Thermal Ground at the Roosevelt Hot Springs Hydrothermal System, Utah*
		Dr. Nori Nakata	*Microseismicity Observation and Characterization at Cape Modern and Utah FORGE*
		Dr. Uwaila Iyare	*Measurements of Therm-Hydro-Mechanical-Chemical Coupling in Granite Shear Fractures at FORGE Using the Triaxial Direct-Shear Method*
		Dr. Marl McClure	*Numerical Modeling of Hydraulic Stimulation and Long-Term Fluid Circulation at the Utah FORGE Project*
		Dr. Fan Fei	*Modeling of Diagnostic Fracture Injection Tests (DFITs) for In-Situ Stress Characterization in the Utah FORGE Reservoir*
		Dr. Torquil Smith	*Thermal Hydrological Mechanical Modelling of Anticipated Stimulation in Utah*

Feb. 12, 2024	*GFZ Potsdam*	*Peter Niemz*	*The Utah FORGE Underground Field Laboratory for Enhanced Geothermal Systems: An Overview of Monitoring Strategies and Seismological Insights from Recent Stimulation and Circulation Tests*
Feb. 27, 2024	*Saudi Aramco*	*Dr. Joseph Moore*	*An Overview of the Utah Frontier Observatory for Research in Geothermal Energy*
Feb. 28, 2024	*University of Utah S.J. Quinney School of Law, Environmental Law Class*	*Dr. Joseph Moore*	*An Overview of Geothermal Energy and Utah FORGE*
Mar. 1, 2024	*Utah Legislature's Rural Caucus*	*Dr. Joseph Moore*	*An Overview of Utah FORGE*
Mar. 7, 2024	*Delegation from the Republic of Singapore*	*Dr. Joseph Moore*	*An Overview of Utah FORGE*
Mar. 13, 2024	*Counselor, Republic of Iceland*	*Dr. Joseph Moore*	*An Overview of Utah FORGE*
Apr. 8, 2024	*Tribal Council of the Paiute Nation*	*Dr. Joseph Moore*	*An Update on Utah FORGE*
Apr. 17, 2024	*Deputy Secretary of Energy David Turk, DOE Officials, and Geothermal and Oil and Gas Industry Representatives*	*Dr. Joseph Moore*	*An Overview of Utah FORGE (as part of site tour)*
April 29-May 3, 2024	*Annual Seismological Society of America Meeting*	*K. Pankow et. al.*	*Monitoring induced microseismicity (M>-1) with the local network at the Utah Frontier Observatory for Research in Geothermal Energy (FORGE)*
April 29-May 3, 2024	*Annual Seismological Society of America Meeting*	*G. Petersen et. al.*	*Heterogeneous seismic swarm activity in central Utah: Triggering*

			mechanisms and their complex interactions
April 29-May 3, 2024	*Annual Seismological Society of America Meeting*	*P. Niemz et. al.*	*Circulation experiments at Utah FORGE: Post-shut-in fracture growth revealed by limited near-surface monitoring*

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

Publications List	
1.	*Mesimeri, M., Pankow, K., et al, (2021). Episodic earthquake swarms in the Mineral Mountains, Utah driven by the Roosevelt hydrothermal system, in J. Geophys. Res.: Solid Earth, 126, e2021JB021659.* *Link*
2.	*Mesimeri, M., Pankow, K., et al, (2021). A frequency-domain-based algorithm for detecting microseismicity using dense surface seismic arrays, in Bull. Seism. Soc. Am.,* *Link*
3.	*Mesimeri, M., Pankow, K., et al, (2021). Unusual seismic signals in the Sevier Desert, Utah possibly related to the Black Rock volcanic field, in Geophys. Res. Lett,* *Link*
4.	*Xing, P., Winkler, D., et al, (2021). In-Situ Stresses and Permeability Measurements from Testings in Injection Well 16A(78)-32 at Utah FORGE Site, Geothermal Resources Council Transactions, 45, pp. 871-884.*
5.	*Xing, P., Damjanac, B., et al, (2021). Numerical Investigation of Stimulation from the Injection Well at Utah FORGE Site, Geothermal Resources Council Transactions, 45, pp. 885-898.*
6.	*Dzubay, A., Mesimeri, M., et al, (2022). Developing a comprehensive seismic catalog using a matched-filter detector during a* 2019 stimulation at Utah FORGE, *Stanford Geothermal Conference.* *Link*
7.	*Lee, S., Ghassemi, A., (2022). Numerical Simulation of Fluid Circulation in Hydraulically Fractured Utah FORGE Wells, Stanford Geothermal Conference.* *Link*
8.	*Xing, P., Wray, A., et al, (2022). In-situ Stresses and Fractures Inferred from Image Logs at Utah FORGE, Stanford Geothermal Conference.* *Link*

9.	*Xing, P., Moore, J., et al, (2022). Minimum in-situ stress measurement using temperature signatures, Geothermics, 98.* Link
10.	*Wells, D., Lin, F-C., et al, (2022). Combining Dense Seismic Arrays and Broadband Data to Image the Subsurface Velocity Structure in Geothermally Active South-Central Utah, Journal of Geophysical Research.* Link
11.	*Dzubay, A., Mesimeri, M., et al, (2022). Developing a comprehensive seismic catalog using a matched-filter detector during a 2019 stimulation at Utah FORGE, Stanford Geothermal Workshop.* Link
12.	*Lee, S., Ghassemi, A., (2022). Numerical Simulation of Fluid Circulation in Hydraulically Fractured Utah FORGE Wells, Stanford Geothermal Workshop.* Link
13.	*Xing, P., Wray, A., et al, (2022). In-situ Stresses and Fractures Inferred from Image Logs at Utah FORGE, Stanford Geothermal Workshop.* Link
14	*XING, P., et. al.,(2023). “Comparison of Modeling Results with Data Recorded During Field Stimulations at Utah FORGE Site.” Stanford Geothermal Workshop.* Link
15	*WILLIS, B., PODGORNEY, R,. (2023) “Thermal Hydraulics Evaluation of Fluid Flow Distribution in a Multi-Stage Stimulated Enhanced Geothermal System Wellbore at the Utah FORGE Site.” Stanford Geothermal Workshop.* Link
16	*WHIDDEN, K., PETERSEN, G., PANKOW, K., (2023) “Seismic Monitoring of the 2022 Utah FORGE Stimulation: the View from the Surface.” Stanford Geothermal Workshop.* Link
17	*SIMMONS, S., KIRBY, S., (2023) “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.”, Stanford Geothermal Workshop.* Link
18	*PODGORNEY, R., et. al., (2023). “Thermal-Hydraulic-Mechanical (THM) Modeling of Fluid Flow and Heat/Tracer Transport Between Injection and Production Wells at the Utah FORGE Site.”, Stanford Geothermal Workshop.* Link
19	*JONES, C., et. al., (2023).“Stimulation, Tracers and Geochemistry at Utah FORGE.” Stanford Geothermal Workshop.* Link
20	*FINNILA, A., DAMJANAC, B., PODGORNEY R., (2023). “Development of a Discrete Fracture Network Model for Utah FORGE Using Microseismic Data Collected During Stimulation of Well 16A(78)-32.” Stanford Geothermal Workshop.* Link

21	*Bradshaw, P., G. M. Petersen, and K. L. Pankow (2023). Orientation of borehole and surface seismic stations at Utah FORGE, Geothermal Data Repository, Data publication available at https://gdr.openei.org/submissions/1508.*
22	*Petersen, G. M. and K. L. Pankow, (2023). Small-magnitude seismic swarms in Central Utah (US): Interactions of regional tectonics, local structures and hydrothermal systems. Geochemistry, Geophysics, Geosystems, 24, e2023GC010867. https://doi.org/10.1029/2023GC010867*
23	*Moore, J. (2023). Current Activities at the Utah Frontier Observatory for Research in Geothermal Energy (FORGE): A Laboratory for Characterizing, Creating and Sustaining Enhanced Geothermal Systems, 57th U.S. Rock Mechanics/Geomechanics Symposium, (June) DOI:10.56952/ARMA-2023-0749*
24	*McLennan, J., England, K., Rose, P., Moore, J., and Ben B.. (2023). Stimulation of a High-Temperature Granitic Reservoir at the Utah FORGE Site. Paper presented at the SPE Hydraulic Fracturing Technology Conference and Exhibition, The Woodlands, Texas, (Jan.) doi.org/10.2118/212346-MS*
25	*Finger, C., P. Niemz, L. Ermert, F. Lanza (2024). A composite 3D seismic velocity model for Utah FORGE. Geothermal Data Repository, Data publication available at https://dx.doi.org/10.15121/2305384.*
26	*Isken, M., et. al., (2024). Qseek: A data-driven Framework for Machine-Learning Earthquake Detection, Localization and Characterization, In revision. Seismica. Code available at https://pyrocko.github.io/qseek/*
27	*Niemz, P., et. al., (2024). Circulation experiments at Utah FORGE: Near-surface seismic monitoring reveals fracture growth after shut-in. Geothermics, 119, 102947.*
28	*Simmons, S., et. al., (2024) The Interplay of Impermeable Crystalline Basement Rocks, Tectonic Fracturing and Magmatic Intrusion in the Development of Geothermal Resources at Utah FORGE and Roosevelt Hot Springs. Stanford Geothermal Workshop (May). Link*
29	*Xing, P., et.al., (2024). Analysis of Circulation Tests and Well Connections at the Utah FORGE. Stanford Geothermal Workshop (Feb.). Link*
30	*Rose, P., McLennan, J., Jones, C., Simmons, S., England, K., (2024). Tracer Testing in Well 16B-32 at the Utah FORGE EGS Project. Stanford Geothermal Workshop (Feb.). Link*

C. LESSONS LEARNED

Significant progress has been achieved in tool and technology development for reservoir creation and monitoring during the current reporting period. Despite Utah FORGE's successes, and the application of past lessons learned, there were significant new challenges. Some were overcome; others still require solutions. In this section, we describe the lessons learned from the Conceptual Geologic Model, Drilling and Reservoir Stimulation, Infrastructure Development, Modeling and Simulation, Outreach and Communication activities, R&D activities, and Seismic Monitoring.

Conceptual Geologic Model

1. Changes in chemistry in backflow samples reflect the dissolution of soluble minerals in the fractures. Dissolution of halite provides chloride to the waters.
2. Spectral gamma logs are extremely useful for geologic characterization.
3. Geologic heterogeneities must be identified. They can have a strong influence on the ability to stimulate the wells.
4. Scale deposited during the stimulations consisted of calcite and magnetite, suggesting precipitation of oxygenated waters during heating. Scale mitigation is necessary.
5. The reservoir is developed mainly at depths where granitoid interfingers with the metamorphic rocks.
6. Core samples were collected from well 16B(78)-32 at the predicted locations of frac hits from well 16A(78)-32. Stage 3 frac hits display planar and semi planer mineralized fractures. Calcite and calcium sulfate (anhydrite or gypsum) are present in the fractures.
7. FMI logs appear to overinterpret fracture abundances. Major fractures were readily identified in the quad combo log suite. The two most prominent zones occur at the contact between the granitoid and metamorphic rocks.
8. There are differences in the number and orientation of fractures in wells 16A(78)-32 and 16B(78)-32. Reason is unknown.

Drilling and Stimulation

Well 16B(78)-32 was successfully completed, logged, stimulated and tested.

1. The application of Rotary Steerable Systems (RSS), which has the potential to increase ROP and drill smooth well bores was tested. Although the potential of RSS was demonstrated, extreme vibrations caused damage to the BHA during drilling.
2. Particle drilling was tested to determine if ROPs could be increased over rates achieved using PDC bits. The tests failed to achieve the desired results.

3. Cooldown was most effective with a constant source of cold water. “Chillers” instead of ‘coolers” may produce better results.
4. Use of viscosified fluid helped to achieve better cooldown in the wellbore.
5. Insulated drill pipe proved effective in reducing well bore temperatures

Stimulation of the reservoir between wells 16A and 16B(78)-32 was successfully executed. A short circulation test was conducted before and after well 16B(78)-32 was cased in July 2024, and again in April 2024, after the two wells were stimulated. Commercial flow rates and temperatures were achieved during the second circulation test.

1. Although the initial circulation tests (July 2024) demonstrated a connection between wells 16A and 16B(78)-32 had been achieved, no attempt had been made to enhance permeabilities in well 16B(78)-32 prior to the test. The July tests yielded subcommercial discharge rates and temperatures.
2. Strain data was measured using a single mode fiber on the UT Austin deployed fiber optic cable. The measurements provided information on the location and migration of the strain fronts during the stimulation; information that was critical for locating the perforation depths in 16B(78)-32.
3. Treatment of both the injector and the producer appears to be necessary. A characteristic feature of the production well frac treatments is indication of initiation, roll over suggesting breakdown/initial propagation and one or more subsequent significant pressure drops suggesting access to previously created fractures occurred.
4. The Petroquip bridge plug passed its initial test but longevity is still an issue.
5. The pump-down plug and guns method for each stage on well 16A worked very well due to the adequate cooldown. Running and setting the frac plugs on tubing was problematic due to lack of cooldown and scale-related problems on the setting tool. Additional work by Nine Energy on plug components and setting mechanism will be required when running the frac plug on pipe.
6. Effective methods for plug drill out require further development. We had very good performance from the Badger bit (manufactured by Throop Rock Bit but supplied by San Joaquin Bit) and if we use a higher rated power swivel probably could probably reduce the drill-out time for each frac plug from ~4.5 hours to ~2.5 hours.
7. Stages 6 and 7 in well 16A(78)-32 both treated at significantly higher pressure and the pump rate was not high enough to start addition of proppant without the high likelihood of screening out.
8. There were no issues pumping the lightweight proppant – but the benefits are unknown.
9. The Tubing Conveyed Perforating (TCP) Gun orientation worked perfectly in well 16B(78)-32.

10. Effectiveness of fiber for designation of frac hits needs further evaluation. This may be provided by analyses from Neubrex and UT-Austin.
11. Preliminary assessment of the distribution of fluid in Stage 9 shows decent coverage amongst the eight (8) perforation clusters. The Stage 9 interval is taking 38.8% of the total injected fluid and only 2 out of the 8 clusters are not contributing. I think this is an important data point for cluster efficiency. The Stage 8 interval is taking 16.2% of the total injected fluid and, as you mentioned, it will be important to quantify the distribution into the eight (8) clusters when running the production log during the thirty-day circulation test.
12. The production log results (PLT) were not conclusive. The original plan was to run PLTs simultaneously in both wells. One of the units brought to location was not adequate for the conditions. After a single pass in 16A(78)-32, the wireline unit was moved to well 16B(78)-32. The conveyance mechanism for the PLT (weights + rollers) was not able to get the PLT log below the Stage 5 perforated interval in well 16B(78)-32.
13. Petroquip bridge plug passed initial testing but longevity is still an issue.
14. No information was obtained regarding the open and cased hole distribution of flow (either injection or production). Tools need development.
15. The utility of the downhole Baker P/T gauge has not been established. Integrating that data with the surface data is still required.
16. Too early to really dissect everything from the microseismic data.
17. No events greater than magnitude 2 were detected but where at Fervo. Was this do to operational or geologic differences. The only real operational difference is that Fervo pump at 100 bpm with a surface treating pressure >9,000 psi during the Pad stage.
18. We may or may not have a casing restriction – indications are yes but the reasons are unclear.
19. Use of viscosified fluid helped to achieve better cooldown in well 16B(78)-32 while circulating prior to running the fiber mapping logs.
20. Significant operation time is required to cool the wells. “Chillers” may be more effective than “coolers”?
21. Pressure communication with wells 58-32, 56-32 and 78B-32 during the stimulation stages and 9-hour circulation test was not predicted.
22. Treatment of both the injector and the producer appears to be relevant. A characteristic feature of the production well frac treatments is indication of initiation, roll over suggesting breakdown/initial propagation and one or more subsequent significant pressure drops suggesting the fluids gained access to previously created fractures. It seems doubtful that we would have had this good of connection without treating the producer.

Infrastructure

The infrastructure was expanded with the drilling of a productive water well, large water storage pits, fiber optic cables that connect the wells and fiber optic cables in 16B(78)-32.

