Oil & Natural Gas Technology

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Quarterly Research Performance

Progress Report (Period Ending 3/30/2020)

Marcellus Shale Energy and Environment Laboratory (MSEEL)

Project Period (October 1, 2014 – September 30, 2021)

Submitted by:
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Executive Summary
Quarterly Progress Report

January 1 – March 30, 2020

The objective of the Marcellus Shale Energy and Environment Laboratory (MSEEL) is to provide a long-term field site to develop and validate new knowledge and technology to improve recovery efficiency and minimize environmental implications of unconventional resource development.

Impacts from COVID-19 have started to diminish, as laboratories reopened in many cases. Other work has progressed relatively on-schedule, and analysis from the samples and data collected from the Boggess Pad has continued as planned. However, our Schlumberger PETREL license required renewal and update for our computer system. We were unable to access the software which is used for both 3D visualization and reservoir simulation. This has been rectified in early January.

This quarter's work focused on using the reservoir characterization results to create simulations for individual wells at the Boggess Pad with good history matches. The simulations were extrapolated for a 10-year estimated ultimate recovery (EUR). 10-year EUR ranged from 0.74 to 1.26 billion cubic feet per 1,000 feet. The Boggess 1H was the best exterior well and the Boggess 3H was the best interior well. These two wells were designed using the WVU completion procedures. Work will continue on simulation to better understand the role of fractures and completion interactions.

All the core and log data for reservoir characterization has been summarized into a single document available at MSEEL.ORG.

Research on machine learning for improved production efficiency with LANL continues and we have provided data and consultation and have contributed to a paper on use of artificial intelligence for a better understanding of reservoir properties.

We continue to sample and monitor produced fluids, and monitor air quality and performance at both MSEEL sites (MIP and Boggess). Several methane audits were completed. Initial work has been completed on the interaction of fracture stimulation fluids with the Marcellus shale under high temperature and pressure conditions and the type of produced fluid.

We continue to develop software to process the 108 terabytes of DAS and completion data from the Boggess pad and are working to develop an improved workflow for delivering the data to the public.

Project Performance

This report summarizes the activities of Cooperative Agreement DE-FE0024297 (Marcellus Shale Energy and Environment Laboratory – MSEEL) with the West Virginia University Research Corporation (WVURC) during the 2nd quarter of FY2021 (Jan 1 through March 31, 2021).

This report outlines the approach taken, including specific actions by subtopic. If there was no identified activity during the reporting period, the appropriate section is included but without additional information.

A summary of major lessons learned to this point of the project are provided as bullet points and will be added to as research progresses. New lessons listed below are:

- The engineered wells at the Boggess Pad (1H and 3H) show the importance of designed stages and cluster placement to improved well performance in terms of decline curve analysis, and simulation of 10-year EUR.
- Fractures at the Boggess Pad are abundant and can be recognized with LWD tools.
- High-pressure and temperature fracture fluid/shale interaction experiments with different stimulation fluids show the effect on produced fluids.

Phase 3

Phase 3 of MSEEL has completed the stimulation and started production from the Boggess Pad in this reporting quarter. Six 10,000+ foot horizontal Marcellus Shale wells off a single pad (Boggess) are near the initial MIP pad (Figure 0.1). The pad has one permanent fiber optic (FO) cable installed in the Boggess 5H lateral provided digital acoustic sensing (DAS) during stimulation, and was monitored during initial production. Distributed temperature sensing (DTS) was monitored during stimulation and continues during initial and long-term production. We acquired DAS data for the entire 5H well, but the FO failed around stage 30 and we do not have long-term DTS data below that stage to the toe. We have data from the upper stages through the heel and continue to download the data. Deployable FO systems were proposed (Boggess 1H and 17H), but due to the fiber failure in the 5H the fiber was not placed in the 17H. However, we acquired significant DAS and DTS and microseismic data from the 5H and 1H that provided insight of stimulation effectiveness in near real-time and the 100's of terabytes of data to evaluate and model the reservoir across each individual stage, and at individual clusters within stages for the 5H, which will be used for all Boggess wells.

Based on production, rate transient analysis (RTA), and fracture analysis (FRACPRO) and simulation using reservoir characterization parameters the new methodology appears to improve completion efficiency. As the wells have come on production, the 1H and 3H wells still have a higher gross production efficiency that either the geometrically completed wells (9H and 17H with identical 200 feet stages with identical number of clusters in each stage) or the commercial design provided which only used the geomechanical logs and ignored the imaged fractures (5H and 13H) (Figure 0.2). On a net production efficiency controlling for variable lateral length (Mcf/1000') outside wells (1H and 17H) are better than interior wells, but engineered wells had a slower ramp-up but are gaining on their counterparts (Figure 0.3).

