Quarterly Research Performance Progress Report

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1. INTRODUCTION

This quarterly research progress report is intended to provide a summary of the work accomplished under this project during the third quarter of the first budget period (October 1st, 2018 – December 31st, 2018). Summarized herein is a description of the project accomplishments to date, along with the planed work to be conducted in the next quarter.

2. ACCOMPLISHMENTS

2.1. Project Goals

The ultimate objective of this project is to help improve the effectiveness of shale oil production by providing new scientific knowledge and new monitoring technology for both initial stimulation/production as well as enhanced recovery via re-fracturing and EOR. This project will develop methodologies and operational experience for optimized production of oil from fractured shale, an end result that would allow for more production from fewer new wells using less material and energy. While aspects of the proposed project are site-specific to the Eagle Ford formation, there will be many realistic and practical learnings that apply to other unconventional plays, or even apply to other subsurface applications such as unconventional gas recovery and geologic carbon sequestration and storage. The main scientific/technical objectives of the proposed project are:

- Develop and test new breakthrough monitoring solutions for hydraulic fracture stimulation, production, and EOR. In particular, for the first time in unconventional reservoirs, use active seismic monitoring with fiber optics in observation wells to conduct: (1) real-time monitoring of fracture propagation and stimulated volume, and (2) 4D seismic monitoring of reservoir changes during initial production and EOR from the re-fractured well.
- Improve understanding of the flow, transport, mechanical and chemical processes during and after stimulation (both initial and re-fracturing) and gain insights into the relationship between geological and stress conditions, stimulation design, and stimulated rock volume.
- Assess spatially and temporally resolved production characteristics and explore relationship with stimulated fracture characteristics.
- Evaluate suitability of re-fracturing to achieve dramatic improvements in stimulation volume and per well resource recovery.
- Evaluate suitability of gas-based EOR Huff and Puff methods to increase per well resource recovery.
- Optimize drilling practices in the Eagle Ford shale based on surface monitoring and near-bit diagnostic measurements during drilling.
- Conduct forward and inverse modeling to test reservoir and fracture models and calibrate simulations using all monitored data. Ultimately, provide relevant guidance for optimized production of oil from fractured shale.
- Disseminate research and project results among a broader technical and scientific audience, and ensure relevance of new findings and approaches across regions/basins/plays.

The project will start with the re-fracturing of a legacy well that was initially stimulated using now outdated fracturing technology (Task 2). The recipient will drill, complete, and instrument one vertical and one horizontal observation strategically located on both sides of the legacy well to allow for real-time cross-well monitoring of evolving fracture characteristics and stimulated volume. These observation wells will also be used for the other two main project stages, involving a new state-of-the art stimulation effort (Task 3) and a Huff and Puff EOR test (Task 4). Task 3 will be conducted in two new wells of opportunity drilled; these wells will be situated parallel to the horizontal observation well on the other side of the re-fracturing well. Task 4 will be conducted in the re-fractured legacy well, testing the efficiency of a Huff and Puff process with natural gas injection for EOR. As described below, each main task comprises various field activities complemented by laboratory testing and coupled modeling for design, prediction, calibration, and code validation. In addition to the three main tasks aligned with re-fracturing, new stimulation, and EOR, the work plan also comprises Task 1 (Project Management and Planning) and Task 5 (Integrated Analysis, Lessons Learned, Products, and Reporting). The project milestones, description of tasks and subtasks, and current milestone status are shown in **Table 1**.

2.2. Accomplishments

This section summarizes the accomplishments for the current reporting quarter (October 1st – December 31st, 2018).

2.2.1. Earth Model Construction and Seismic Feasibility Modeling

In support of the seismic feasibility modeling and imaging studies, a 3D elastic earth model was constructed from well logs and 3D seismic horizons for the Bronco site that were provide by WHRD. The resulting 3D model of P-wave and S-wave velocities and density preserves the geological horizons of the main 11 formations (e.g., Austin Chalk, Eagle Ford, Buda) over a 3.5 km x 3.5 km x 2 km volume centered on the Bronco A2H, A3H and Dennis W Drgac-1 wells. Gen 1 (legacy) fractures and Gen 3 (planned) re-fractures were added to the model using fracture geometries estimated from well completions for the Bronco, and conservative fracture properties estimated from a theoretical fracture model.

3D seismic simulations were then carried on the 3D earth model using both full-waveform finite difference modeling and ray-based modeling codes. These simulations included a range of acquisition designs under consideration, including surface-to-borehole using LBNL's surface orbital (SOV) system (**Appendix - Figure 1 (b)**) and cross-borehole geometries for LBNL's CASSM system and Schlumberger's Z-Track system. These simulations indicate that time delays on the order of 1 ms can be expected for seismic waves traveling sub-vertically across the parallel fracture system. Additionally, converted and diffracted waves generated on the fractures will also be generated, and could potentially allow the use of full-waveform inversion (FWI) methods for high resolution discrete fracture imaging.

2.2.2. Fracture Imaging Feasibility & SOV Array Design

One component of the monitoring effort at the EFSL site is the deployment of semi-permanent surface seismic sources to allow for continuous monitoring of changes in subsurface seismic properties. Our hope is that these changes in subsurface seismic properties (e.g. P & S wave velocity, attenuation, and anisotropy) can be used to effectively map the stimulated volume, even in regions which exhibit minimal microseismicity. The sources selected for this component of the experiment are surface-mounted orbital vibrators (SOVs), a source design developed at LBNL and piloted at several locations (Otway, ADM, and Fairbanks AK). A requisite component of planning this component of the experiment was an evaluation of possible source geometries to maximize subsurface resolution. This design process is particularly important given the small number of planned SOVs and the constraints on surface locations due to availability of power and land owner permissions.

We conducted a series of forward-modeling and inversion tests examining the ability of a variety of SOV geometries to effectively reconstruct test targets located above the proposed horizontal monitoring well; in these geometries, the SOVs would be recorded by the behind-casing DAS arrays installed in the horizontal monitor well. As can be seen in **Appendix - Figure 2**, capacity to resolve a sequence of positive and negative velocity anomalies is enhanced by a larger number of surface sources, not a surprising result.

More surprising is the relatively high quality of result possible with only 7 surface sources and the decreasing marginal returns beyond this array density in a linear configuration. Of course, placement of out-of-plane sources improves information on fracture width, suggesting that a “cross” geometry might be effective. Another relevant result is the benefit of having sources located well beyond the end of the well; this additional aperture improved the lateral resolution of recovered velocity anomalies. These general rules, combined with the on-the-ground constraints for source deployment, will guide the final source locations. We should mention that the general approach used was the technique proposed in Ajo-Franklin (2009).