1. Aquifer permeabilities are highest on the eastern side of the Utah FORGE site. The best permeabilities are in gravels at depths of 500-1000 ft.
2. Plan to build out electric infrastructure to accommodate unforeseen future needs.
3. Maintaining good relationships with local service providers is essential to accommodate unforeseen needs.
4. Earthwork construction must occur between October – December to comply with biological regulations.

Modeling and Simulation

Modeling of the 2022 and 2023 stimulations and injection tests is an ongoing.

1. There is large uncertainty in the absolute MEQ locations for stage 1 and 2 during the 2022 stimulation of well 16A(78)-32; hence fitting fracture planes may be an over-interpretation. MEQ data cannot be related to natural fractures with any certainty. Accordingly, the DFN based on the plane-fitting to the MEQ catalog that we have been using for modeling the reservoir has little validity.
2. Effects of various stimulation fluids are likely only to occur in the vicinity of 16A(78)-32. Viscosity is a function of temperature and time at a given temperature, which means the far field fluid rheology is likely the same between all stimulations.
3. Salts were mobilized during flowback of well 16A(78)-32 during the 2022 stimulation. Increased porosity/permeability is hypothesized to have occurred near the 16A(78)-32 wellbore through dissolution of fracture related mineralization.
4. A radial model best fit the slug tests, and the volume interrogated was likely to be relatively small. Transmissivity (near wellbore) is quite high but the extent is uncertain perhaps only 10s of meters and probably <50 m. This means that potentially planar fractures were stimulated near the 16A wellbore.
5. A large portion fractures in the tangent section of well 16B(78)-32 were vertical (FMI indicates 80-90%). If with further analysis this proves to be true it would indicate that vertical fracturing dominates both the original natural fracture orientations and stimulated fracture orientations.
6. The rate of leakoff/pressure drop after shut in seems “smaller” after larger volume injections, i.e., the formation holds more pressure after higher volume injection events. Accordingly, the larger volume injections essentially “fill” all the available storage (natural fractures?), and the reservoir is effectively isolated and closed.
7. Zones of high fracture intensity approximately align between wells 16A and 16B(78)-32. Individual fractures (most highly conductive zones on FMI) seem to be oriented

vertically. While the geologic structures between wells 16A and 16B(78)-32 have continuity, the exact geometric relationship needs to be confirmed.

8. The fracture opening pressure is different between open hole and perforated zones, and this is likely a near wellbore tortuosity artifact related to wellbore pressure. Near wellbore pressure drop is influenced and controlled by more than just the number of effective perforations.
9. Tracer was found in the cored intervals of 16B(78)-32 and correlated to injection locations, and also cross-zone flow in the formation, but not necessarily in the injection well.
10. The pressure response time between wells 16A and 16B(78)-32 decreased over the testing campaign from 40 minutes to <1 minute. Once the available storage is filled, the reservoir is more responsive.
11. There seem to have been no changes in permeability over the July 2023 testing campaign; hence later injection did not have a permanent effect on the reservoir. Furthermore, the reservoir permeability did not respond in an expected poro-elastic manner.
12. Permeability near well 16A(78)-32 is significantly higher than the permeability near well 16B(78)-32 and the nature of the transition is uncertain.
13. Fracturing appears not to have occurred during the July 2023 flow testing, and this is mostly measurable in Stage 3 (cannot comment on other stages). Accordingly, the pressure drop associated with flowing well 16B(78)-32 was not enough, or the well was not connected to the formation enough, to keep the far field pressure below the frack gradient.

Seismic Monitoring

Seismicity was monitored during subsurface activities at Utah FORGE. The monitoring employed geophone strings, DAS fibers, and nodal arrays. Exceptional data sets were obtained. Specific lessons learned during the 2023 circulation and 2024 stimulation are:

1. It was helpful to have a Seismic Manager on-site to coordinate between the operations and seismic teams during the stimulation. This was one of the suggestions from the post-2022 seismic meeting.
2. Reservoir resolution achieved with advanced processing of near-surface stations is approaching what can be achieved with deep borehole monitoring. Near surface seismometers might be a viable option for long term operational seismic monitoring of EGS.
3. Nodal stations need to be buried ~10 cm below the surface to protect from wind noise. The high frequencies generated by the microseismicity require closer station spacing.
4. All borehole seismic sensors and cable heads need to be inspected before deploying.

5. With closely spaced reservoir operations between different groups (e.g., Utah Forge and Cape Station), it is important to note that magnitude determinations may not be calibrated. This may result in differing triggers for Traffic Light Systems even if the threshold values are the same.
6. Geophone lifetimes are substantially greater at temperatures less than ~150^{o}C compared to deployment at higher temperatures.
7. The UT Austin fiber optic cable (flat pack) deployed in well 16B(78)-32 at a temperature >~200^{o}C has provided high quality data since it was deployed, but the Silixa cable deployed by Rice University has not.

R&D Projects

Throughout the year, rigorous progress monitoring was maintained for R&D projects, with field deployments strategically coordinated when necessary to advance project objectives. R&D activities at the Utah Forge site were conducted by Battelle, Clemson University, LBNL, PetroQuip, Rice University, and UT Austin.

1. The PetroQuip locking bridge plug was successfully deployed and met the required specifications. However, the tool failed after approximately one week. This highlights the critical need to continue focusing on developing tools that can operate reliably under EGS conditions. Advancements in materials, design, and testing are necessary to overcome the unique challenges presented by the high-temperature and high-pressure environments characteristic of EGS.
2. Deployment of fiber optic cables requires extreme care to avoid damage. Successful installation necessitates the presence of an onsite expert or team and the implementation of a strategic cable deployment plan to ensure proper casing wrapping.
3. Although UT Austin's flat pack and Rice University's Silixa fiber optic cables were deployed simultaneously, the Silixa cable degraded quickly. Only minor degradation of the flat pack was observed. No degradation of the PT gauge deployed at the heel of 16B(78)-32 was seen. High quality seismic, strain and temperature data were obtained from the flat pack.
4. Clemson University deployed two high resolution strainmeters in shallow boreholes prior to the 2024 stimulation. The environment at Utah FORGE could potentially pose challenges due to high levels of noise interference for the strainmeters. Further analysis of the data collected is required to determine if the instruments recorded strain data related to the 2024 stimulation.
5. The implementation of quarterly calls with each R&D project PI facilitated clear and consistent communication and has proven to be vital. Regular updates and meetings will continue to maintain project alignment and to promptly address issues.
6. GDR uploads are essential for facilitating collaboration, transparency, and innovation by centralizing data, enabling efficient access, analysis, and sharing across research

teams, while also ensuring compliance. Clear guidelines and expectations were established, aimed at improving compliance and consistency. However, shortcomings remain. Regular audits will be conducted to identify gaps and areas for improvement, with feedback provided to ensure continuous adherence to guidelines.

7. Improved timeliness and accuracy of technical and financial reports, including invoicing, are imperative for effective R&D technical monitoring. Efforts will continue to proactively communicate requirements to enable early identification and resolution of potential delays and to ensure timely interventions and adjustments.

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 Phase 3B Year 2, the Outreach and Communication team's engagement with existing and new audiences was successfully initiated and realized.

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

1. The Outreach and Communication team's consistent presence in the community, whether at public events or during in-class presentations, has created a sense of familiarity by the local populace of both the team and the project. In turn, this familiarity has led to a greater feeling of "ownership" of and pride in the project by the residents of Beaver County. It is not uncommon for grade school students to proactively greet team members by name or ask about former team members. When interacting with the Utah FORGE representatives, parents have frequently explained to their children how they have worked in some capacity at the site.
2. Media relations is an important part of any scientific project. Journalists of all stripes help keep the key industry players and the general public apprised of the goals and direction of the project, and the latest successes. However, when the research site is located in a remote area, it can be difficult for members of the media to visualize operations and scope, leading to inaccuracies and misinformation in news articles. Hosting a media day at the site proved incredibly beneficial. This allowed journalists to see the site firsthand and gain a sense of the scope of the project, as well as to spend time asking subject matter experts questions in real time. This also resulted in several positive stories in the general media.
3. Fun trivia has proven to be an enjoyable and successful method of engaging audiences of all ages. Whereas using a "wheel of fortune" to offer random prizes or branded "swag" is effective, a surprisingly large number of people prefer to attempt to answer a trivia question about geothermal energy in order to win the item of their choosing. This has led to greater engagement, more in-depth understanding about geothermal energy, and often times lighthearted competition between friends.
4. Young students are most drawn to learning about "interesting facts" related to geothermal energy. Hearing how animals use the resource – particularly the snow

monkeys of Jigokudani Park in Japan – captivates this audience. Additionally, they enjoy trying to answer less technical questions, such as which European nation grows the most bananas by using geothermal greenhouses. This type of trivia led to additional questions from the students and the information was included in their posters.

5. Teacher involvement is vital in student engagement. In order to gain access to the classroom, the Outreach and Communication team has learned that it is imperative to ensure that any presentation by the team requires little effort by the teachers and offers educational information relevant to their curricula. Also important, teachers are invaluable in guiding student participation in contests.

Table C-1*. Comments received from public*

The following questions and comments were made by visitors to the Utah FORGE booth at various community events
Are there field trips to the site available?
Is Utah FORGE only out of the University of Utah?
How long did it take to get the core out?
How close to a building do heat pumps need to be?
How do heat pumps work?
Are you doing those quizzes again like last year? (Asked by a child)
How’s the lab going?
What’s the end goal of the project?
What happens to the water that doesn’t come up the production well?
Since you’re not selling anything, what do you hope to get out of being here today?
I follow you on Facebook!
This is amazing!
This is solving problems.
This is so cool, thank you.
I remember that you guys were here last year, too.
I imagine we’ll be able to get a lot of energy from this.
Good luck on your research.
Keep up the good work!
This is my favorite booth of all! (Made by a 12-year-old.)

D. CONCLUSIONS & FORWARD PLAN

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 without significant reservoir cooling; 3) mitigate detrimental induced seismicity; and 4) develop a roadmap for commercialization of EGS.

Phase 4 represents a continuation of Phase 3B activities. In Phase 3B, wells 16A-16B(78)-32 were successfully connected, resulting in commercial flow rates during a short flow test. The stimulation program tested proppants, bridge plugs, treating fluids, number of clusters per stage and the application of fiber optic cables for monitoring temperature, strain, and seismicity. In addition, drilling technologies and tools (particle drilling, mud hammer, PetroQuip plug, insulated drill pipe) were tested.

Ten stages were stimulated in well 16A(78)-32, including a refrac of the original three stages, and four stages were stimulated in well 16B(78)-32. Commercial flow rates were achieved during a 9-hour flow test. Approximately 70% of the injected fluid was returned during the test. The fluid reached at a temperature of 282^{o}F.

Despite the achievements of Phase 3B, Utah FORGE faced numerous challenges. It is clear from the results of Phase 3B that important questions remain regarding the best approaches to stimulating the wells (e.g. effectiveness of different cluster geometries, flow measurements), the extent and mitigation of reservoir scale, interpretation of monitoring data (e.g. fiber optic and seismic data). Phase 4 and Solicitation 2 R&D projects will continue to address these issues.

The primary activities of Phase 4 are to:

- Design, plan, drill and test well 16C(78)-32/ WOO 2;
- Stimulate the 16A(78)-32/16B(78)-32/16C(78)-32 wells to create the Utah FORGE reservoir;
- Initiate circulation testing between the 16A(78)-32/16B(78)-32/16C(78)-32 wells;
- Incorporate R&D project tools and technologies into the well designs;
- Monitor and utilize seismic data to quantify event magnitudes and locations;
- Continue monitoring for characterization, creation, evolution, management, and hazard mitigation of EGS reservoirs;
- Monitor, evaluate, and manage R&D activities conducted by Solicitation 1 & 2 awardees;
- Conduct outreach activities that showcase to the public, stakeholders, and the energy industry that EGS technologies have the potential to contribute significantly to power generation in the future;
- Provide educational and research opportunities for students at all levels;
- Place all drilling, stimulation, and monitoring data in the public domain;

- In collaboration with DOE, develop a comprehensive annual report summarizing activities, successes, and lessons learned at the Utah Milford site.

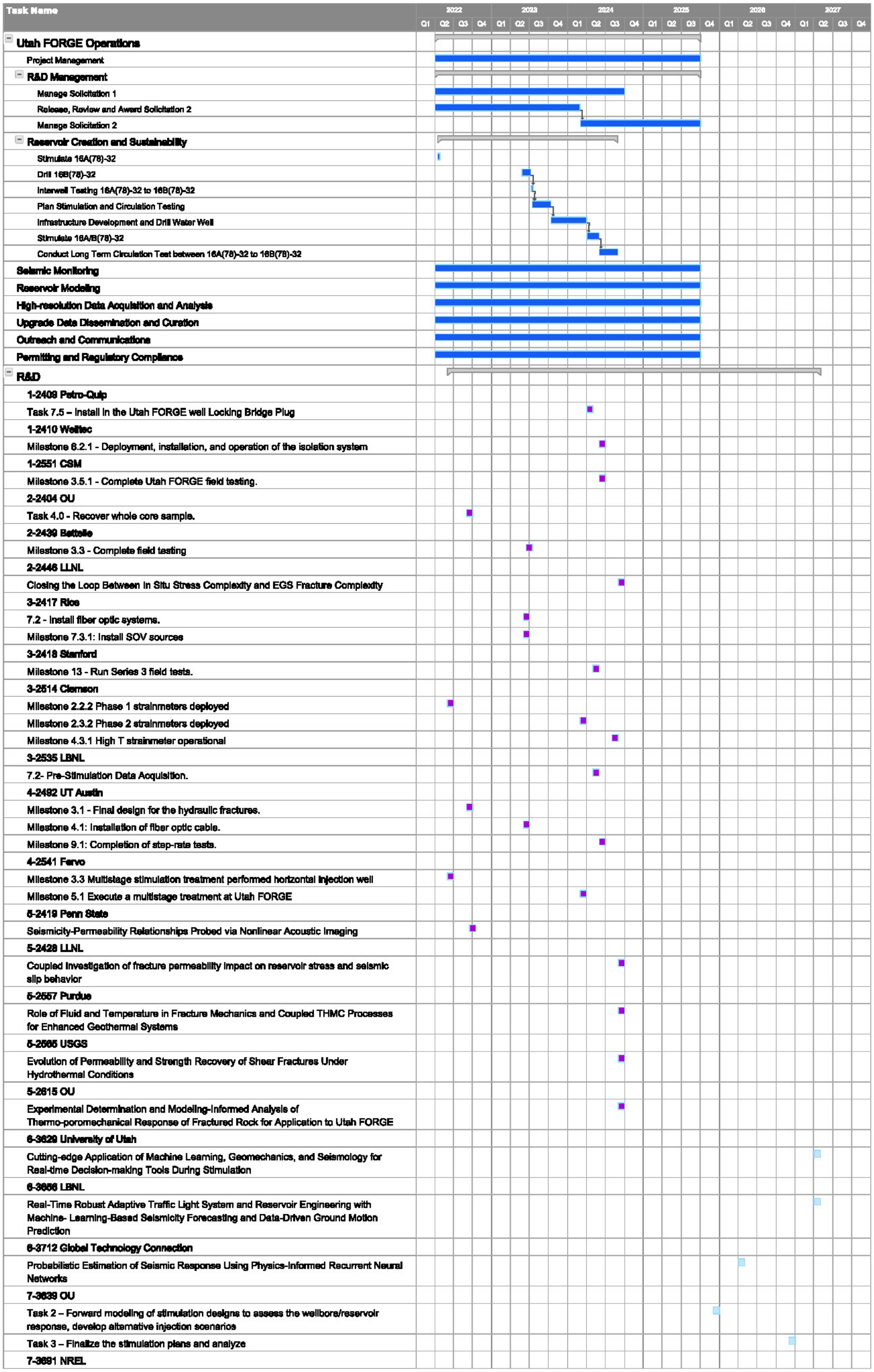
The technical outcomes of these activities will:

- Improve and refine methods for inter-well interconnections;
- Establish connections between 16C(78)-32, 16A(78)-32 and/or 16B(78)-32b;
- Stimulating well 16C(78)-32 and additional stimulations to wells 16A(78)-32 and 16B(78)-32
- Test and prove multistage stimulation and isolation technologies that are effective and environmentally benign;
- Create and image a network of fluid conductivity pathways;
- Develop and document an understanding of how and why the pathways were created and a methodology for repeatability of the reservoir creation process;
- Test methods for controlling fracture morphology and maintaining or optimizing conductivity;
- Characterize heat exchange, and undertake numerical simulations that predict and validate long term heat exchange potential;
- Provide a test of high-temperature logging and fracture imaging tools and equipment as well as novel stimulation and heat exchange techniques.