We received the core analysis and used the cored and logged vertical pilot well to develop a reservoir characterization for the Marcellus. Logging while drilling (LWD) logs in each of the six laterals provided similar geomechanical logs and image logs to geomechanically type each foot of the laterals as the horizontal laterals move stratigraphically up and down through the Marcellus. This approach could be the basis for engineering stages wells. It was applied to two of the Boggess wells (Boggess 1H and 3H).

We continue to gather fiber optic and production data from the Boggess wells to compare across each of the six wells, and with the two wells at the MIP pad (MSEEL 1) and use these data to form the basis for robust big data modeling and improved simulation.

We are working on a new workflow for simplified access to MSEEL data especially the large multi-terabyte data from the Boggess pad.

We have worked with NETL, LANL, and other labs on various projects of the Marcellus at the MIP and Boggess site.

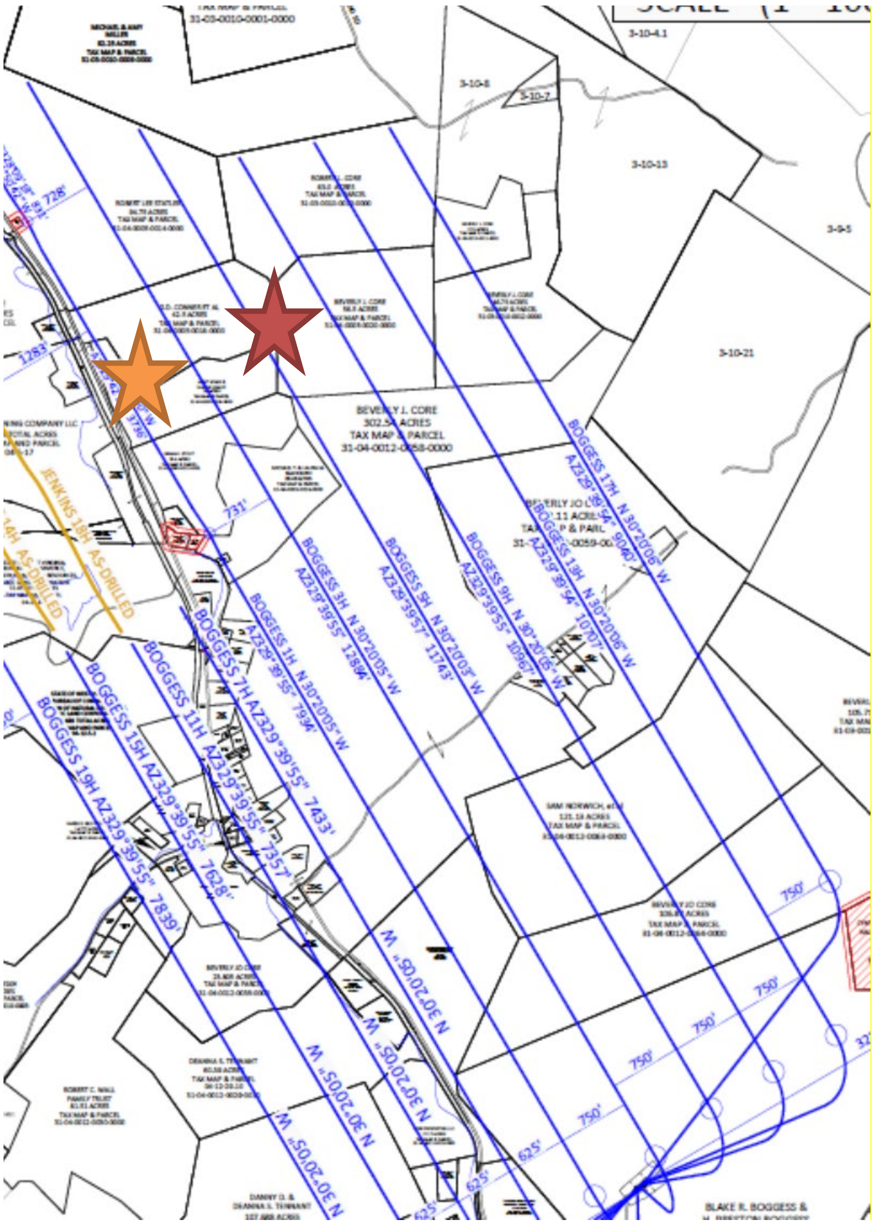

Figure 0.1: Boggess Pad with new generation permanent fiber in the central well (Boggess 5H, red star)) and deployable fiber in adjoining wells skipping one (orange stars). We were able to monitor in near-real time fracture stimulation in the central 3 wells (3H, 5H and 9H). A vertical pilot was drilled, cored and logged. We continue to collect DTS data from the 5H.