2.2.3. **Surface Orbital Vibrator (SOV) Acquisition Planning & Test Design**

The original EFSL project plan proposed the use of crosswell Continuous Active Source Seismic Monitoring (CASSM; Daley et al., 2007, Geophysics, 72, A57-A61), a permanent borehole seismic monitoring system developed at LBNL over the past decade. CASSM was to be deployed between horizontal wells using an array of semi-permanent piezoelectric borehole seismic sources and semi-permanent borehole seismic receivers (3C geophones and DAS). The primary goal of CASSM at the EFSL was to track hydraulic fractures, re-fractures and the EOR fracture stimulation processes at reservoir depths and out to distances of 100’s of meters between boreholes with high spatial and temporal resolutions. However, during the planning stage, it was determined by the operator (WildHorse Resource Development) that it would not be operationally feasible to emplace permanent seismic sources or sensors (geophones or DAS) behind casing in either of the two horizontal re-fracturing wells (Bronco A2H and A3H wells) because of casing size restrictions.

Recognizing the unique opportunity afforded by this field project to observe the evolution of re-fracturing, fracturing and EOR processes, the project team decided to exercise the backup option of replacing the borehole piezoelectric CASSM source array with a surface array of SOVs. SOVs also utilize permanent source emplacement to achieve high repeatability. Utilizing a linear array of 10 SOVs mounted above the Horizontal Observation Well (HOW), LBNL (Jonathan Ajo-Franklin) performed a synthetic traveltime tomography imaging analysis that supported the use of SOVs for imaging the vertical growth of the fractures generated during the re-fracturing of the Bronco A3H well (previous section). The use of stationary surface source acquisition as a monitoring tool for monitoring hydraulic fracture growth was highlighted in a recent study by Byerley et al. (2018, The Leading Edge, 802-810). In this field study, Apache Corp monitored 78 individual hydraulic frac stages using DAS in a horizontal shale well and two fixed vibroseis sources off the two ends of the monitoring well. A key finding from this study was that the continuous monitoring data recorded changes in the stimulated rock that diminished over a period of days. These changes, which included subtle changes in the P-wave velocity and the generation of P-to-S converted waves by the hydraulically-induced fractures, would have "been completely missed using the conventional approach of having a single monitor survey acquired after the well was treated." The 10 source SOV array that will be used in the EFSL field program will allow our program to go beyond fracture characterization, as in the 2 source Apache study, to fracture imaging.

To validate the utility of SOV's for monitoring hydraulic fractures in the Bronco site and a removable SOV foundation design, a single SOV pilot test was designed for the WHRD Harden CP3 well pad located south of Caldwell, TX off of FM975. This feasibility test will test a new modular foundation design that allows for easy construction, removal and remediation. This test will also validate the use of a new slewing bearing mount that allows the SOV to be rotated over 360 degrees. This new capability will provided a full angular range of horizontally-polarized shear waves to be used in the fracture imaging.

2.2.4. **CASSM Source Development**

While the CASSM deployment has been decreased in size (i.e. number of sources) due to deployment constraints in the re-fracturing well, we still plan to field a single CASSM source on wireline (7 conductor) in the vertical observation well to provide high frequency seismic data in the near-fracture zone. We initiated construction for this source and have procured the piezoceramic rings needed for the build. As part of another project, we have also developed a new amplifier system which should improve CASSM transmission distances, particularly for lower frequencies.

2.2.5. **Behind Casing 3C Geophone Pod Design**

Behind casing instrumentation in the Horizontal Observation Well (HOW) and Vertical Observation Well (VOW) at the EFSL will include three control lines/instrumentation strings: (1) pressure/temperature gauges, (2) 3C geophone string, and (3) integrated fiber-optic monitoring line. The pressure/temperature gauge string will be supplied by Halliburton; the 3C geophone string will be designed and production outsourced by LBNL. The integrated fiber-optic monitoring line will be either provided by either a JIP partner or a subcontractor.

The 3C geophone string designed by LBNL consists of a 3/8" OD control line connecting 1.75" OD x 12" geophone pods. The collapse pressure rating for the string is 10,000 psi and temperature rating of 150 °C. **Appendix - Figure 3 (a)** shows a spool containing the control line with geophone pods on a pneumatic spooling unit, and **Appendix - Figure 3 (b)** shows a sheave block being used to route the string to the rig floor for clamping to the casing. Geophones will be space both in the vertical well section and along the horizontal. The geophone pods require protection during installation using protective clamps or by collocating centralizers at each geophone pod location.

2.2.6. Behind Casing Dynamic Strain Sensing (DSS) Cable Testing & Design

With the objective of developing an Brillouin Optical Time Domain Reflectometry (BOTDR) system for fiber optic Distributed Strain Sensing (DSS) that will be deployed in a borehole (behind casing) for use in monitoring the strains produced by hydraulic fracture growth, the UC Berkeley (UCB) team held a series of meetings with the LBNL team to develop the design and specifications of the special combined strain and temperature fiber optic cable. Meetings were also held with fiber optic cable manufacturing companies to discuss the details of the materials, size and protective measures (**Appendix - Figure 4 (a)**).

A preliminary cable design has been completed. After the design is finalized, additional tests will be performed on the new fiber optic cable for combined strain and temperature at ambient temperature conditions. A large scale laboratory test that examines the feasibility of the cable embedded in a 3 m long pipe-cement model subjected to bending (**Appendix - Figure 4 (b)**) will be conducted in February. These test results will allow us to quantify the sensitivity and applicability of the cable structure for *in situ* dynamic strain measurements. Based on these results, we will design a new cable that can cope with the higher temperature environment (up to 120 degrees Celsius) expected at the Eagle Ford Shale Laboratory site.

We have also started procurement for BOTDR optical components needed for the EFSL system and developed a new PCB design for the associated system.

2.2.7. Vertical Fracture Propagation Modeling and Design of Experiments

Hydraulic fracture propagation requires pressure in the fracture to exceed the magnitude of the least principal stress. In this context, vertical propagation of hydraulic fractures is controlled by variations of the magnitude of the least principal stress with depth, which appear to be controlled by relative degrees of viscoplastic relaxation of stress. This time-dependent behavior is affected by the mechanical and mineralogical properties of the rocks (Sone and Zoback, 2014; Rassouli and Zoback, 2018), especially clay plus kerogen content. This concept has been used to interpret vertical fracture propagation in the Woodford formation and Marcellus formation by Ma and Zoback (2017) and Alalli and Zoback (2018), respectively. In the Eagle Ford formation, Patel et al., 2014 observed fewer recorded seismic events (and lower production) from a ductile clay-rich layer near the top of the lower Eagle Ford. In the EFSL project, we intend to study the effect of viscoplastic behavior of different lithofacies with different geomechanical properties on the hydraulic fracturing operations.

The main focus of this research group is to find the variations of the least principal stress based on the formation encounters in the Eagle Ford. To do this, we are planning to run time-dependent creep experiments on samples from different depths that will be provided to us after drilling of the vertical observation well. Results of these experiments will be integrated with the further associated data from the project to get a better understanding of how different layers of the formation will respond to the re-fracturing operation.

Appendix - Figure 5 shows how vertical hydraulic fracture propagation out of the Eagle Ford can occur when pumping rates are too high (after Maxwell, 2014), apparently because the pressure in the hydraulic fracture exceeds the magnitude of the least principal stress in the upper Eagle Ford and Austin Chalk.