In summary, 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, field scale tests. 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. Only recently are we seeing large scale commercial development of EGS.

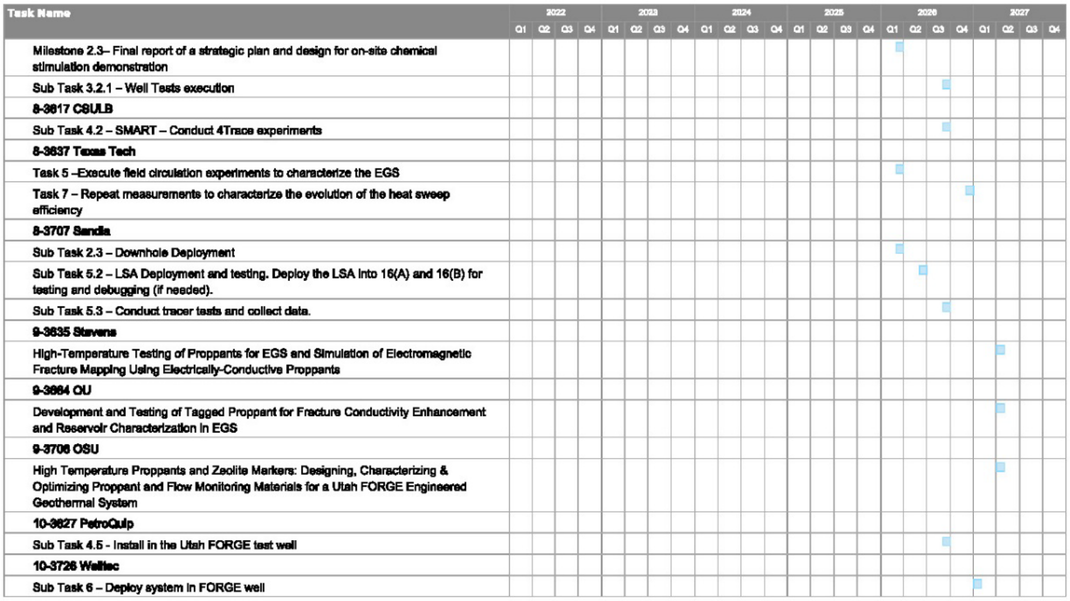
Utah FORGE is on the verge of demonstrating the necessary technology to expand EGS to hotter, deeper environments. No similar field-scale laboratory exists elsewhere in the world. in In Phase 4, seven deep wells more than 1000 ft deep will be available for reservoir creation and the testing of tools and technologies.

Our vision for Utah FORGE will continue to include Outreach and Communication activities to help increase overall geothermal literacy. The Virtual Visitor Center and an exhibit at the Natural History Museum of Utah provide access to information about the project, geothermal energy and EGS to unlimited audiences. Phase 4 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.



Task Name

Utah FORGE Operations
Project Management
R&D Management
Manage Solicitation 1
Release, Review and Award Solicitation 2
Manage Solicitation 2
Reservoir Creation and Sustainability
Stimulate 16A(78)-32
Drill 16B(78)-32
Interwell Testing 16A(78)-32 to 16B(78)-32
Plan Stimulation and Circulation Testing
Infrastructure Development and Drill Water Well
Stimulate 16A/B(78)-32
Conduct Long Term Circulation Test between 16A(78)-32 to 16B(78)-32
Seismic Monitoring
Reservoir Modeling
High-resolution Data Acquisition and Analysis
Upgrade Data Dissemination and Curation
Outreach and Communications
Permitting and Regulatory Compliance
R&D
1-2409 Petro-Quip
Task 7.5 – Install in the Utah FORGE well Locking Bridge Plug
1-2410 Welltec
Milestone 6.2.1 - Deployment, installation, and operation of the isolation system
1-2551 CSM
Milestone 3.5.1 - Complete Utah FORGE field testing.
2-2404 OU
Task 4.0 - Recover whole core sample.
2-2439 Battelle
Milestone 3.3 - Complete field testing
2-2446 LLNL
Closing the Loop Between In Situ Stress Complexity and EGS Fracture Complexity
3-2417 Rice
7.2 - Install fiber optic systems.
Milestone 7.3.1: Install SOV sources
3-2418 Stanford
Milestone 13 - Run Series 3 field tests.
3-2514 Clemson
Milestone 2.2.2 Phase 1 strainmeters deployed
Milestone 2.3.2 Phase 2 strainmeters deployed
Milestone 4.3.1 High T strainmeter operational
3-2535 LBNL
7.2- Pre-Stimulation Data Acquisition.
4-2492 UT Austin
Milestone 3.1 - Final design for the hydraulic fractures.
Milestone 4.1: Installation of fiber optic cable.
Milestone 9.1: Completion of step-rate tests.
4-2541 Fervo
Milestone 3.3 Multistage stimulation treatment performed horizontal injection well
Milestone 5.1 Execute a multistage treatment at Utah FORGE
5-2419 Penn State
Seismicity-Permeability Relationships Probed via Nonlinear Acoustic Imaging
5-2428 LLNL
Coupled investigation of fracture permeability impact on reservoir stress and seismic slip behavior
5-2557 Purdue
Role of Fluid and Temperature in Fracture Mechanics and Coupled THMC Processes for Enhanced Geothermal Systems
5-2565 USGS
Evolution of Permeability and Strength Recovery of Shear Fractures Under Hydrothermal Conditions
5-2615 OU
Experimental Determination and Modeling-Informed Analysis of Thermo-poromechanical Response of Fractured Rock for Application to Utah FORGE
6-3629 University of Utah
Cutting-edge Application of Machine Learning, Geomechanics, and Seismology for Real-time Decision-making Tools During Stimulation
6-3656 LBNL
Real-Time Robust Adaptive Traffic Light System and Reservoir Engineering with Machine- Learning-Based Seismicity Forecasting and Data-Driven Ground Motion Prediction
6-3712 Global Technology Connection
Probabilistic Estimation of Seismic Response Using Physics-Informed Recurrent Neural Networks
7-3639 OU
Task 2 – Forward modeling of stimulation designs to assess the wellbore/reservoir response, develop alternative injection scenarios
Task 3 – Finalize the stimulation plans and analyze
7-3691 NREL



Task Name	2022				2023				2024				2025				2026				2027			
	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4
Milestone 2.3– Final report of a strategic plan and design for on-site chemical stimulation demonstration																	■							
Sub Task 3.2.1 – Well Tests execution																			■					
8-3617 CSULB																								
Sub Task 4.2 – SMART – Conduct 4Trace experiments																			■					
8-3637 Texas Tech																								
Task 5 –Execute field circulation experiments to characterize the EGS																	■							
Task 7 – Repeat measurements to characterize the evolution of the heat sweep efficiency																				■				
8-3707 Sandia																								
Sub Task 2.3 – Downhole Deployment																	■							
Sub Task 5.2 – LSA Deployment and testing. Deploy the LSA into 16(A) and 16(B) for testing and debugging (if needed).																		■						
Sub Task 5.3 – Conduct tracer tests and collect data.																			■					
9-3635 Stevens																								
High-Temperature Testing of Proppants for EGS and Simulation of Electromagnetic Fracture Mapping Using Electrically-Conductive Proppants																						■		
9-3664 OU																								
Development and Testing of Tagged Proppant for Fracture Conductivity Enhancement and Reservoir Characterization in EGS																						■		
9-3706 OSU																								
High Temperature Proppants and Zeolite Markers: Designing, Characterizing & Optimizing Proppant and Flow Monitoring Materials for a Utah FORGE Engineered Geothermal System																						■		
10-3627 PetroQuip																								
Sub Task 4.5 - Install in the Utah FORGE test well																			■					
10-3726 Welltec																								
Sub Task 6 – Deploy system in FORGE well																					■			

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

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APPENDICES

Appendix A1: Infrastructure Assessment

Phase 3B 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, 84105

Prepared for the U.S. Department of Energy

Office of Energy Efficiency and Renewable Energy

Contract DE-EE0007080

June 1, 2024

A1. FORGE INFRASTRUCTURE ASSESSMENT

This section considers the infrastructure required to support Utah FORGE operations and complimentary R&D activities in Phase 3B.

WELL 16B(78)-32

Well 16B(78)-32 was spudded on April 26, 2023 and completed on July 20, 2023 in under 100 days (Fig A1-1). Well 16B(78)-32 was drilled from the same pad as Well 16A(78)-32, with a similar trajectory, placing 16B(78)-32 ~300 ft above 16A(78)-32 in the tangent section (Fig A1-2).

The operational and scientific objectives met in drilling Well 16B(78)-32 were as follows:

- Provide a doublet pair to Well 16A(78)-32 with a trajectory of nominally 105° at an inclination of 65° to the vertical. Build angle at 5.5°/100 ft MD so that Well 16B(78)-32 is vertically offset from Well 16A(78)-32 by 300 ft TVD (Fig A1-2).
- Establish a connection with well 16A(78)-32 through hydraulic fractures created in April 2022.
- Drill and complete to accommodate fiber optics cemented in the anulus for the University of Texas and Rice University research programs.
- Leave the production section (from the 11-3/4-inch casing shoe at 4,837 feet MD to TD at 10,947 ft MD[4]) uncased to accommodate open hole stress measurements for the Battelle research program.
- Core the toe section in strategic sections (Figs A1-3 and A1-4) to search for fractures, tracers, and other fracture diagnostics (e.g., microproppant) that were injected during the hydraulic fracturing at the toe of Well 16A(78)-32. Also, acquire core from a vertical section of the well in granite for geologic characterization and mechanical properties determinations. This coring occurred from 4,855 to 4,878 ft MD. Core was also allocated for geologic characterization, mechanical properties measurements, and other R&D activities. The core bit size is 8-3/4-inch and required subsequent reaming to 9-1/2-inch.
- Acquire multiple open hole and cased hole logs – in particular, multiple ultrasonic and resistivity imaging runs, a quad combo at TD, and cement evaluation runs. This also includes monitoring for tracers and microproppant from the stimulations at the toe of Well 16A(78)-32.

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[4] Unless stated specifically otherwise, MD is relative to the rig's RT/KB.

- Limited injection/circulation testing for preliminary evaluations of connectivity between the two wells. Monitor wellhead pressures in offset wells.
- Near-bit vibrations were measured in all sections of the hole (providing low and high-frequency data from near-bit pucks, centerline centralizers and in BHA sensor packages). Ensuring that the complete waveforms are captured, and that high frequency data are acquired. The primary goals of this are evaluating drilling dysfunction and assessing if formation mechanical properties can be inferred independent of logging. We are also interested in crosswell logging in the future.
- Reduce rugosity by bit redesign, BHA modifications, and running RSS.

Other activities associated with the drilling of Well 16B(78)-32 are as follows:

- Earthwork
    - A 50 by 50 ft gravel pad was installed and compacted below the rig footprint.
    - Construction of the cellar, mouse hole and rat hole before rig move in.
    - The 16A/B pad was regraded prior to rig move in.
- Power was trenched to the north side of the sump for the Rice/Silixa and UT Austin/Shell fiber optic data acquisition trailers and conduit was installed between the trailers and the 16B(78)-32 wellhead to safely route the fiber optic cables.
- A fiber junction box and 120V power feed were installed at the 16B(78)-32 wellhead.
- Windsocks were installed on the 16A/B pad prior to spudding Well 16B(78)-32.
- Temporary housing was placed on the 16A/B pad to support drilling operations and tied into the electrical grid and temporary water/sewer systems.
- Signage was replaced that had been destroyed by weather and livestock.
- 16B(78)-32 wellhead repairs.
- Upon completion of Well 16B(78)-32 the command center trailer was repositioned to its long-term location on the north side of the 16A/B(78)-32 drill pad, near the entrance. New electric service was run to the trailer and water/sewer tanks were installed.
- Cleaned up site after rig move off.