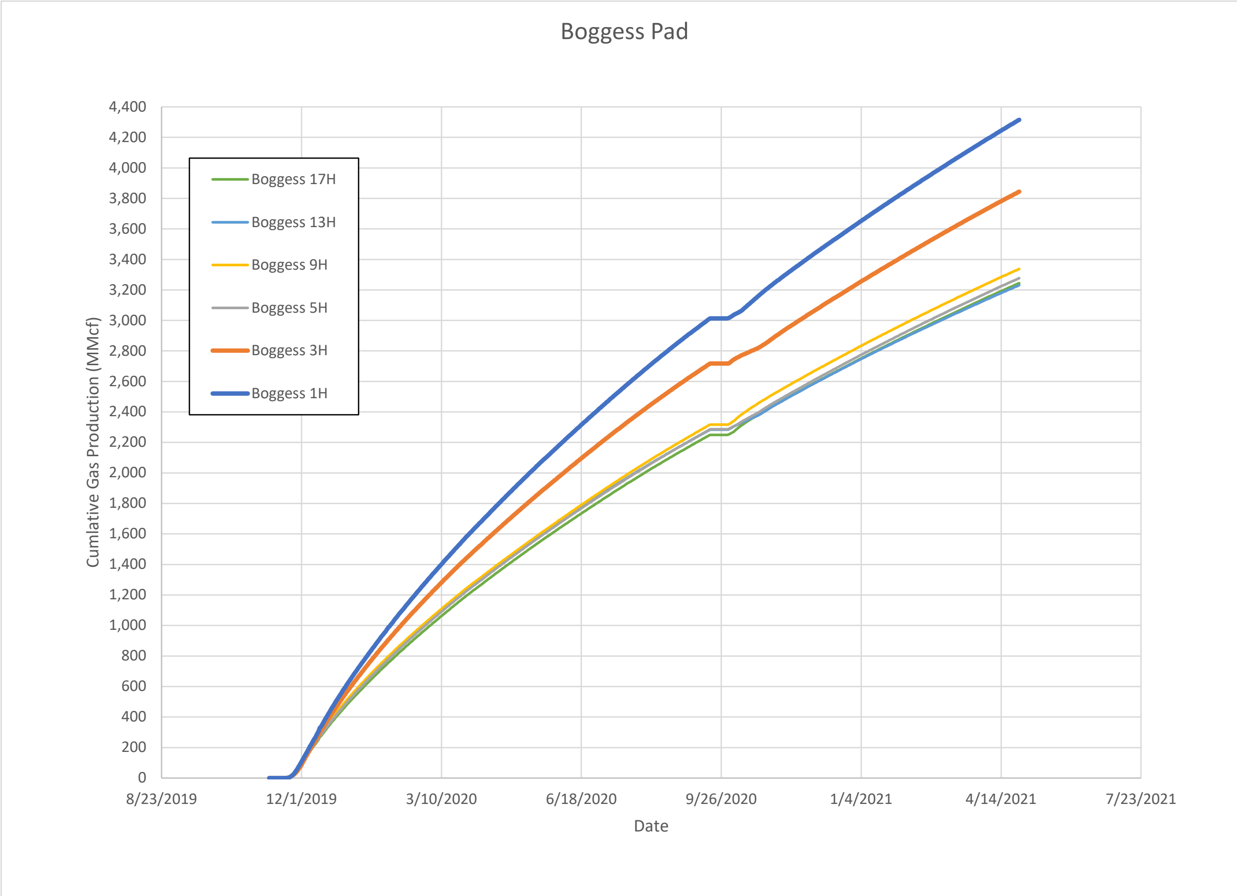

Figure 0.2: Updated (4/27/2021) cumulative production from the Boggess Pad. The wells engineered using the MSEEL software are highlighted with thicker lines (1H and 3H). Wells have different lateral lengths that need to be evaluated to derive a better evaluation of production efficiency. Also outside wells typically perform better than interior wells due to reduced competition. The wells were shut-in for a period because of low gas prices.