The variation of the gamma-ray in the log data provides an estimate of the changes in the clay+ kerogen and carbonate contents. In these data, the higher gamma-ray value indicates the higher value of clay and kerogen, while the carbonate-rich zones have a lower gamma-ray values. In **Appendix - Figure 6**, we used type log data provided for the EFSL test site area to pick five depths of interest from the Eagle Ford formation with various gamma-ray values and one in the Austin Chalk formation range with high carbonate content.

The main reason for making a stress measurement in the Austin Chalk is to know the state of stress after depletion. Eagle Ford. Existing microseismic data from the hydraulic operation in the A1H, A2H and A3H horizontal wells shows very few events recorded for the Austin Chalk layer, which can be an indication that this layer is a fracture barrier. Depletion of the Austin Chalk may have decreased the magnitude of the least principal stress sufficiently to promote upward propagation of hydraulic fractures out of the Eagle Ford.

To have a better understanding of the current geomechanical state of the zone of study, we are also interested in getting the geomechanical information from MDT microfrac tests, which will be conducted in the same depths that we are requesting samples from. The results of these tests will provide us with a good understanding of the in-situ stresses in the depths of interests as well as the pore pressure and permeability of these different lithofacies. Combination of these data with the laboratory test results will help us to predict the response of the reservoir to the re-fracturing operation.

2.2.8. Engineering of Integrated Monitoring Completion (Ongoing)

The research team has been focused on the design, engineering, and sourcing of the integrated monitoring completions for both the horizontal observation well and the vertical observation well. Work in support of Activity 2.1.3 includes the following:

- Engineering and design of integrated monitoring instrumentation to be permanently installed behind casing for the horizontal observation well (HOW). This includes simultaneous installation and conveyance of the following:
  - ✓ DAS/DTS Fiber Optic Cable
  - ✓ DSS Fiber Optic Cable
  - ✓ Geophone Array
  - ✓ P&T Gauge Array
- Engineering and design of integrated monitoring instrumentation to be permanently installed behind casing for the vertical observation well (VOW). This includes simultaneous installation and conveyance of the following:
  - ✓ DAS/DTS Fiber Optic Cable
  - ✓ DSS Fiber Optic Cable
  - ✓ Geophone Array

The research team is currently working with various service providers to determine the best engineering solution and to evaluate the corresponding competitive bids.

2.2.9. Radioactive Proppant Tracing of Re-fracture Well

Four radioactive (RA) proppant tracing programs have been designed in support of Activity 2.5.3. These four tracing programs represent different options for tracing the proppants in various fracturing stages of the re-fracture study well (Bronco A3H). Each option contains unique stages where proppant will be tagged with 3 different radioactive isotopes, with the first 1/3 tagged with tracer 1, the second 1/3 tagged with tracer 2, and the last 1/3 tagged with tracer 3. In other stages, an entire stage will be tagged with a single isotope, then a different isotope used to tag the next stage, in order to locate where the proppant from each stage went. These four different options are shown in **Appendix - Figure 7.**

2.2.10. Cuttings Analysis and Proppant Detection

Testing and calibration for mineralogical (XRD, SEM-EDX) and geomechanical (nano-indentation, micro-scratch) experiments combined with micromechanical analysis is being performed on cutting samples to characterize mechanical properties (small scale and log scale), amount of porosity, TOC, and brittleness of the shales. These same measurements are planned to be performed on cuttings from the EFSL test site under Activity 3.2.3.

The research team is developing a methodology to translate the mechanical information at micro-scale on randomly oriented samples to macro-scale measurements for anisotropic material. Micro-indentation experiments are being conducted on multiple samples with multiple loading directions. Using this data along with the explicit relationship between the indention moduli and transversely anisotropic elastic properties of solids, an inverse problem is being formulated to identify the mean values and associated uncertainty for the quantities of interest that best fit the data. The results will be presented in terms of the best representative (average) values of quantities of interest and the associated confidence bound. The obtained mechanical properties at macroscale will be validated and compared with measurements performed on core samples.

This subgroup at TAMU is also working on proppant sampling and detection from mud return samples. It is planned to collect drill cuttings and mud return samples during the drilling of the horizontal observation well (HOW) which will intersect legacy hydraulic fractures from the re-fracture candidate well (Bronco A3H). This work, in combination with the open hole image logging, will allow detection and determination of proppant distribution along the stimulated rock volume created by the legacy hydraulic fracturing stimulation of the re-fracture well.

2.2.11. Observation Well Drilling and Logistics Planning

The drilling research team at TAMU met with WildHorse Resource Development drilling teams on two of their rigs in Burleson County in late October to discuss the drilling aspect of the project. We discussed the typical well design and the reasoning being casing setting points. In addition we discussed potential issues around logging and coring operations associated with the EFSL project.

Due to the transition from WildHorse Resource Development to Chesapeake Energy Corporation as the field test site operator, there has not been any more information on the preferred well design, the rig to be used or the service providers. Once we start to get this information from the Chesapeake operations team, we expect to rapidly complete the plans and set up services for the drilling data collection.

2.2.12. Coupled Multiphase Flow and Geomechanics Modeling Efforts

The modeling research team at TAMU has identified and hired a competent PhD candidate, whom is currently training in coupled multiphase flow and geomechanics. Additionally, the team is actively evaluating potential students for participation in this project, the demands of which require a minimum of two students.

As part of his work, the PhD student is scouring the literature for possible data on the properties of the reservoir and conditions at the selected site. We have attempted to obtain such data from the operator, but personnel issues associated with the merger of the company with Chesapeake have made communications difficult. Additionally, we have been reviewing all available literature that list properties and conditions in the entire Eagle Ford formation (there is scant specific and widely dispersed information in the literature) in an effort to develop a database on the subject.

Furthermore, the team is enhancing/strengthening the simulation codes by introducing new options and capabilities to describe (a) the behavior of the oil and gas across the expected pressure spectrum, ensuring multiple options to deal with both specified and unspecified oil and gas compositions that require different variables for property estimation, and (b) the geotechnical behavior, by introducing additional matrix failure (secondary fracture development) criteria more appropriate for shales in addition to the standard Mohr-Coulomb ones.

2.2.13. Reservoir Simulation and Forward Modeling Efforts

The reservoir simulation and forward modeling group at TAMU has been primarily working on building a Petrel geologic model and fluid model (shown in **Appendix – Figure 8**), which is to be used for preliminary history matching, and collecting additional data needed for the modeling. The raw log data has been imported to petrel and a surface modeling has almost finished using formation top information at a few wells in/around the EFSL field test site area. The modeling process should be followed by log interpretation for determination of reservoir properties. Also the existence of faults are indicated by microseismic data and they should be added when the latest data is available. As for fluid modeling, the typical properties for the Eagle Ford Shale are to be used due to lack of data or in case the data is available in the future, it will be incorporated.