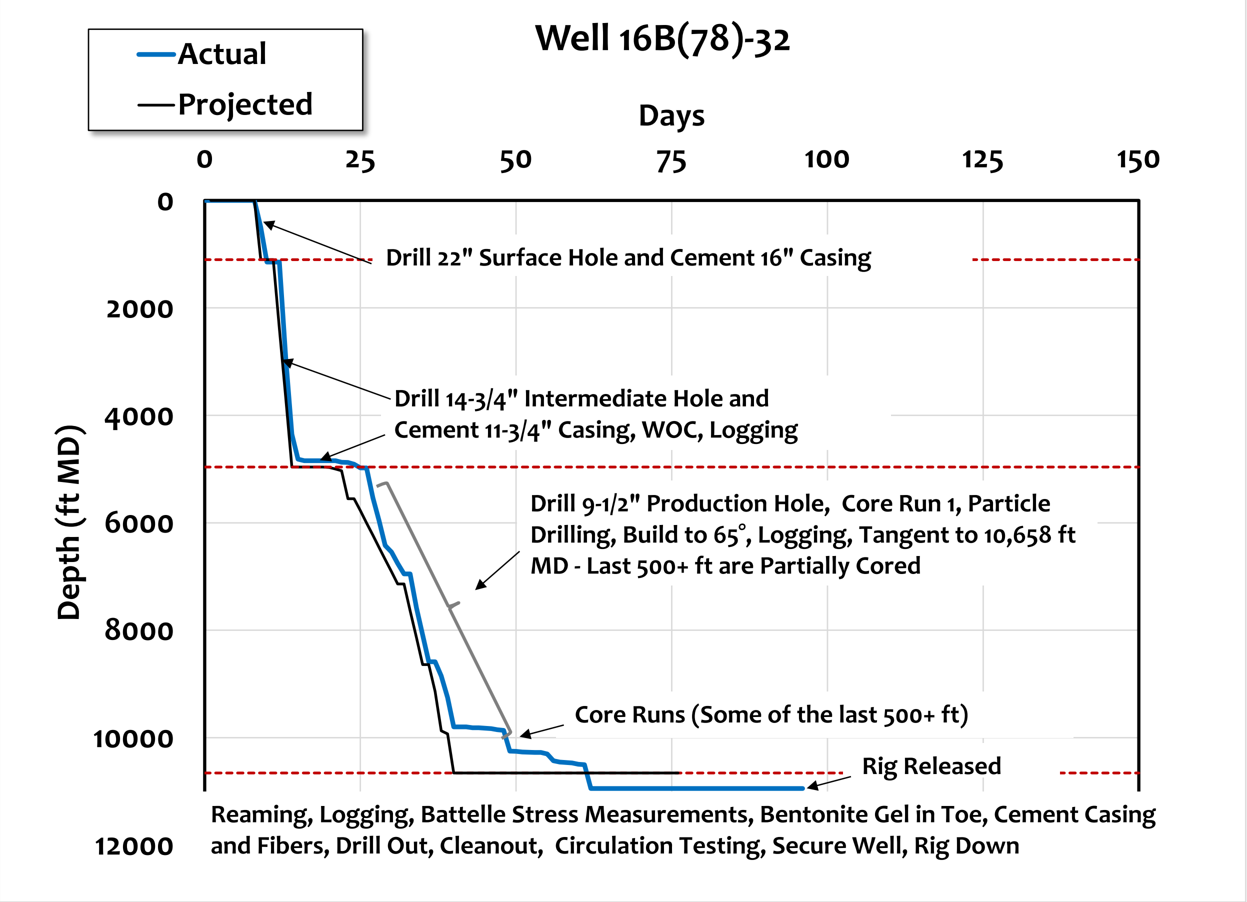
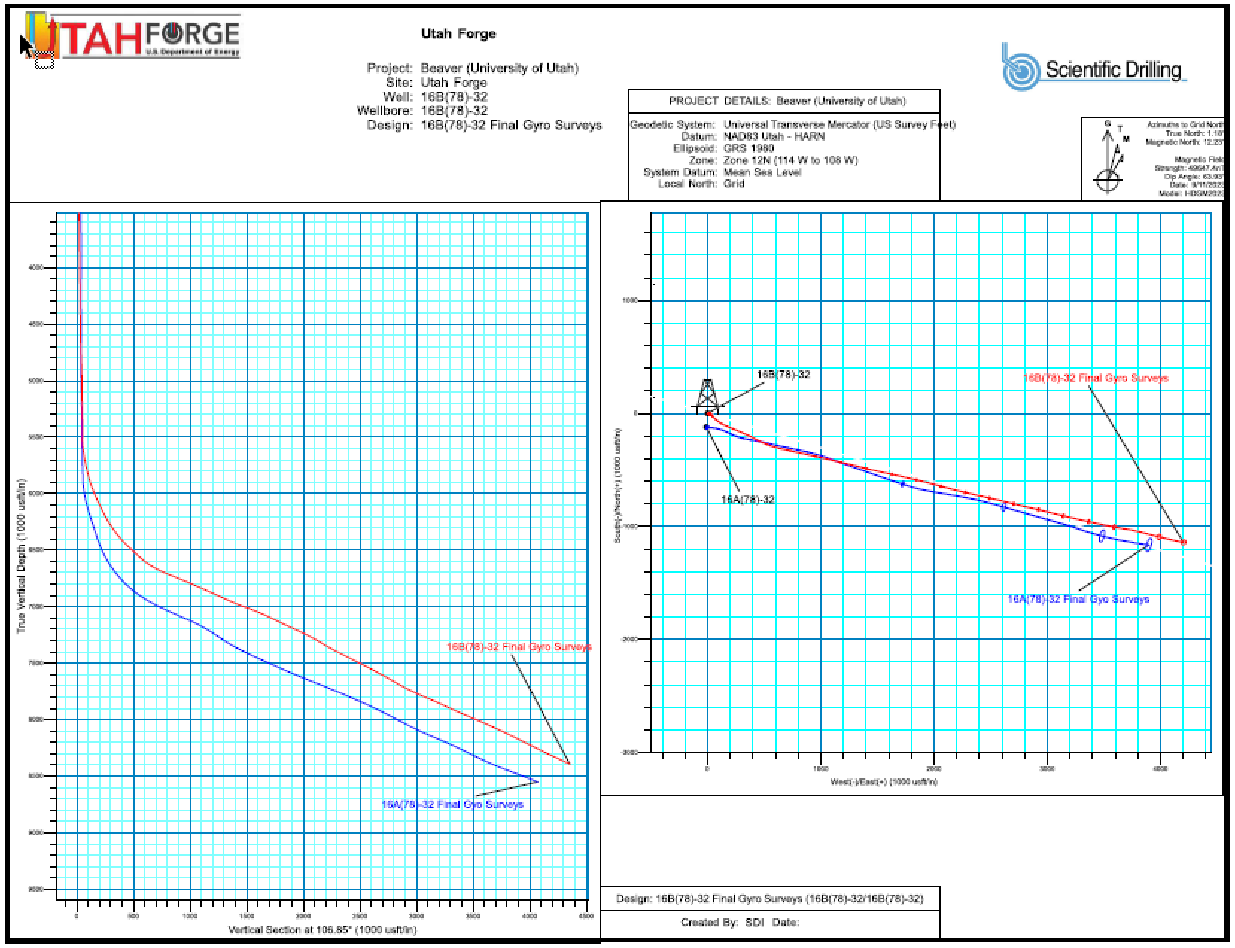


Figure A1-1. *Days versus depth.*



Utah Forge

Project: Beaver (University of Utah)
Site: Utah Forge
Well: 16B(78)-32
Wellbore: 16B(78)-32
Design: 16B(78)-32 Final Gyro Surveys

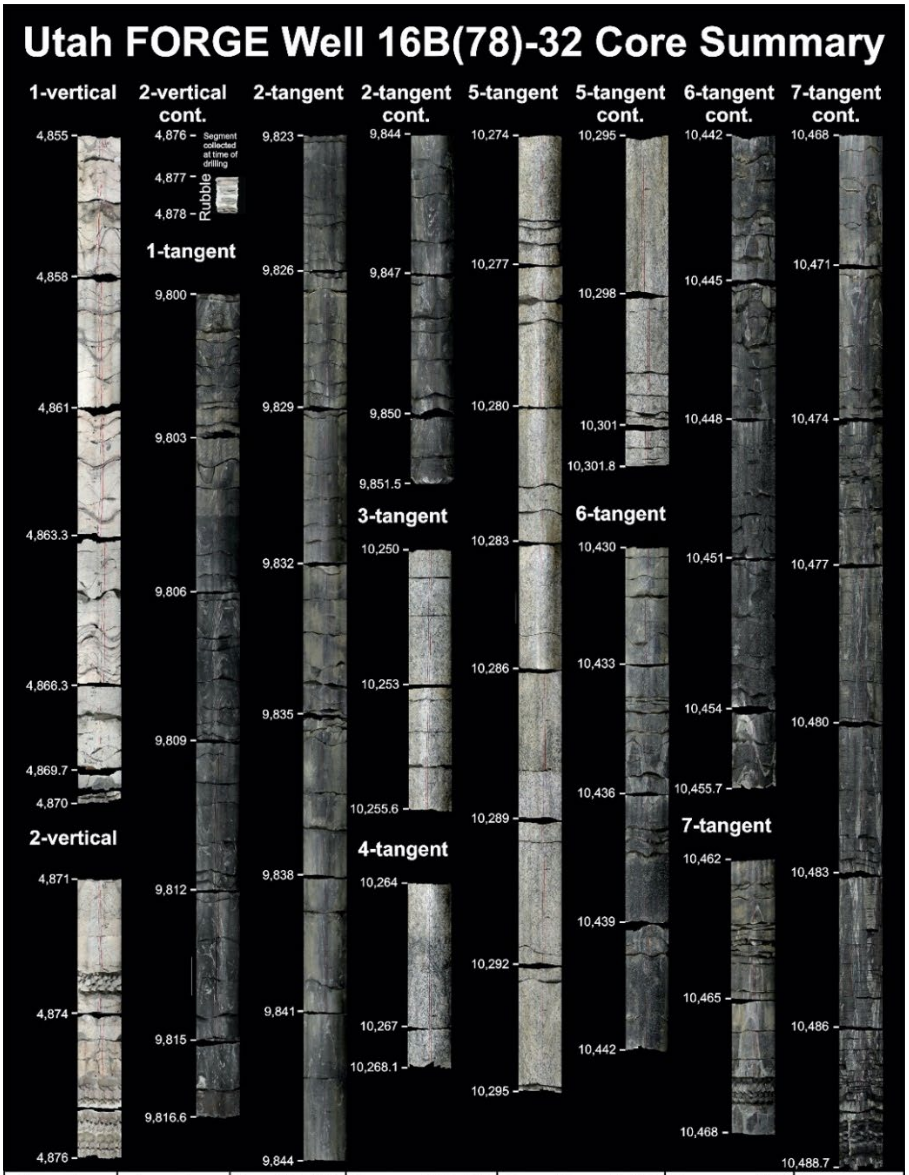
PROJECT DETAILS: Beaver (University of Utah)

Geodetic System: Universal Transverse Mercator (US Survey Feet)
Datum: NAD83 Utah - HARN
Ellipsoid: GRS 1980
Zone: Zone 12N (114 W to 108 W)
System Datum: Mean Sea Level
Local North: Grid

Design: 16B(78)-32 Final Gyro Surveys (16B(78)-32/16B(78)-32)

Created By: SDI Date:

Figure A1-2. *As built well trajectories of 16A(78)-32 (blue) and 16B(78)-32 (red).*



Core Run	Location	Top MD (ft)	Bottom MD (ft)	Cored Length (ft)	Recovery (ft)	Recovery %
1 - vertical	Shallow	4,855.0	4,871.0	16	14.6	91%
2 - vertical	Shallow	4,871.0	4,878.0	7	6.0	86%
1 - tangent	Stim 3	9,800.0	9,817.0	17	16.6	98%
2 - tangent	Stim 3	9,823.0	9,853.0	30	28.4	95%
3 - tangent	Stim 2	10,250.0	10,256.0	6	5.5	92%
4 - tangent	Stim 2	10,264.0	10,272.0	8	4.6	58%
5 - tangent	Stim 2	10,274.0	10,304.0	30	28.0	93%
6 - tangent	Stim 1	10,430.0	10,460.0	30	25.7	86%
7 - tangent	Stim 1	10,462.0	10,493.0	31	27.0	87%
			Totals	**175.0**	**156.4**	**89%**

Figure A1-3. *Stitched images showing the exterior of core recovered from Well 16B(78)-32 and a summary of coring activities.*

WELL 58B-32

Well 58B-32 was completed to access the shallow aquifer at the Utah FORGE site to support drilling, stimulation, and circulation activities. Utah FORGE has a Fixed Time Water Right of 49.55 acre feet/year. Well 58B-32 was drilled to 1200 ft, completed from ~700 to 910 ft, and produces up to 260 gpm. Drilling and testing were performed by the USGS.

The following activities were completed in conjunction with the drilling of Well 58B-32

- Power has been routed from the meter base at the NE corner of the 58-32 drill pad to where the mud cleaning system for the USGS's drill rig will be located. The mud cleaning system will be powered by the grid rather than a diesel generator. Upon completion of well 58B-32 power was trenched to the wellhead to power the downhole pump.
- Re-located casing and surplus materials on 58-32 to prepare for water well construction.
- The sump on the 58-32 drill pad was cleaned out prior to drilling to store produced cuttings.

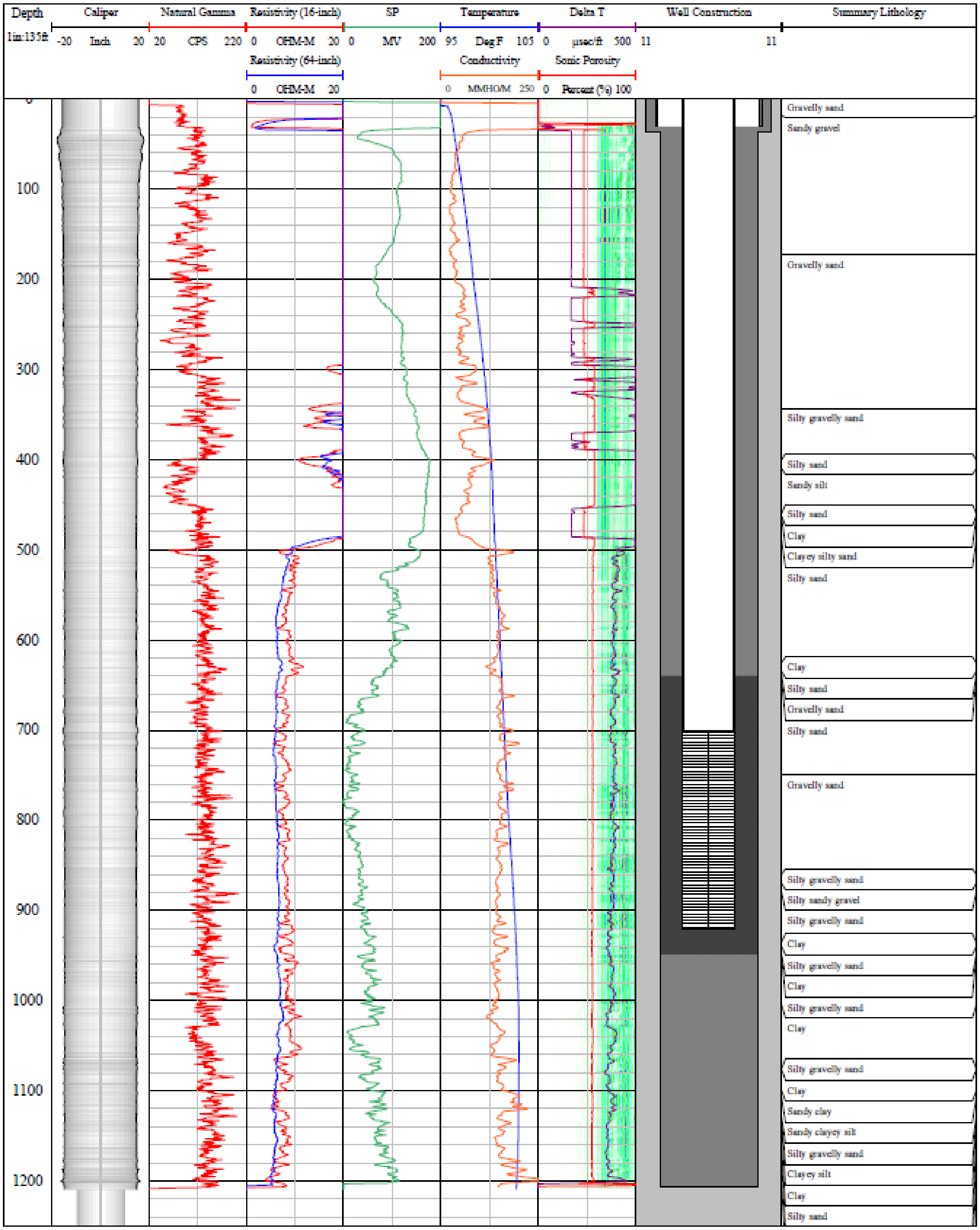


Figure A1-4. *Completion diagram and logs for Well 58B-32.*

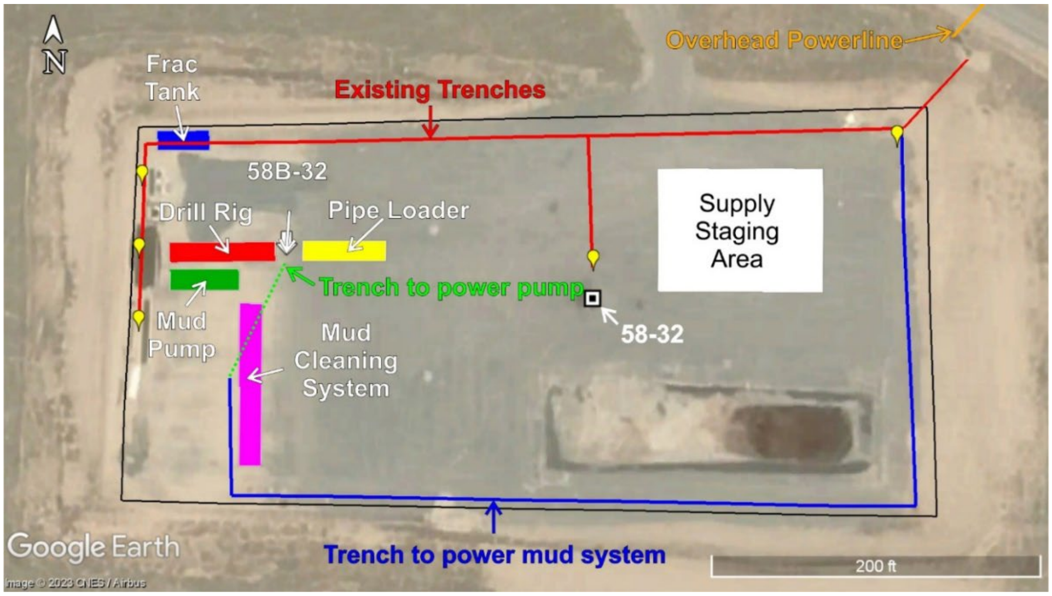


Figure A1-5. *Map of the 58-32/58B-32 drill pad showing existing (orange and red), and new (blue & green) electric infrastructure and the layout for the USGS's water well drilling operations.*

WATER STORAGE

In anticipation of the April 2024 stimulation activities, and future circulation testing, the following infrastructure developments occurred:

- Two lined lakes were constructed that have capacities of 75,000 and 125,000 bbl. To construct the lakes the total volume of cut was 25,735 yd^3 and the total fill was 19,540 yd^3 (Fig A1-6).
- An 8 ft fence was erected around the perimeter of the two lined lakes to keep out cattle and wildlife.
- The southern edge of the 16A/B(78)-32 drill pad was expanded and a road was constructed between the drill pad and the lined lakes.
- Four large harpoon tanks were erected for water storage on the 58-32 and 16A/B(78)-32 drill pads.
- A 6” water line was installed to transfer water from well 58B-32 to the lined lakes and harpoon tanks.
- In addition, the sump on the 16A/B(78)-32 drill pad was cleaned out prior to the April 2024 stimulation activities.