Work completed during this reporting quarter (BP1-Q3) includes the following:

- Confirming data availability
- Importing the data to petrel project
- Creating the surface from formation tops

Work planned for the next reporting quarter (BP1-Q4) includes the following:

- Interpreting raw log data and determining reservoir properties
- Add faults to the model utilizing micro-seismic data
- Preliminary history matching after the geological model is created

2.2.14. DAS / DTS Data Processing and Interpretation Efforts

The DAS/DTS fiber optic data research group at TAMU has been focused on enhancing/strengthening their data processing and interpretation techniques. The group interprets DTS and DAS independently, then compares the results from two interpretations and validates the results against each other. For DTS interpretation, the warmback of temperature at each cluster location after pumping stops is used to obtain the cumulative fluid volume taken by each cluster by the end of the injection. Different fluid volume taken by each cluster will result in different temperature recovery behavior during the warmback period. A numerical simulation is set up to simulate the transient response of temperature from the start of injection to the warmback period. Meanwhile, an inversion model is performed to match the simulated temperature with the measured temperature and invert the fluid volume for each cluster by the end of injection.

The analysis techniques for DAS data allow effective prediction of flowrate by means of a correlation with an acoustic signal. On the basis of correlation to the Frequency Band Energy (FBE) as follows:

$$\boldsymbol{FBE = A * log(q^3) + B,}$$

where $\boldsymbol{q}$ represents flowrate; $\boldsymbol{A}$ and $\boldsymbol{B}$ are correlation constants, which the research group has obtained through prior studies and supporting datasets. This correlation can be implemented in the EFSL study wells for DAS fiber data interpretation. The research group can use acoustic measurements along the depth of wellbore and calculate FBE, and will observe FBE peaks near the perforation cluster locations. For each time step, a system of equations is solved according to the FBE correlation as follows:

$$\begin{cases} \boldsymbol{FBE_1(t) = A * log(q_1^3(t)) + B(t)} \\ \vdots \\ \boldsymbol{FBE_n(t) = A * log(q_n^3(t)) + B(t)} \\ \boldsymbol{q_n(t) + \cdots + q_n(t) = q_T(t)} \end{cases}$$

where $\boldsymbol{q_i}$ represents flowrate for perforation cluster $\boldsymbol{i}$; $\boldsymbol{q_T}$ is the total flowrate for each stage. According to the solution of this system we can calculate cumulative volume for each perforation cluster and predict what the percentage of flow corresponds to each perforation cluster.

2.3. Opportunities for Training and Professional Development.

Nothing to Report.

2.4. Dissemination of Results to Communities of Interest

Nothing to Report.

2.5. Plan for Next Quarter (BP1-Q4: January-March, 2019)

Building on the current progress achieved by the research team, work planned for the next quarter will include, but is not limited to, the following:

- Continue work related to the HOW and the VOW in support of Subtask 2.2, 2.3, and 2.5:
    - ✓ Surface location selection.
    - ✓ Planning for permitting.
    - ✓ Vertical pilot and well path design (for HOW).
    - ✓ Casing design to accommodate coring and subsequent instrumentation.
- Continue ongoing design and planning for surface monitoring in support of Subtask 2.5:
    - ✓ Carry out SOV pilot test on Harden CP3 well pad.
    - ✓ Procure SOV components for linear surface array.
    - ✓ SOV linear surface array location determination, planning, and permitting.
    - ✓ Initiate development of EFSL-specific seismic data processing and interpretation tools.
    - ✓ Procure CASSM source components and begin assembly of CASSM sources.
    - ✓ Complete DSS fiber optic cable design and testing, along with constructing a custom BOTDR in support of the DSS measurements.
- Select DAS/DTS fiber optic cable and interrogator supplier.
- Finalize proppant tracing program and contract with tracing supplier/service company.
- Design of geomechanical testing experiments to be conducted on core and cuttings.
- Continue simulation and modeling efforts in support of Subtask 3.5.

2.6. Summary of Tasks for Next Quarter (BP1-Q4: January-March, 2019)

The following provides a summary of the tasks, subtasks, and activities planned in BP1-Q4:

- Task 1 – Project Management and Planning

  Activity is ongoing.
- Task 2 – Phase 1: Evaluation of Re-fracturing
    - ✓ Subtask 2.1 – Evaluation of Existing Data and Design of Observation Wells
        - ▪ *Activity 2.1.2 Design of the Active Source and Passive Monitoring Arrays*

          Activity is ongoing.
        - ▪ *Activity 2.1.3 Engineering of Integrated Monitoring Completion*

          Activity is ongoing.

- Special Reporting Requirements
    - ✓ No special reporting requirements scheduled.

Table 1. Summary of Milestone Status

Milestone	Task	Sub-task	Title/Description	Planned Completion Date	Actual Completion Date	Verification Method	Comments
A	1	1	Project Management & Planning	3/31/2021	Ongoing	Report	None
	2 - Phase 1: Re-Fracturing Evaluation	2.1	Evaluation of Existing Data and Design of Observation Wells	9/30/2018	Ongoing	Report	None
B		2.2	Drill, Complete, & Instrument Horizontal Observation Well	9/30/2018	*Not Started	Report	*Delayed due to change in operator*
		2.3	Drill, Complete, & Instrument Vertical Observation Well	9/30/2018	*Not Started	Report	*Delayed due to change in operator*
		2.4	Recomplete Well to be Re-Fractured	9/30/2018	*Not Started	Report	*Delayed due to change in operator*
C		2.5	Monitoring of Re-Fracturing	12/31/2018	*Not Started	Report	*Delayed due to change in operator*
		2.6	Analysis of Re-Fracturing Monitoring	12/31/2019	Not Started	Report	None
D		2.7	DTS/DAS/DSS & Seismic Monitoring During Production	12/31/2019	Not Started	Report	None
		2.8	Laboratory Evaluation of EOR Potential	6/30/2020	Not Started	Report	None
E		2.9	Coupled Modeling for Design, Prediction, Calibration & Code Validation	9/31/2020	Not Started	Report	None
	3 - Phase 2: Fracturing Evaluation	3.1	Drill, Complete & Instrument Two New Producing Wells	6/30/2019	Not Started	Report	None
F		3.2	Drilling Optimization	6/30/2020	Not Started	Report	None
		3.3	Monitoring of Fracturing of Two New Producing Wells	12/31/2019	Not Started	Report	None
		3.4	Analysis of Fracturing Monitoring of Two New Producing Wells	12/31/2020	Not Started	Report	None
		3.5	Coupled Modeling for Design, Prediction, Calibration & Code Validation	12/31/2020	Not Started	Report	None
	4 - Phase 3: EOR Pilot Test	4.1	Conduct Huff & Puff EOR Pilot Test	6/30/2020	Not Started	Report	None
		4.2	Monitor Injected Gas Placement with Active & Passive Seismic Monitoring	12/31/2020	Not Started	Report	None
		4.3	Monitor Injected Gas Distribution with DTS/DAS in Pilot Well	12/31/2020	Not Started	Report	None
G		4.4	Modeling of the Huff & Puff EOR Pilot Test	12/31/2020	Not Started	Report	None
	5 - Final Report	5.1	Multi-Purpose Optimization & Lessons Learned	3/31/2021	Not Started	Report	None
		5.2	Products & Reporting	3/31/2021	Not Started	Report	None

3. PRODUCTS

Nothing to Report.