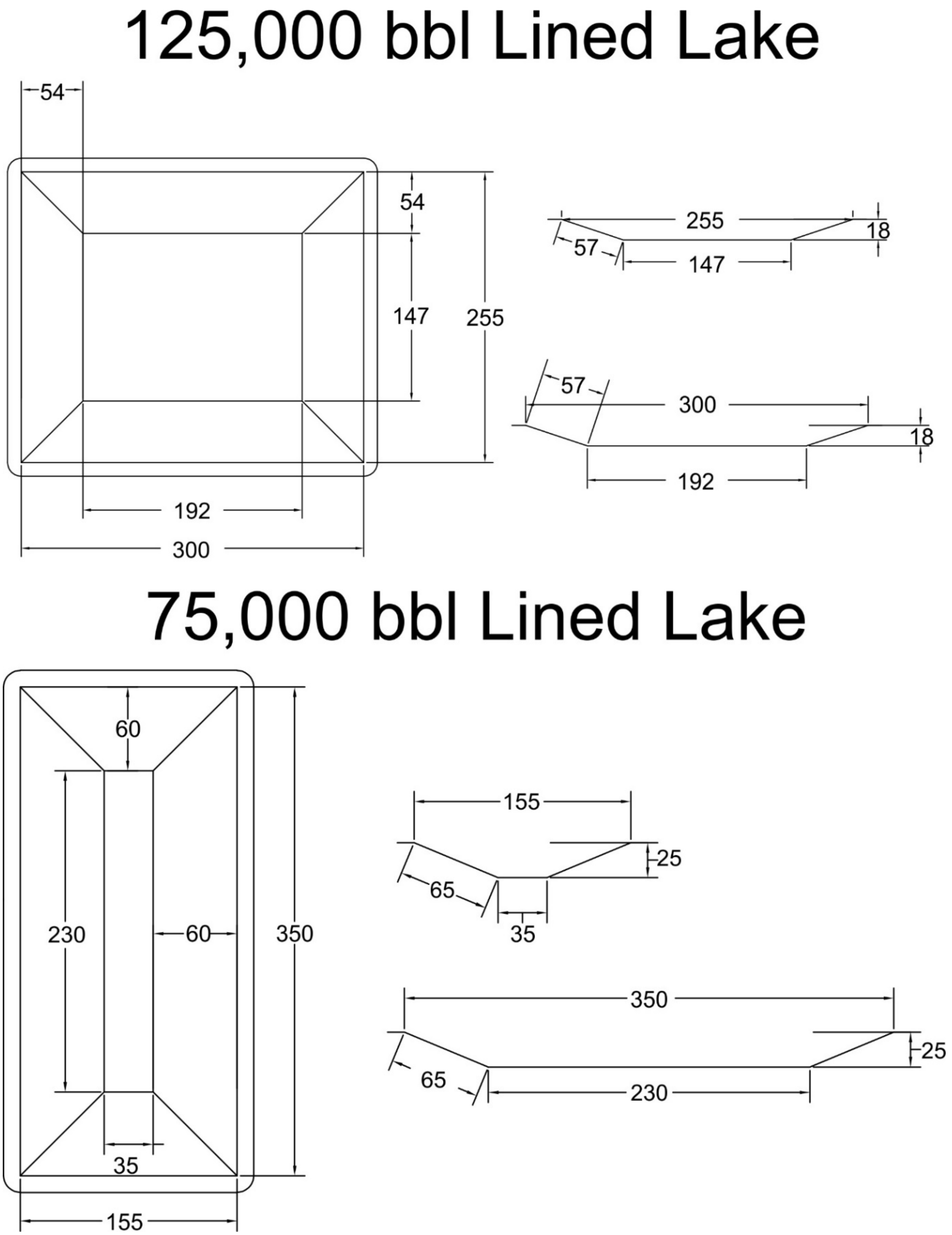


Figure A1-6. *Dimensions of the lined lakes in plan view and cross-section.*

SEISMIC MONITORING NETWORK

Real time monitoring of low magnitude induced and natural seismicity is an essential component of the Utah FORGE program. Microseismic data are necessary for monitoring the creation and evolution of the reservoir's fracture network and for hazard mitigation. To enable real time data acquisition fiber optic cables have been trenched between the 16A/B(78)-32, 58-32, 78-32, 78B-32 and 56-32 well pads (Figure A1-7). Figure A1-8 illustrates the permanent microseismic monitoring network at the Utah FORGE site. The network is monitored continuously. During stimulation activities and circulation testing, temporary multilevel geophone strings can be installed in deep, vertical wells 58-32, 56-32 and 78B-32.

Figure A1-7. *Trenches by fiber optic cable run. Approximate lengths in legend.*

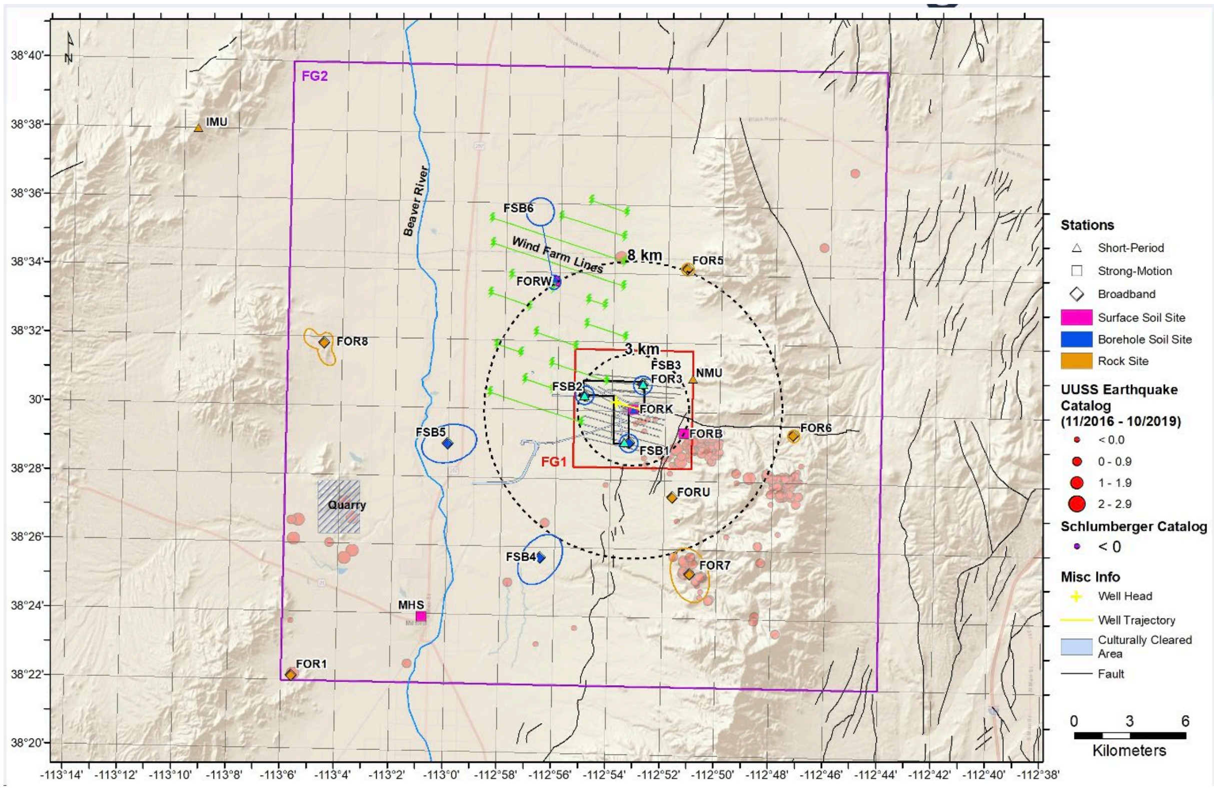


Figure A1-8. *Permanent seismic network at Utah FORGE. Symbols: triangle = short period instrument; square = strong motion sensor; diamond = broadband instrument. Locations of proposed shallow boreholes are shown in blue and rock stations in gold.*

ELECTRICAL REQUIREMENTS

Electric power is available at all of the pads (Fig. A1-9). 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. Trailers, including the Command Center trailer, fiber optic data acquisition trailers on the 16A/B(78)-32 drill pad: as well as temporary office/living quarters on the 16A/B(78)32 and 78B-32 drill pads.

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 58B-32 and a transfer pump. This power drop was also utilized during the drilling of Well 58B-32 to power the rigs mud system.

d. Power has been run to SOVs 2 and 3 adjacent to the 16A/B(78)-32 and 56-32 drill pads to support Rice University's R&D efforts, negating the need for generators. (Fig A1-10).
e. Microseismic monitoring
f. R&D activities occurring on the pads
g. 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.

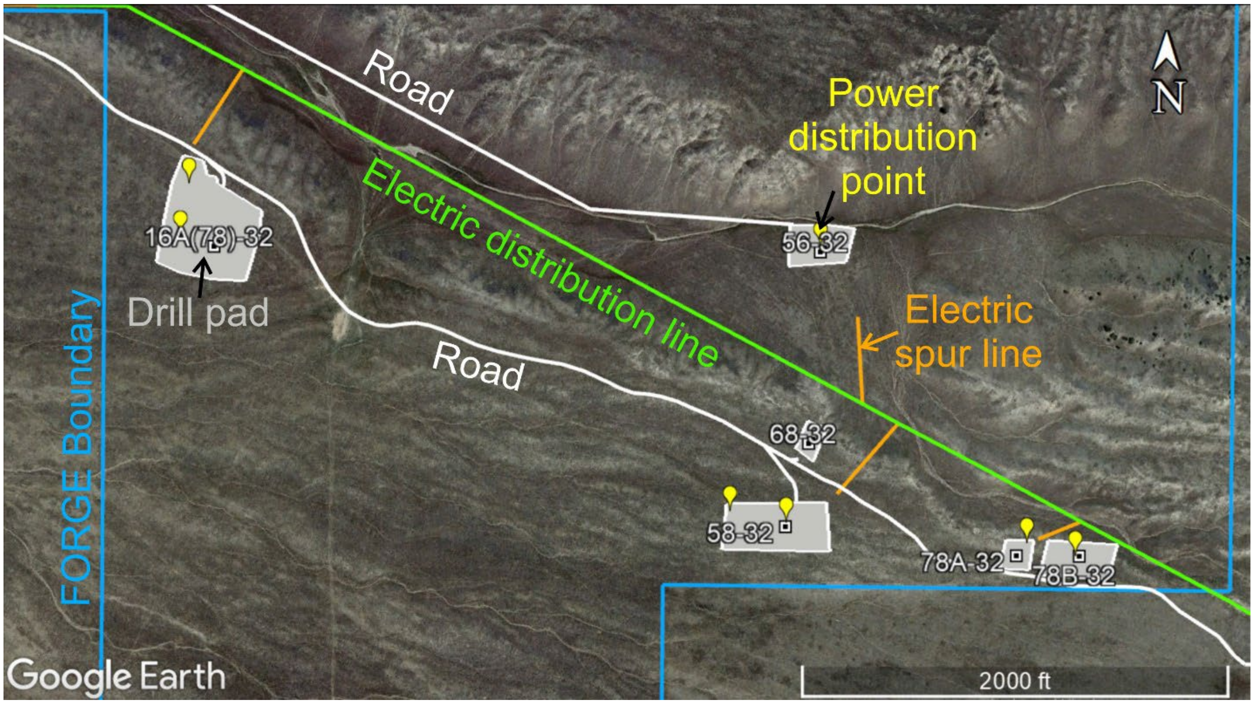


Figure A1-9. *Electric infrastructure map for Utah FORGE. The main, overhead electric distribution line in shown in green. Electric spur lines to various points within the Utah FORGE footprint (blue) are shown in orange. Power distribution points on the drill pads (gray) are shown in yellow.*

Figure A1-10. *Map showing the locations of SOVs 2 and 3 adjacent to the 16A/B(78)-32 and 56-32 drill pads, which have been connected to grid power.*

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). To increase data throughput within the site fiber optic cables have been installed to facilitate the high data throughput required for real time seismic data acquisition (Fig A1-7). In addition, nine cameras have been installed across the various drill pads at the FORGE site to enable remote monitoring and documentation of visitation.

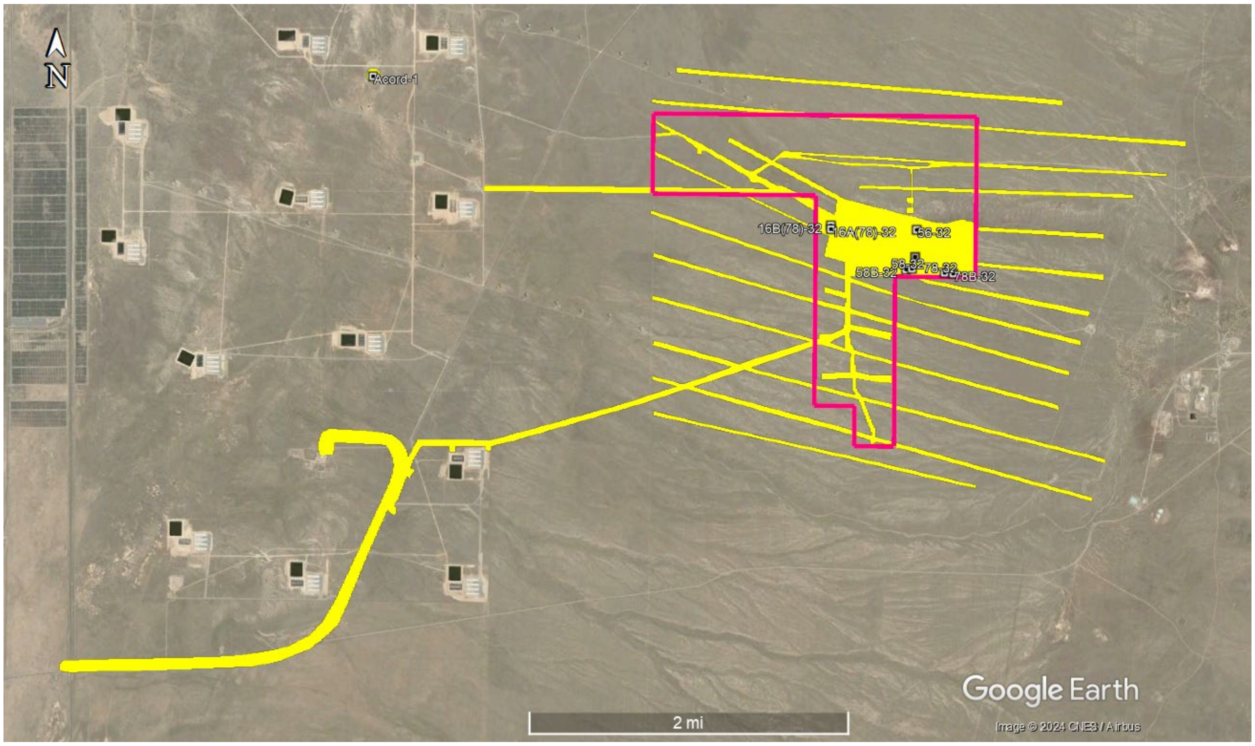
ROAD MAINTENANCE AND CONSTRUCTION

All of the well pads drill pads are accessible by roads. During Phase 3B, Utah FORGE continued to provide routine maintenance of the roads and pads. A new road was built to access the lined lakes constructed for stimulation and circulation activities. The majority of the work will consist of road grading and snow clearing.