4. PARTICIPANTS & OTHER COLLABORATING ORGANIZATIONS

The acquisition of WildHorse Resource Development by Chesapeake Energy Corporation, which was announced on October 30th, 2018, has led to a change in the industry partner for the project. The acquisition is set to officially close on February 1st, 2019, at which point Chesapeake Energy Corporation will become the new industry partner and EFSL field test site operator.

The project PI, Dr. Dan Hill, and the supporting project team at TAMU, has been in constant communication with WildHorse Resource Development's management team as well as upper level management at Chesapeake Energy Corporation to manage this transition and the possible impact on the EFSL project. This transition in industry partners has caused a delay in the performance of field test site activities planned during this reporting quarter (BP1-Q3). The EFSL team has submitted a No-Cost Time Extension (NCTE) request to DOE (as described in **Section 7.3**) in order to complete all activities originally planned for BP1.

5. IMPACT

Nothing to Report.

6. CHALLENGES/PROBLEMS

A change in industry partner for the project has caused a delay to field test site activities as described in **Section 4** of this report. The team is actively managing this transition and has submitted a No-Cost Time Extension (NCTE) request to DOE (as described in **Section 7.3**) in order to complete all activities originally planned for BP1.

The team expects no additional challenges or problems to the project.

7. SPECIAL REPORTING REQUIREMENTS

7.1. Environmental Questionnaire

A revised Environmental Questionnaire (EQ) for the selected EFSL test site was submitted on 10/02/2018. This revised EQ was approved by the DOE Project Manager on 10/03/2018.

7.2. Categorical Exclusion (CX) Designation Form

The Categorical Exclusion (CX) Designation Form for the project test site was approved by the NEPA Compliance Officer on 10/10/2018. This approval allows the project to proceed past Subtask 2.2.

7.3. No-Cost Time Extension (NCTE) Request for Budget Period 1

Due to the project delays experienced by the project (described in **Section 4** and **Section 6** of this report), the team submitted a three (3) month No Cost Time Extension (NCTE) to budget period (BP) 1 of the award. This request will move BP1's end date from 03/31/2019 to 06/30/2019. With this request, BP2 will start on 07/01/2019 and end on 06/30/2020. BP3 will start on 07/01/2020 and end on 06/30/2021. Thus the end date for the award will also be extended by three (3) months. New end date for the award will be 06/30/2021.

8. BUDGETARY INFORMATION

A summary of the budgetary information for Q1-Q3 of BP1 for the project is provided in **Table 2**. This table shows the original planned costs, the actual incurred costs, and the variance. The costs are split between federal share and non-federal share.

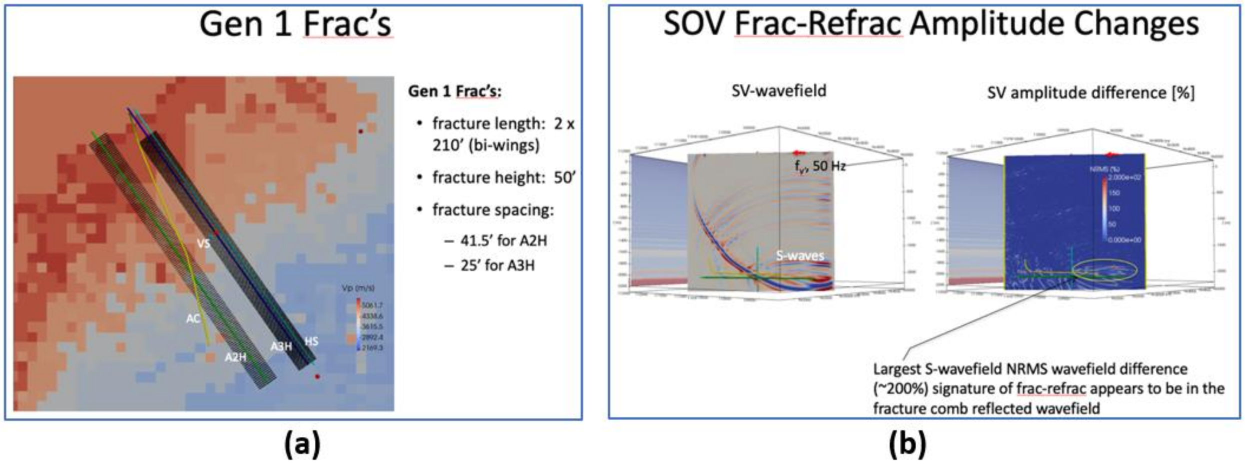
Table 2. Budgetary Information for Budget Period 1, Q1- Q3

Baseline Reporting Quarter	**EFSL Budget Period 1 (04/01/2018-03/31/2019)**							
	Q1		**Q2**		**Q3**		**Total**	
	04/01/2018 - 06/30/2018		07/01/2018 - 09/30/2018		10/01/2018 - 12/31/2018		04/01/2018 - 12/31/2018	
	Federal Share	Non-Federal Share	Federal Share	Non-Federal Share	Federal Share	Non-Federal Share	Federal Share	Non-Federal Share
Baseline Cost Plan								
TAMU	$182,670	$0	$182,670	$0	$182,670	$0	$548,009	$0
WildHorse	$850,001	$500,000	$850,001	$500,000	$850,001	$500,000	$2,550,002	$1,500,000
LBNL	$500,000	$0	$500,000	$0	$500,000	$0	$1,500,000	$0
Stanford	$31,456	$0	$31,456	$0	$31,456	$0	$94,369	$0
Total Planned	$1,564,127	$500,000	$1,564,127	$500,000	$1,564,127	$500,000	**$4,692,380**	**$1,500,000**
Actual Incurred Cost								
TAMU	$119,579	$0	$152,177	$0	$108,898	$0	$380,655	$0
WildHorse	$0	$0	$0	$0	$0	$0	$0	$0
LBNL	$56,678	$0	$104,546	$0	$168,294	$0	$329,518	$0
Stanford	$0	$0	$0	$0	$46,613	$0	$46,613	$0
Total Incurred Cost	$176,257	$0	$256,723	$0	$323,805	$0	**$756,785**	**$0**
Variance								
TAMU	$63,090	$0	$30,492	$0	$73,771	$0	$167,354	$0
WildHorse	$850,001	$500,000	$850,001	$500,000	$850,001	$500,000	$2,550,002	$1,500,000
LBNL	$443,322	$0	$395,454	$0	$331,706	$0	$1,170,482	$0
Stanford	$31,456	$0	$31,456	$0	($15,156)	$0	$47,756	$0
Total Variance	$1,387,869	$500,000	$1,307,403	$500,000	$1,240,322	$500,000	**$3,935,594**	**$1,500,000**

9. PROJECT OUTCOMES

Nothing to Report

10. APPENDIX



Gen 1 Frac's

Gen 1 Frac's:

- fracture length: 2 x 210' (bi-wings)
- fracture height: 50'
- fracture spacing:
  - 41.5' for A2H
  - 25' for A3H

SOV Frac-Refrac Amplitude Changes

Largest S-wavefield NRMS wavefield difference (~200%) signature of frac-refrac appears to be in the fracture comb reflected wavefield

(a) (b)

Figure 1. Seismic feasibility modeling: (a) 3D elastic earth model showing Gen 1 fractures on Bronco A2H and A3H horizontal wells. (b) 3D finite difference and ray simulations for an SOV source.

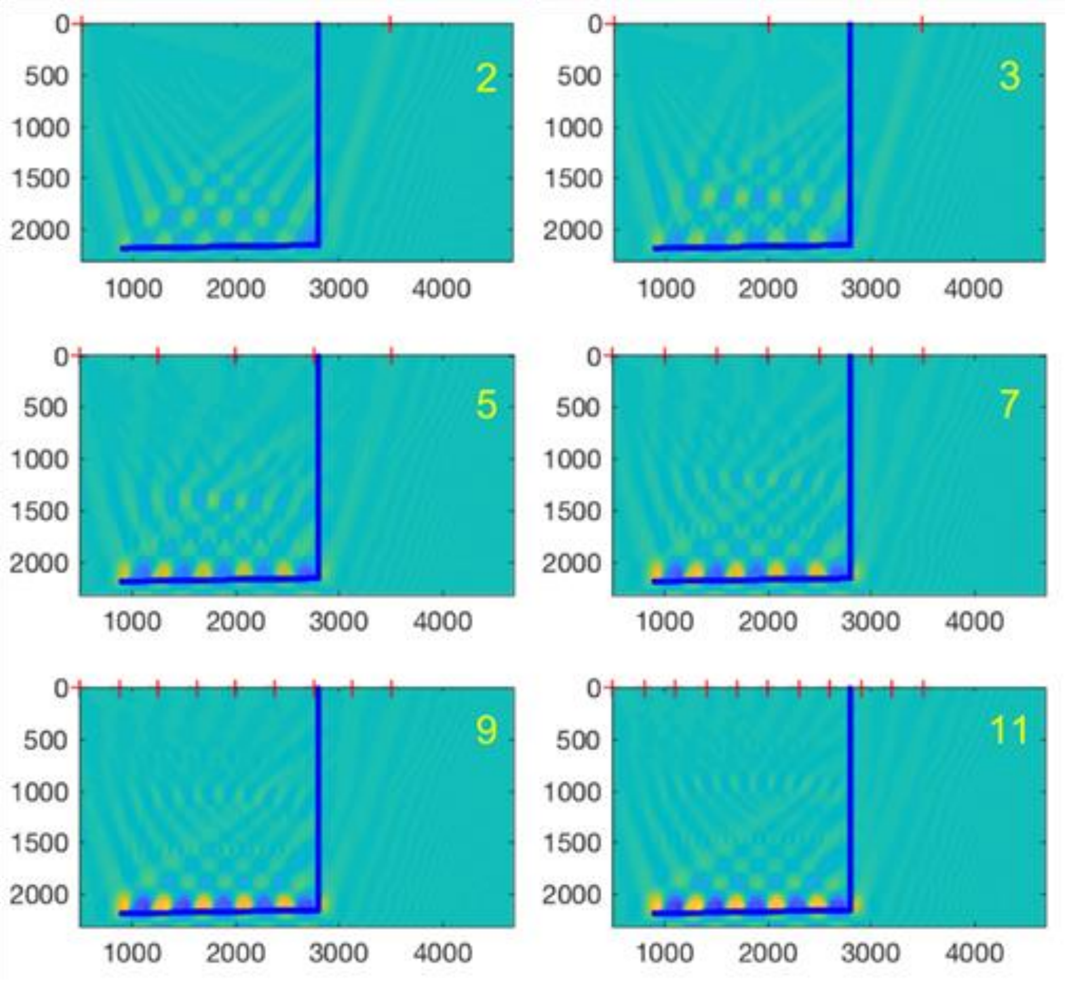


Figure 2. Example of reconstructed velocity anomalies (depth limited checkerboard test) given a different number of surface source locations. Receivers were assumed to be located along the observation well at a 10 m density.

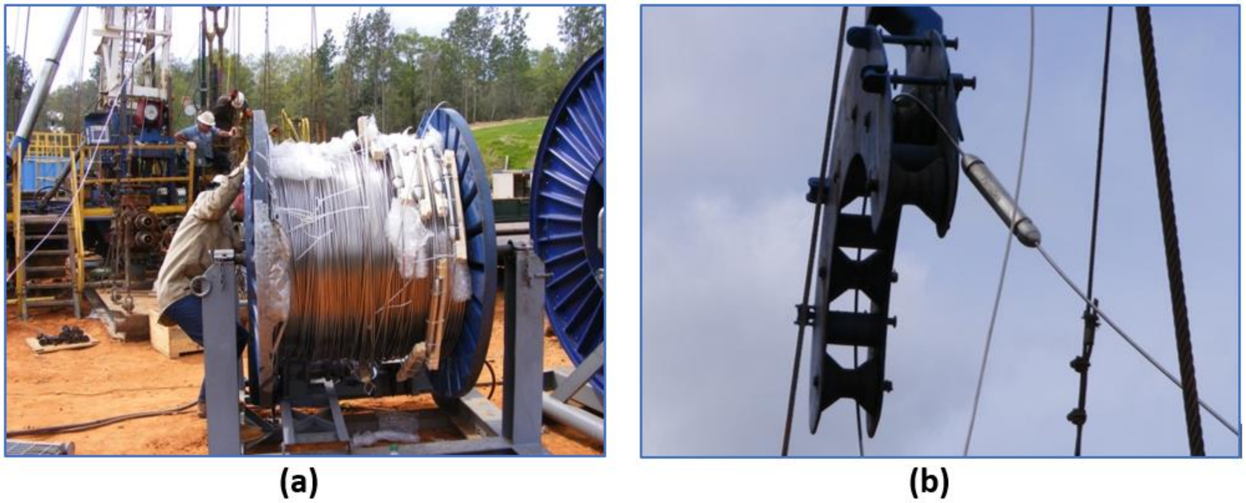
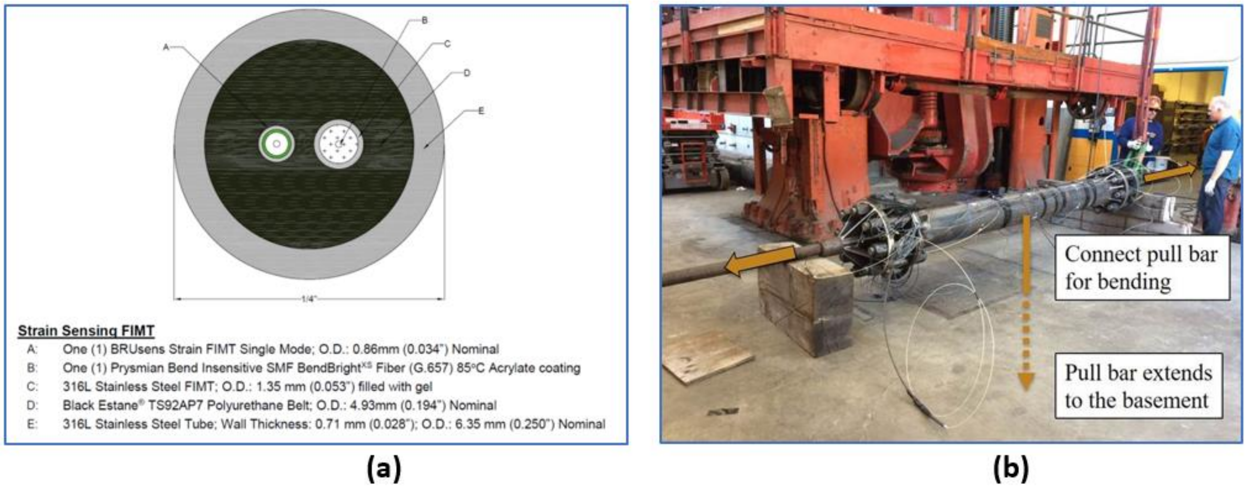