CULTURAL AND BIOLOGICAL SURVEYS

The existing culturally cleared (Fig A1-11) areas provide flexibility for the operational and R&D activities that were 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.

A biological survey was conducted by SWCA environmental consultants prior to the construction of the lined lakes for burrowing owl and kit fox (Fig A1-12). No nests, burrows, or signs of current or past activity were observed. The lined lakes were built on land that had previously been surveyed for cultural significance.



FigureA1-11. *Areas that have been culturally cleared are shown in yellow.*

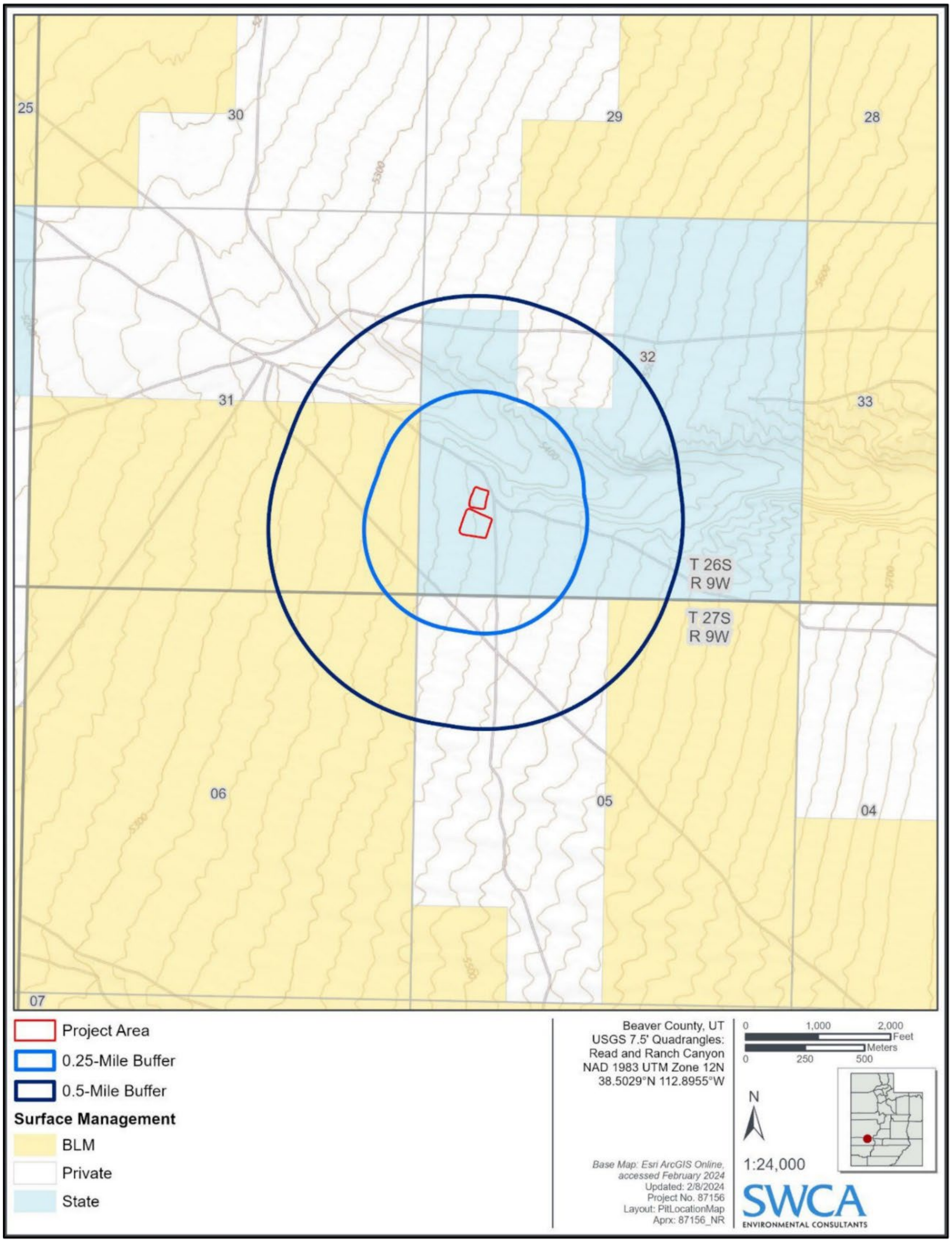


Figure A1-12. *Map showing the areas surveyed, centered on the lined lakes (red), by SWCA for burrowing owl and kit fox prior to construction.*

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.

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.

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).

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

Utah FORGE
University of Utah
423 Wakara Way, ste 300
Salt Lake City, UT, 84105

Prepared for the U.S. Department of Energy

Office of Energy Efficiency and Renewable Energy

Contract DE-EE0007080

June 1, 2024

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 April 30, 2024 has been uploaded to the Geothermal Data Repository and the Utah FORGE wiki site and are available for downloading. Additionally, a new wiki page was added to the wiki site for well 16B(78)-32.
The 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)
1 file

(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)
1 file

(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 Imager(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)
3 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 shallow seismic 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)

2 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)
3 files

(95) 2020 Synthetic Aperture Radar data from the TerraSAR-X and the TanDEM-X satellite missions operated by the German Space Agency (DLR) were used under the terms and conditions of Research Project RES1236. Interferometric pairs (interferograms) were created using GMT-SAR processing software [Sandwell et al., 2011] (added 4/11/2023).
GDR: Utah FORGE InSAR Data from 2020 (openei.org)
8 files

(96) 2021 Synthetic Aperture Radar data from the TerraSAR-X and the TanDEM-X satellite missions operated by the German Space Agency (DLR) were used under the terms and conditions of Research Project RES1236. Interferometric pairs (interferograms) were created using GMT-SAR processing software [Sandwell et al., 2011] (added 4/11/2023).
GDR: Utah FORGE InSAR Data from 2021 (openei.org)
8 files

(97) 2022 Synthetic Aperture Radar data from the TerraSAR-X and the TanDEM-X satellite missions operated by the German Space Agency (DLR) were used under the terms and conditions of Research Project RES1236. Interferometric pairs (interferograms) were created using GMT-SAR processing software [Sandwell et al., 2011] (added 4/11/2023).
GDR: Utah FORGE InSAR Data from 2022 (openei.org)

4 files

(98) USGS R&D: Evolution of Permeability and Strength Recovery of Shear Fractures Under Hydrothermal Conditions (added 4/13/2023).
GDR: Laboratory experiments examining the effect of thermal and mechanical processes on hydraulic transmissivity evolution (openei.org)
1 link

(99) This is a link to the Utah FORGE seismic data distribution site hosted by the University of Utah Seismograph Stations. The data was collected from downhole geophone strings in wells 56-32, 58-32 and 78B-32 during the 2022 stimulation of well 16A(78)-32. This dataset, which was updated in April 2023, now contains SGY formatted data (added 4/19/2023).
GDR: Utah FORGE: 2022 Well Stimulation Seismicity Data Including SGY Data -- Updated 4/2023. (openei.org)
1 link

(100) LBNL R&D: Final report on "Development of a Reservoir Seismic Velocity Model and Seismic Resolution Study" (added 4/20/2023).
GDR: Utah FORGE LBNL 3-2535 Final Report on Development of a Reservoir Seismic Velocity Model and Seismic Resolution Study (openei.org)
1 file

(101) LBNL R&D: Reservoir seismic P- and S- wave velocity model (added 4/20/2023).
GDR: Utah FORGE LBNL 3-2535 3D Reservoir Seismic P- and S-wave Velocity Model (openei.org)
1 file

(102) FORGE telluric monitoring experiment transfer functions (added 6/6/2023).
GDR: Utah FORGE Telluric Monitoring Experiment Transfer Functions (openei.org)

265 files

(103) A report from the University of Utah Seismograph Stations titled Orientation of Borehole and Surface Seismic Stations (added 6/22/2023).
GDR: Utah FORGE: Orientation of Borehole and Surface Seismic Stations (openei.org)
1 file

(104) Welltec R&D: Compute stress distribution on the wellbore wall (or casing) and the packer stress and deformation caused by applying high pressure in the interior of the packer (added 6/22/2023).
https://gdr.openei.org/submissions/1507

1 file

(105) Welltec R&D: Set-up of the large-scale testing being built in Oklahoma University for geothermal projects (added 6/22/2023).
https://gdr.openei.org/submissions/1505
1 file

(106) Welltec R&D: Report on the pipe preparation that will be used on the geothermal project testing in OU (added 6/22/2023).
https://gdr.openei.org/submissions/1506
1 file

(107) Welltec R&D: Thermoplastic and elastomeric materials testing at high temperatures. Dimension and hardness testing has been performed in samples subjected to 8 temperature cycles of 2 weeks duration up to 650 Degrees F (added 6/22/2023).
https://gdr.openei.org/submissions/1504
1 file

(108) Battelle R&D: Report titled “Training Machine Learning Algorithms to Laboratory Triaxial Ultrasonic Velocity Data for Utah FORGE Well 16A(78)-32” (added 7/12/2023).
GDR: Training Machine Learning Algorithms to Laboratory Triaxial Ultrasonic Velocity Data for Utah FORGE Well 16A(78)-32 (openei.org)
1 file

(109) Penn State University R&D: data on shear reactivation experiments on laboratory faults pre-loaded close to failure and reactivated by the injection of fluid into the fault. The sample comprises a single-inclined-fracture (SIF) transecting a cylindrical sample of Westerly granite (added 7/17/2023).
GDR: Utah FORGE Fluid Injection Induced Seismicity Laboratory Experiments (openei.org)
27 files

(110) Lawrence Livermore National Laboratory R&D: Powder X-ray diffraction data from well 16A(78)-32 core (added 7/29/2023).
GDR: Utah FORGE: Powder X-ray Diffraction Data from Well 16A(78)-32 Core (openei.org)
6 files

(111) Utah FORGE induced Seismicity Mitigation Plan (2023) (added 8/9/2023).
GDR: Utah FORGE: 2023 Induced Seismicity Mitigation Plan (openei.org)

1 file

(112) Utah FORGE Phase 3B Annual Report (2023) (added 8/9/2023)
GDR: Utah FORGE: 2023 Phase 3B Year 1 Annual Report (openei.org)
1 file

(113) Penn State R&D: Slide-hold-slide experiments on Utah FORGE Gneiss at increased temperature data (added 8/8/2023).
GDR: Slide-hold-slide experiments on UtahFORGE Gneiss at increased temperature (openei.org)
22 files

(114) Los Alamos National Laboratory (LLNL sub) R&D: Triaxial Direct Shear Results (added 8/18/2023).
GDR: Utah FORGE: Triaxial Direct Shear Results (openei.org)
75 files

(115) InSAR data best 112 pairs (added 8/28/2023).
GDR: Utah FORGE InSAR Data Best 112 Pairs (openei.org)
11 files

(116) Well 16B(78)-32 drilling data (added 9/6/2023).
GDR: Utah FORGE: Well 16B(78)-32 Drilling Data (openei.org)
901 files

(117) Reports on northwestern Nevada well doublet drilling and testing by Fervo Energy (added 9/6/2023).
GDR: Utah FORGE: Reports on Northwestern Nevada Well Doublet Drilling and Testing by Fervo Energy. (openei.org)
2 files

(118) Well 16B(78)-32 Schlumberger logs (added 9/14/2023).
GDR: Utah FORGE: Well 16B(78)-32 Logs from Schlumberger Technologies (openei.org)
196 files

(119) PetroQuip Energy Services R&D: Zonal Isolation Solution for Geothermal Wells – Annual Workshop Presentation (added 9/15/2023).
GDR: Utah FORGE 1-2409: Zonal Isolation Solution for Geothermal Wells - Workshop Presentation (openei.org)

1 file

(120) Fervo Energy R&D: Optimization and Validation of a Plug-and-Perf Stimulation Treatment Design – Annual Workshop Presentation (added 9/15/2023).
GDR: Utah FORGE 4-2541: Optimization and Validation of a Plug-and-Perf Stimulation Treatment Design - Workshop Presentation (openei.org).
1 file

(121) Pennsylvania State University R&D: Seismicity-Permeability Relationships Probed via Nonlinear Acoustic Imaging – Annual Workshop Presentation (added 9/15/2023).
GDR: Utah FORGE 5-2419: Seismicity-Permeability Relationships Probed via Nonlinear Acoustic Imaging - Workshop Presentation (openei.org)
1 file

(122) LLNL R&D: Fracture Permeability Impact on Reservoir Stress and Seismic Slip Behavior – Annual Workshop Presentation (added 9/15/2023).
GDR: Utah FORGE 5-2428: Fracture Permeability Impact on Reservoir Stress and Seismic Slip Behavior - Workshop Presentation (openei.org)
1 file

(123) Perdue R&D: Fluid and Temperature in Fracture Mechanics and Coupled THMC Processes - Annual Workshop Presentation (added 9/15/2023).
GDR: Utah FORGE 5-2557: Fluid and Temperature in Fracture Mechanics and Coupled THMC Processes - Workshop Presentation (openei.org)
1 file

(124) USGS R&D: Hydrothermal Evolution of Fracture Properties – Annual Workshop Presentation (added 9/15/2023).
GDR: Utah FORGE 5-2565: Hydrothermal Evolution of Fracture Properties - Workshop Presentation (openei.org)
1 file

(125) University of Oklahoma R&D: Thermo-poromechanical Response of Fractured Rock – Annual Workshop Presentation (added 9/15/2023).
GDR: Utah FORGE 5-2615: Thermo-poromechanical Response of Fractured Rock - Workshop Presentation (openei.org)
1 file

(126) Joint EM-Seismic-InSAR Imaging of Fracture Properties – Annual Workshop Presentation (added 9/15/2023).
GDR: Utah FORGE 3-2535: Joint EM-Seismic-InSAR Imaging of Fracture Properties - Workshop Presentation (openei.org)
1 file

(127) Clemson University R&D: A Strain Sensing Array to Characterize Deformation at the FORGE Site – Annual Workshop Presentation (added 9/15/2023).
GDR: Utah FORGE 3-2514: A Strain Sensing Array to Characterize Deformation at the FORGE Site - Workshop Presentation (openei.org)
1 file

(128) Stanford University R&D: Wellbore Fracture Imaging Using Inflow Detection Measurements - Annual Workshop Presentation (added 9/15/2023).
GDR: Utah FORGE 3-2418: Wellbore Fracture Imaging Using Inflow Detection Measurements - Workshop Presentation (openei.org)
1 file

(129) Rice University R&D: Fiber-Optic Geophysical Monitoring of Reservoir Evolution – Annual Workshop Presentation (added 9/15/2023).
GDR: Utah FORGE 3-2417: Fiber-Optic Geophysical Monitoring of Reservoir Evolution - Workshop Presentation (openei.org)
1 file

(130) LLNL R&D: Closing the Loop Between In-situ Stress Complexity and EGS Fracture Complexity – Annual Workshop Presentation (added 9/15/2023).
GDR: Utah FORGE 2-2446: Closing the Loop Between In-situ Stress Complexity and EGS Fracture Complexity - Workshop Presentation (openei.org)
1 file

(131) Battelle Memorial Institute R&D: A Multi-Component Approach to Characterizing In-Situ Stress: Laboratory, Modeling and Field Measurement - Annual Workshop Presentation (added 9/15/2023).
GDR: Utah FORGE 2-2439: A Multi-Component Approach to Characterizing In-Situ Stress: Laboratory, Modeling and Field Measurement - Workshop Presentation (openei.org)
1 file

(132) University of Oklahoma R&D: Application of Advanced Techniques for Determination of Reservoir-Scale Stress State at Utah FORGE – Annual Workshop Presentation (added 9/15/2023).
GDR: Utah FORGE 2-2404: Application of Advanced Techniques for Determination of Reservoir-Scale Stress State at Utah FORGE - Workshop Presentation (openei.org)
1 file

(133) Colorado School of Mines R&D: Multi-Stage Fracturing System and Well Tractor to Enable Zonal Isolation During Stimulation and EGS Operations in Horizontal Wellbores – Annual Workshop Presentation (added 9/15/2023).
GDR: Utah FORGE 1-2551: Multi-Stage Fracturing System and Well Tractor to Enable Zonal Isolation During Stimulation and EGS Operations in Horizontal Wellbores - Workshop Presentation (openei.org)
3 file

(134) WellTec Inc. R&D: Development of a Smart Completion and Stimulation Solution – Annual Workshop Presentation (added 9/15/2023).
GDR: Utah FORGE 1-2410: Development of a Smart Completion and Stimulation Solution - Workshop Presentation (openei.org)
1 file

(135) University of Texas at Austin R&D: Design and Implementation of Innovative Stimulation Treatments to Maximize Energy Recovery - Annual Workshop Presentation (added 9/15/2023).
GDR: Utah FORGE 4-2492: Design and Implementation of Innovative Stimulation Treatments to Maximize Energy Recovery - Workshop Presentation (openei.org)
1 file

(136) 2023 large upscaled discrete fracture network models (added 10/4/2023).
GDR: Utah FORGE: 2023 Large Upscaled Discrete Fracture Network Models (openei.org)
78 files

(137) Hydraulic Fracture Width Determination Using Stoneley Wave Pressure Testing and Electrical Borehole Scans (added 10/13/2023).
GDR: Utah FORGE: Hydraulic Fracture Width Determination Using Stoneley Wave Pressure Testing and Electrical Borehole Scans (openei.org)
1 file

(138) Microseismic Event Catalogues from the Well 16A(78)-32 Stimulation in April, 2022 (added 10/13/2023).