Figure 3. 3C geophone string: (a) reel of geophone pods loaded on pneumatic spooling unit; and (b) deployment showing single 3C geophone pod and control line string.



Strain Sensing FIMT

A: One (1) BRUsens Strain FIMT Single Mode; O.D.: 0.86mm (0.034") Nominal
B: One (1) Prysmian Bend Insensitive SMF BendBright^{XS} Fiber (G.657) 85°C Acrylate coating
C: 316L Stainless Steel FIMT; O.D.: 1.35 mm (0.053") filled with gel
D: Black Estane® TS92AP7 Polyurethane Belt; O.D.: 4.93mm (0.194") Nominal
E: 316L Stainless Steel Tube; Wall Thickness: 0.71 mm (0.028"); O.D.: 6.35 mm (0.250") Nominal

Figure 4. Dynamic strain sensing and temperature cable design (a) and testing at UCB's Richmond Field Station test facility (b).

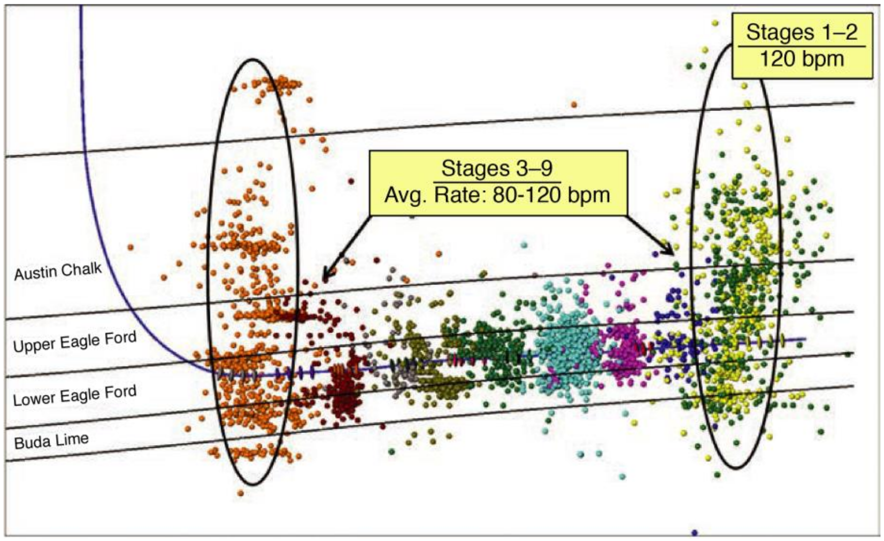


Figure 5. Upward propagation of hydraulic fractures in the Eagle Ford when injection rates are too high (from Maxwell, 2014).

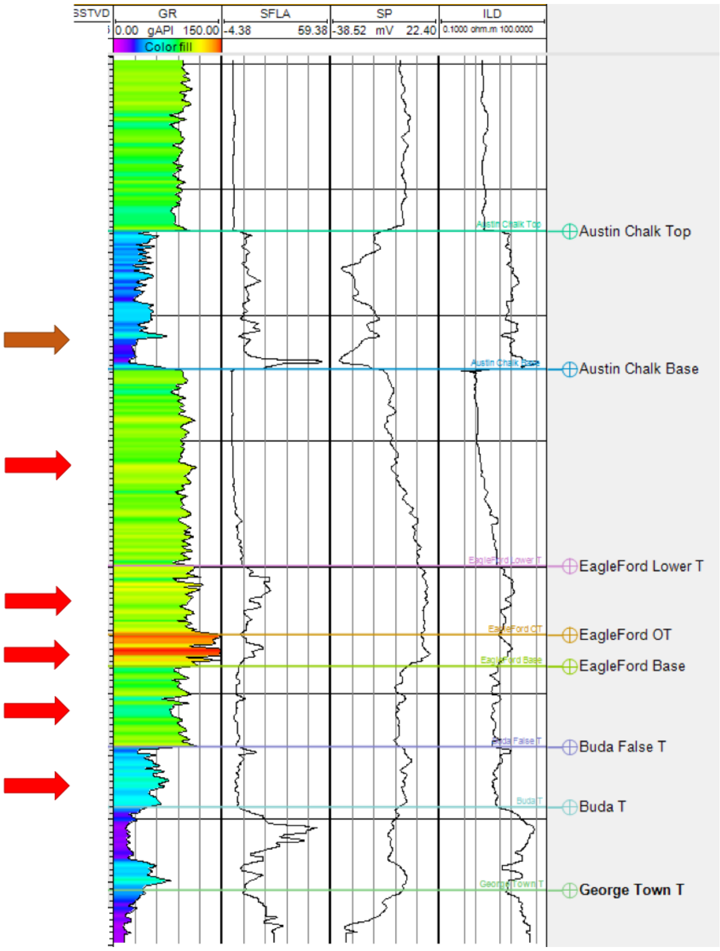
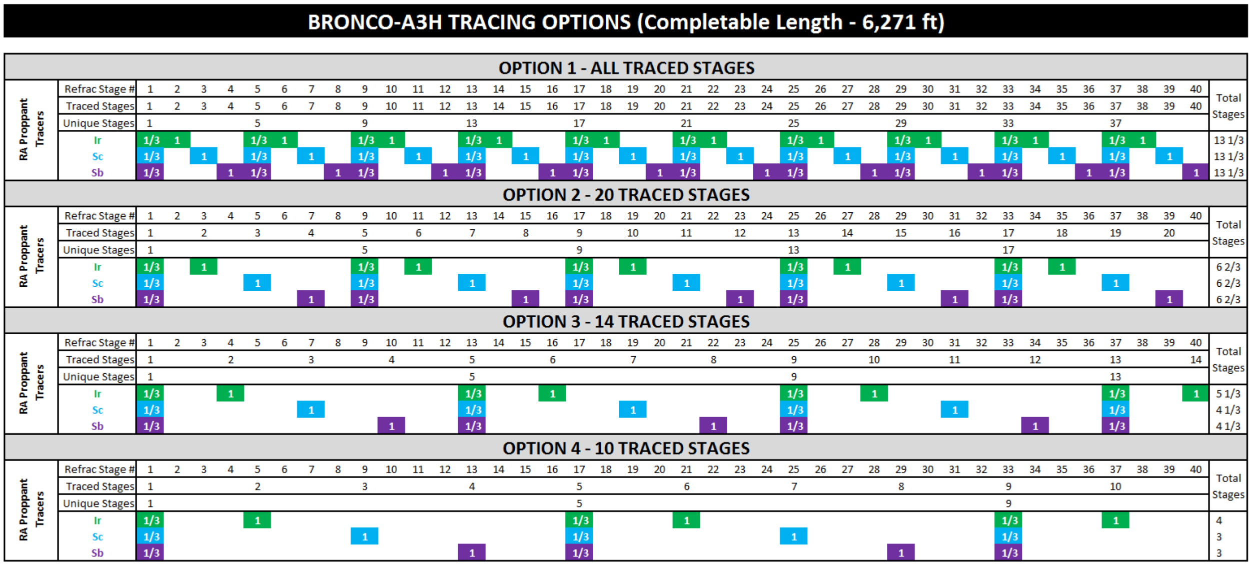


Figure 6. Type log for the EFSL field test site area. The depths of interest are indicated by the arrows and are picked based on the variations in the gamma-ray value.



BRONCO-A3H TRACING OPTIONS (Completable Length - 6,271 ft)

OPTION 1 - ALL TRACED STAGES

RA Proppant Tracers	Refrac Stage #	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	Total Stages
	Traced Stages	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	
	Unique Stages	1				5				9				13				17				21				25				29				33				37				
	Ir	1/3	1			1/3	1			1/3	1			1/3	1			1/3	1			1/3	1			1/3	1			1/3	1			1/3	1			1/3	1			13 1/3
	Sc	1/3		1		1/3		1		1/3		1		1/3		1		1/3		1		1/3		1		1/3		1		1/3		1		1/3		1		1/3		1		13 1/3
	Sb	1/3			1	1/3			1	1/3			1	1/3			1	1/3			1	1/3			1	1/3			1	1/3			1	1/3			1	1/3			1	13 1/3

OPTION 2 - 20 TRACED STAGES

RA Proppant Tracers	Refrac Stage #	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	Total Stages
	Traced Stages	1		2		3		4		5		6		7		8		9		10		11		12		13		14		15		16		17		18		19		20		
	Unique Stages	1								5								9								13								17								
	Ir	1/3		1						1/3		1						1/3		1						1/3		1						1/3		1						6 2/3
	Sc	1/3				1				1/3				1				1/3				1				1/3				1				1/3				1				6 2/3
	Sb	1/3						1		1/3						1		1/3						1		1/3						1		1/3						1		6 2/3

OPTION 3 - 14 TRACED STAGES

RA Proppant Tracers	Refrac Stage #	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	Total Stages
	Traced Stages	1			2			3			4			5			6			7			8			9			10			11			12			13			14	
	Unique Stages	1												5												9												13				
	Ir	1/3			1									1/3			1									1/3			1									1/3			1	5 1/3
	Sc	1/3						1						1/3						1						1/3						1						1/3				4 1/3
	Sb	1/3									1			1/3									1			1/3									1			1/3				4 1/3

OPTION 4 - 10 TRACED STAGES

RA Proppant Tracers	Refrac Stage #	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	Total Stages
	Traced Stages	1				2				3				4				5				6				7				8				9				10				
	Unique Stages	1																5																9								
	Ir	1/3				1												1/3				1												1/3				1				4
	Sc	1/3								1								1/3								1								1/3								3
	Sb	1/3												1				1/3												1				1/3								3

Figure 7. Re-fracture well (Bronco A3H) radioactive proppant tracing program design options.

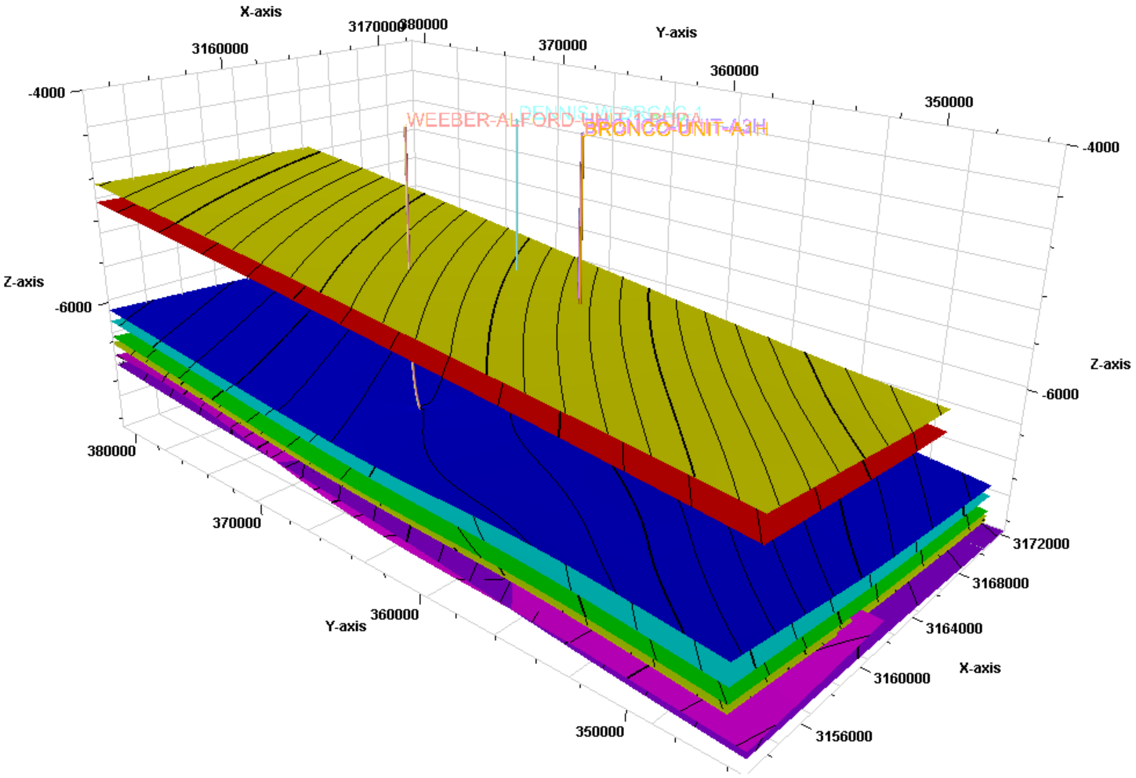


Figure 8. Geologic surface model created using Petrel software.