GDR: Utah FORGE: Microseismic Event Catalogues from the Well 16A(78)-32 Stimulation in April, 2022 (openei.org)
2 links

(139) Well 16A(78)-32 Core Analysis Results (added 10/20/2023).
GDR: Utah FORGE: Well 16A(78)-32 Core Analysis Results (openei.org)
52 files

(140) Neubrex Well 16B(78)-32 Fiber Optics Monitoring Reports (added 10/22/2023).
GDR: Utah FORGE: Neubrex Well 16B(78)-32 Fiber Optics Monitoring Reports (openei.org)
2 files

(141) Sanvean Technologies Drilling Data from Well 16B(78)-32 (added 10/26/2023).
GDR: Utah FORGE: Sanvean Technologies Drilling Data from Well 16B(78)-32. (openei.org)
29 files

(142) Neubrex Energy Services Well 16B(78)-32 Circulation Test Period with Fiber Optics Monitoring (added 11/20/2023).
GDR: Utah FORGE: Well 16B(78)-32 2023 Neubrex Energy Services Circulation Test Period with Fiber Optics Monitoring. (openei.org)
14 files

(143) Well 16B(78)-32 Core Photos (added 11/21/2023).
GDR: Utah FORGE: Well 16B(78)-32 Core Photos (openei.org)
60 files

(144) U.S. Geological Survey R&D: Report and data for Slide-Hold-Slide experiments on westerly granite at temperatures up to 250 degrees C (added 12/26/2023).
GDR: Utah FORGE: Slide-Hold-Slide Experiments on Westerly Granite at Temperatures up to 250 Degrees C (openei.org)
9 files

(145) Sanvean Technologies 16B(78)-32 bit data analysis report (added 1/2/2024).
GDR: Utah FORGE: Sanvean Technologies Drilling Data from Well 16B(78)-32 (openei.org)
1 file

(146) Batelle R&D: Well 16B(78)-32 Field-Test Data from Mini-Frac Tests (added 1/5/2024).
GDR: Utah FORGE Project 2439: Well 16B(78)-32 Field-Test Data from Mini-Frac Tests (openei.org)
59 files

(147) Well 16A(78)-32/Well16B(78)-32 Circulation Test Data (added 1/24/2024).
GDR: Utah FORGE: Well 16A(78)-32/Well16B(78)-32 Circulation Test Data (openei.org)
18 files

(148) Southwestern Utah reprocessed Magnetotelluric (MT) data (added 1/25/2024).
GDR | Submission Status for Utah FORGE: Southwestern Utah Magnetotelluric (MT) Data (openei.org)
2404 files

(149) Microseismic Surface Network Catalogs for Wells 16A(78)-32 and 16B(78)-32 Stimulation 2022 and Circulation 2023.
GDR: Utah FORGE: Microseismic Surface Network Catalogs for Wells 16A(78)-32 and 16B(78)-32 Stimulation 2022 and Circulation 2023 (openei.org)
2 files

(150) Composite 3D Seismic Velocity Model 2024.
GDR: Utah FORGE: Composite 3D Seismic Velocity Model (openei.org)
7 files

(151) LBNL R&D: Milestone 2.2 Status Report on the VEMP Tool 2024.
GDR: Utah FORGE LBNL 3-2535 Milestone 2.2 Report (openei.org)
1 file

(152) Stanford R&D: Thermal Earth Model for the Conterminous United States (added 3/15/2024).
GDR: Stanford Thermal Earth Model for the Conterminous United States (openei.org)
2 files and 1 link

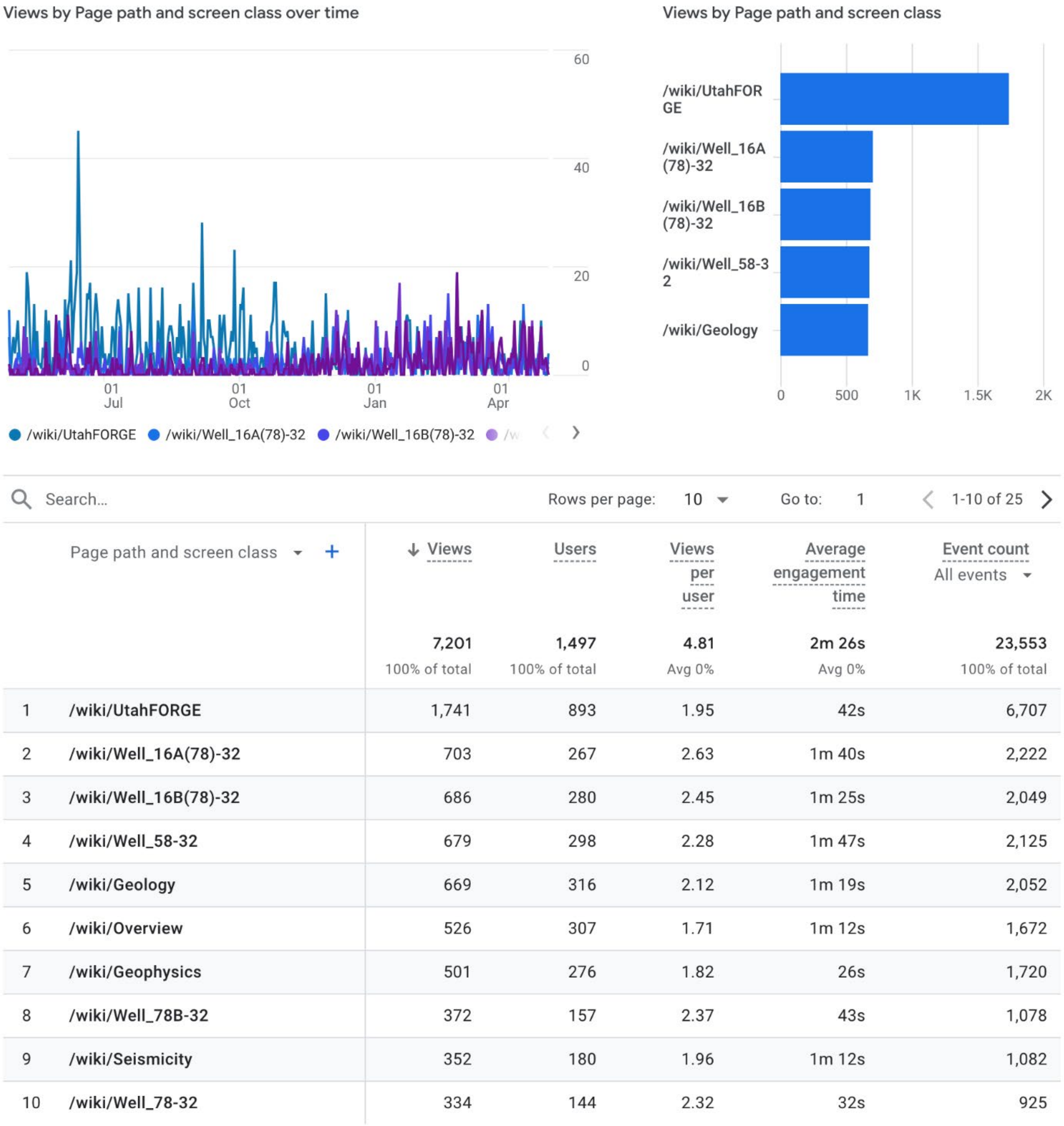
(153) University of Oklahoma R&D: Shear Enhanced Permeability in a Granitoid Fracture - Presentation Slides (added 4/2/2024).
GDR: Utah FORGE 5-2615: Shear Enhanced Permeability In a Granitoid Fracture - Presentation Slides (openei.org)
1 file

(154) Battelle Memorial Institute R&D: Report on Stress Estimation for Well 16A(78)-32 Based on Sonic Logging Data Using Machine Learning Model Trained to Laboratory Triaxial Ultrasonic Velocity Data (added 4/1/2024).
GDR: Utah FORGE Project 2439: Stress Estimation for Well 16A(78)-32 Based on Sonic Logging Data Using Machine Learning Model Trained to Laboratory Triaxial Ultrasonic Velocity Data (openei.org)
1 file

(155) Updated FMI Fracture Log from Well 16A(78)-32 (added 4/19/2024).
GDR: Utah FORGE: Updated FMI Fracture Log from Well 16A(78)-32 (openei.org)
1 file

(156) Battelle R&D: Report on Minifrac Tests for Stress Characterization (added 4/22/2024).
GDR: Utah FORGE Project 2439: Report on Minifrac Tests for Stress Characterization (openei.org)
1file

Phase 3 work has produced a total of **133715** files and **12** external data links. Additionally, there have been numerous hits on the wiki site since its inception (Figure A2-1).



	Page path and screen class	↓ Views	Users	Views per user	Average engagement time	Event count All events
		7,201 100% of total	1,497 100% of total	4.81 Avg 0%	2m 26s Avg 0%	23,553 100% of total
1	/wiki/UtahFORGE	1,741	893	1.95	42s	6,707
2	/wiki/Well_16A(78)-32	703	267	2.63	1m 40s	2,222
3	/wiki/Well_16B(78)-32	686	280	2.45	1m 25s	2,049
4	/wiki/Well_58-32	679	298	2.28	1m 47s	2,125
5	/wiki/Geology	669	316	2.12	1m 19s	2,052
6	/wiki/Overview	526	307	1.71	1m 12s	1,672
7	/wiki/Geophysics	501	276	1.82	26s	1,720
8	/wiki/Well_78B-32	372	157	2.37	43s	1,078
9	/wiki/Seismicity	352	180	1.96	1m 12s	1,082
10	/wiki/Well_78-32	334	144	2.32	32s	925

Figure A2-1. Utah FORGE wiki site hits.

Citations

Sandwell, D., R. Mellors, X. Tong, M. Wei, and P. Wessel (2011), Open radar interferometry software for mapping surface deformation, Eos, Transactions American Geophysical Union, 92, 234-234. http://topex.ucsd.edu/gmtsar.

Appendix A3: Updated Permitting Inventory

Phase 3B Year 1 Annual Report

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

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Prepared for the U.S. Department of Energy

Office of Energy Efficiency and Renewable Energy

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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 University PI to select appropriate sites for the installation of borehole strain meters to optimize data acquisition, minimize land disturbances, and reduce construction/reclamation costs, while dealing with constraints such as land ownership, topography and infrastructure.

- A CX was issued by NETL for phase IIa strain meter borehole locations within and adjacent to the FORGE footprint, on both BLM and SITLA properties (Fig A-3-1).

- A Non-Production Well Application for the construction of two boreholes was submitted to, and approved by the Utah Division of Water Rights, triggering the issue of a start card for the driller.

- A written proposal was approved by SITLA for the construction of the strainmeter boreholes on their property.

- Confirmation was received from the local BLM office in Cedar City Utah that no biological surveys were required if the boreholes were completed between Oct and Dec.

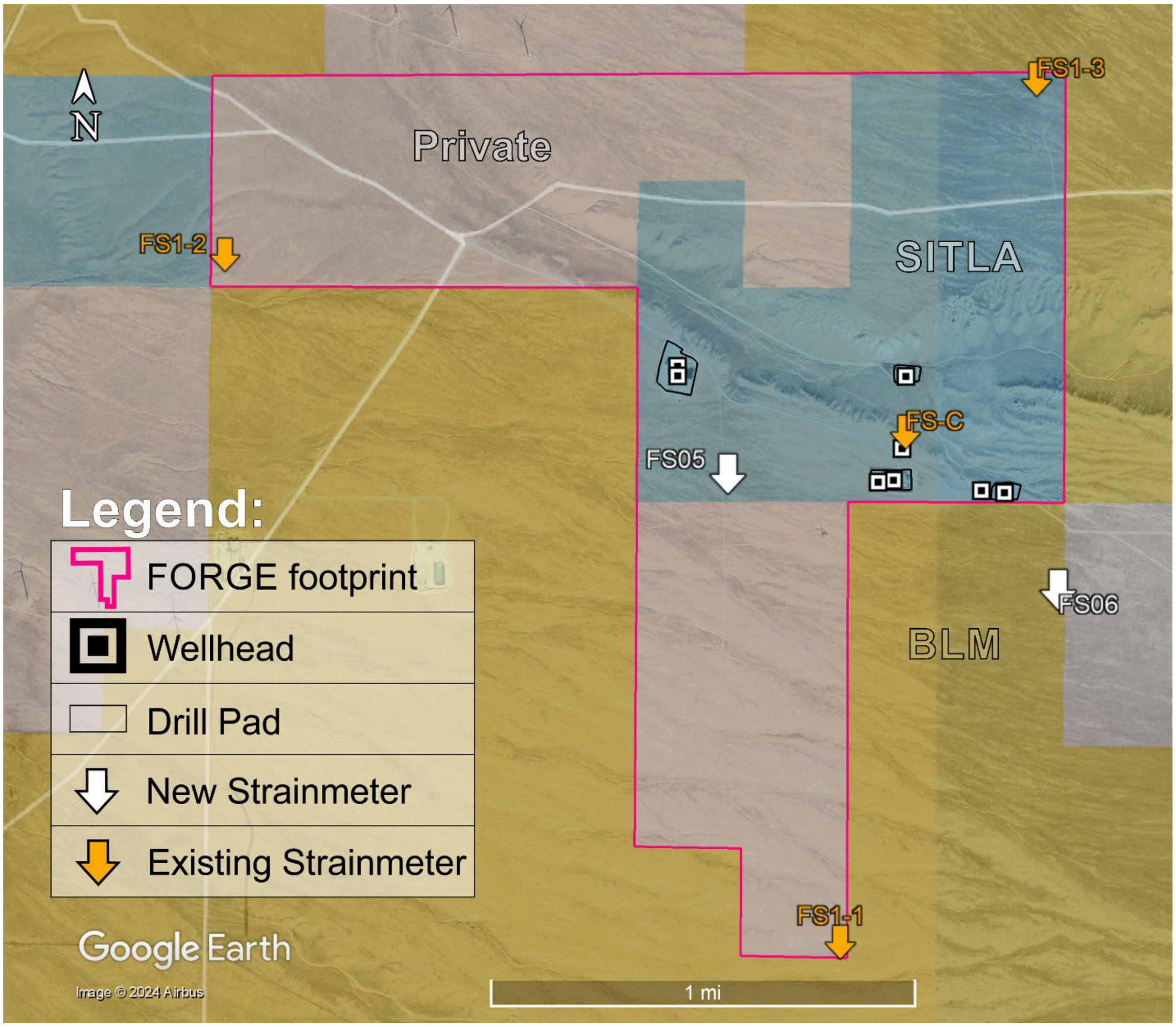


Figure A3-1. *Map showing the locations of existing and new strainmeters, as well as land ownership, the FORGE footprint, drill pads and wellheads.*

Rice – Fiber Optic Cable Installation in 16B(78)-32 & Nodal Array deployment.

- Assistance was rendered to Rice University to complete their Utah FORGE site NEPA EQ documentation that included installation of fiber in the anulus of Well 16B(78)-32 and deployment of stational orbital vibrators (SOVs). A CX was granted by NETL for these activities.

- Prior to the deployment of Nodal Arrays on BLM land, confirmation was received that these activities fall under the classification of ‘Casual Use’ and do not require cultural or biological surveys.

UT Austin – Fiber Optic Cable Installation in 16B(78)-32

- Assistance was rendered to the University of Texas at Austin to complete their Utah FORGE site NEPA EQ documentation for the installation of fiber in the anulus of Well 16B(78)-32. A CX was granted by NETL for this activity.

PHASE II R&D AWARDEES NEPA EQS

- NEPA EQs submitted during the proposal process were reviewed from the 13 awardees and their subrecipients.
- Utah FORGE has been working with the Principal Investigators to appropriately document sponsored activities at the various locations they will occur in their respective NEPA EQs.
- NEPA EQs reviewed by Utah FORGE have been passed along to NETL for final review and approval.
- As of March, 2024 CXs have been granted for 3 of the 13 awardees.
- In addition, Utah FORGE assisted Alfred W. Eustes III of the Colorado School of Mines in completing updated NEPA EQs for an upcoming go/no-go decision.

UTAH FORGE

Stimulation & Short-Term Circulation Testing

- A Conditional Use Permit application was approved by the Beaver County Planning and Zoning Commission for stimulation and circulation testing, including the construction of two lined lakes (Fig A3-2). Presentations were given to the Beaver County Planning and Zoning Commission and County Commissioners at two, separate, in person meetings. These meetings are open to the public and are critical in keeping the community informed and engaged.
- A biological survey was conducted by SWCA environmental consultants prior to the construction of the lined lakes for burrowing owl and kit fox (Fig A3-3). No nests, burrows, or signs of current or past activity were observed. The lined lakes were built on land that had previously been surveyed for cultural significance.
- A proposal to stimulate 16A(78)-32 and 16B(78)-32 was submitted to the Utah Division of Water Rights, and approved.

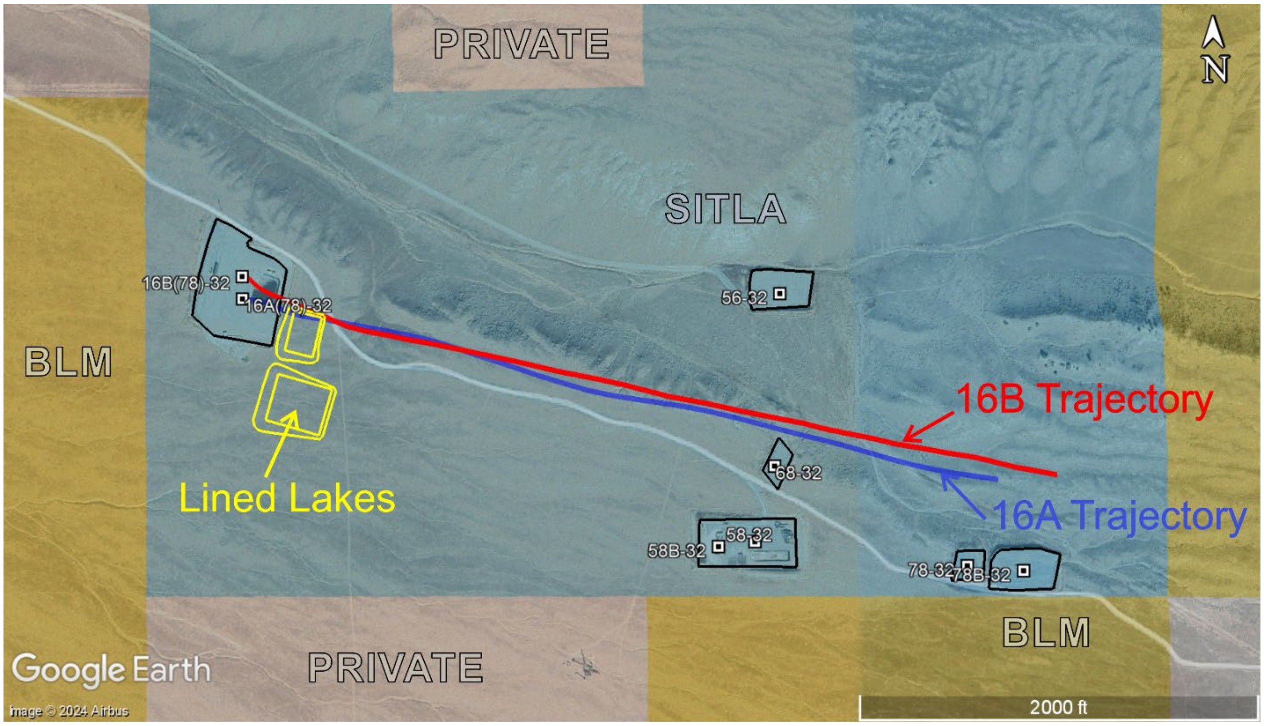


Figure A3-2. *Map showing land ownership, drill pads, well heads, the trajectories of wells 16A(78)-32 and 16B(78)-32 and the locations of he lined lakes constructed to support stimulation and circulation testing (yellow).*

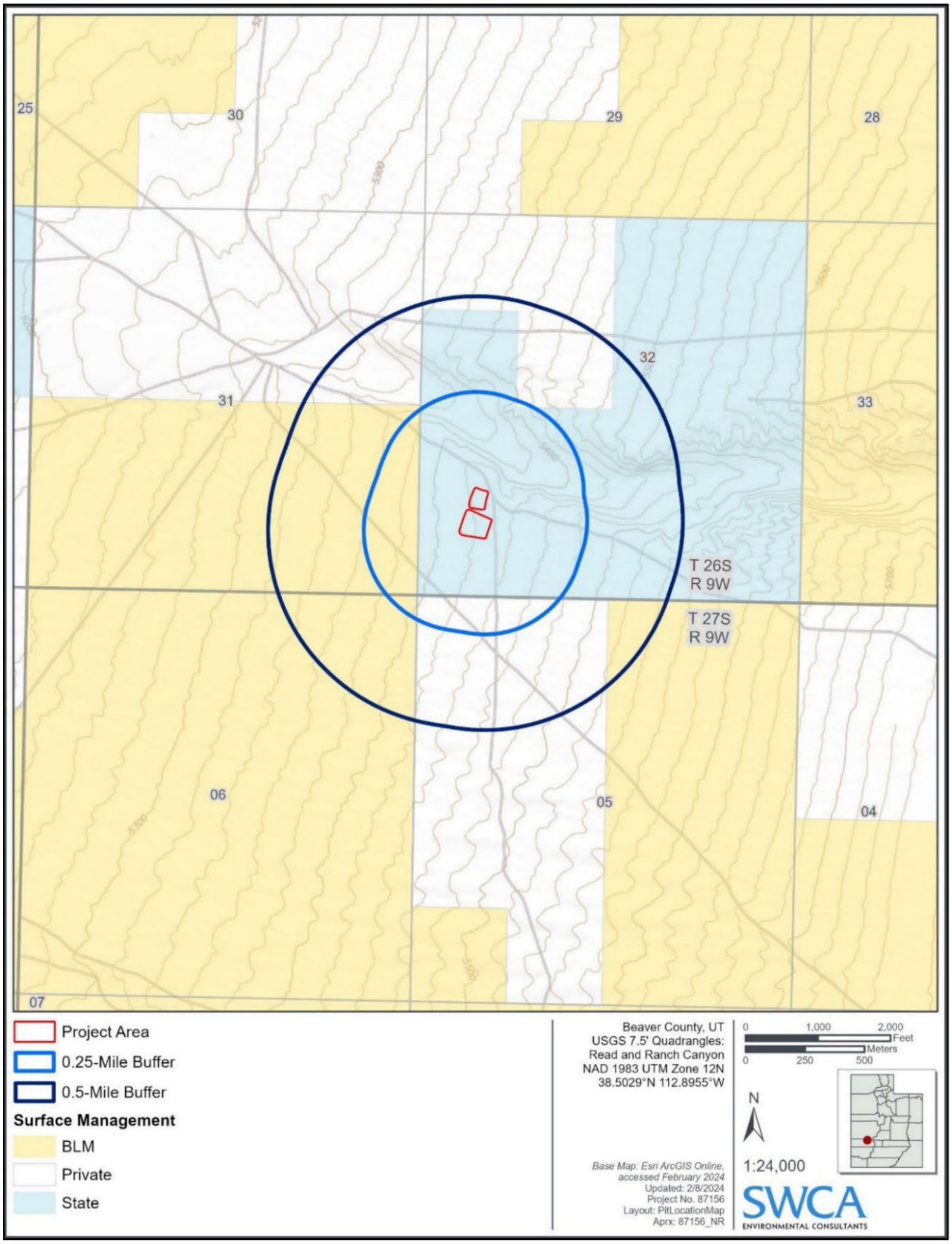
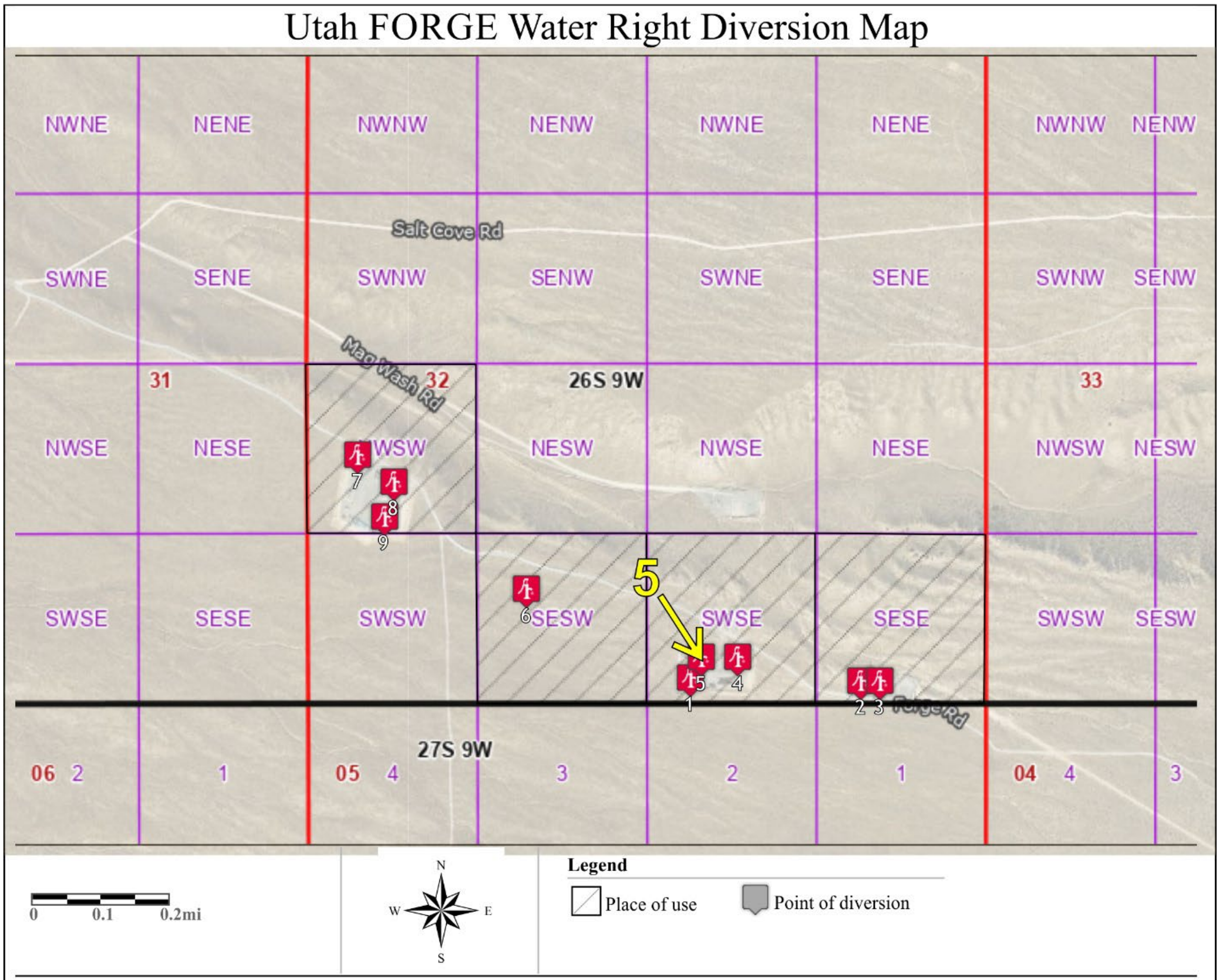


Figure A3-3. *Map showing the areas surveyed, centered on the lined lakes, by SWCA for burrowing owl and fit fox prior to construction.*

Water Rights

- A Fixed-Time Water Right Change Application has been approved by the Utah Division of Water Rights to extend the use of our existing water-right of 49.55 Acre feet annually through January of 2033.
- An Annual Water Usage Report was submitted to the Utah Division of Water Rights detailing water usage, including the two circulation tests in July 2023 conducted after drilling and completion of well 16B(78)-32.
- A Small Dam Application was submitted to the Utah Division of Water Rights for the construction of two lined lakes to support hydraulic stimulations and circulation testing.
- Through documentation of the drilling of well 16B(78)-32 was supplied to the Utah Division of Water Rights for public dissemination.



(1) N 196 ft, E 349 ft, from S4 cor, Sec 32, T 26S, R 9W, SL B&M (UTM-83: 335383.1, 4263012.2)
(2) N 197 ft, W 973 ft, from SE cor, Sec 32, T 26S, R 9W, SL B&M (UTM-83: 335786.8, 4262996.5)
(3) N 201 ft, W 824 ft, from SE cor, Sec 32, T 26S, R 9W, SL B&M (UTM-83: 335832.2, 4262997.7)
(4) N 349 ft, E 719 ft, from S4 cor, Sec 32, T 26S, R 9W, SL B&M (UTM-83: 335495.9, 4263058.8)
(5) N 352 ft, E 446 ft, from S4 cor, Sec 32, T 26S, R 9W, SL B&M (UTM-83: 335412.6, 4263059.7)
(6) N 909 ft, W 915 ft, from S4 cor, Sec 32, T 26S, R 9W, SL B&M (UTM-83: 334997.8, 4263229.5)
(7) S 721 ft, E 393 ft, from W4 cor, Sec 32, T 26S, R 9W, SL B&M (UTM-83: 334606.8, 4263556.9)
(8) S 941 ft, E 666 ft, from W4 cor, Sec 32, T 26S, R 9W, SL B&M (UTM-83: 334690, 4263489.8)
(9) S 1207 ft, E 590 ft, from W4 cor, Sec 32, T 26S, R 9W, SL B&M (UTM-83: 334666.8, 4263408.8)

Figure A3-4. *Permitted diversion points and places of use under the Utah FORGE water right. Well 58B-32 was drilled within 160 ft of diversion point 5.*

Utah Trust Lands

- A Special Use Lease Agreement (SULA) to supplement our Right of Mineral Entry (ROME) agreement was put in place to facilitate the construction the lined lakes.

- A proposal to stimulate 16A(78)-32 and 16B(78)-32 and conduct a short-term circulation test was submitted to the Utah Division of Water Rights, and approved.
- Copies of all approval letters and survey results were supplied to Utah Trust Lands that pertain to the acreage leased.

Groundwater well 58B-32.

- A Conditional Use Permit was granted by Beaver County for the construction of a groundwater well, water treatment facilities, buried pipe and tankage. In-person presentations were given to both the Beaver County Planning and Zoning Commission and the County Commissioners.
- A Request for Provisional ("Rush") Approval of the Fixed-Time Water Right Change Application was submitted to, and approved by the Utah Division of Water Rights regional Engineer, triggering the issue of a start card for the driller.