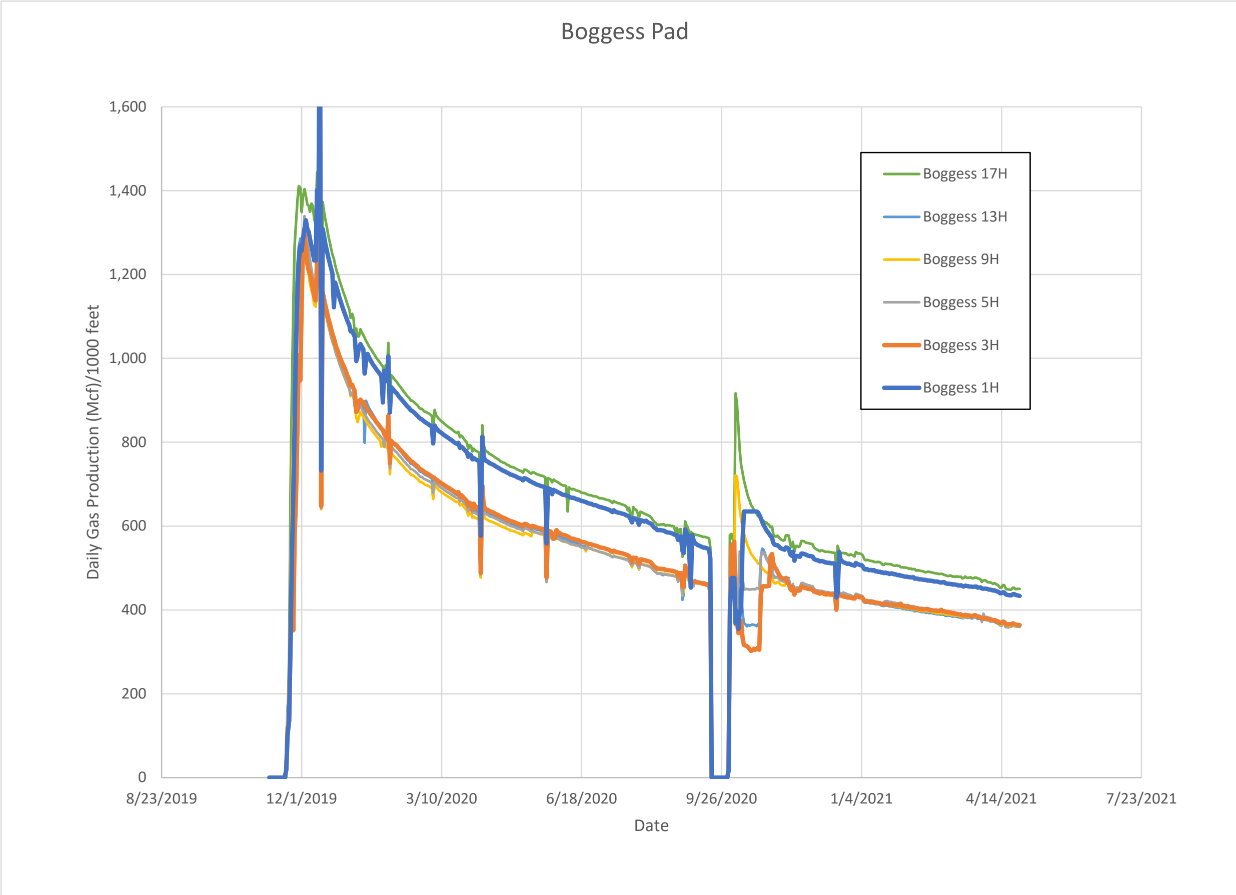

Figure 0.3: Updated (4/27/2021) daily net production from the Boggess Pad adjusted for Mcf per 1000' of completed lateral. The wells engineered using the MSEEL software are highlighted with thicker lines (1H and 3H). As you can see outside wells (1H and 17H) perform better than interior wells due to reduced competition. In addition, wells engineered using the MSEEL approach got off to a slower start but continue to narrow the gap in daily production and in the case of the 3H, it is producing more than any other interior well. In the case of the 17H more sand was used per stage and we need to adjust for sand per foot. However, the 1H is closing the gap. The wells were shut-in for a period because of low gas prices.

Project Management Update

Approach

The project management team will work to generate timely and accurate reporting, and to maintain project operations, including contracting, reporting, meeting organization, and general oversight.

Results and Discussion

The project team is tracking ten (10) milestones in this budget period.

	Task	Milestone	Status	Due Date
1.	3.2.1	Sample collection and analysis of flowback/produced water; data analysis	Complete	20-Mar
2.	3.2.1	Comparison of OTM33A vs. Methane Audits vs. Eddy Covariance System Measurements Complete	This task is ongoing, with initial results expected next quarter (June 2020). There was a short delay in tower deployment at MSEEL 1.0. During this delay, the team focused on the baseline analysis of controlled data from the NSF project. This will lead to two collaborative publications to highlight refinement of approach prior to application to MSEEL data. Early analysis of MSEEL 1.0 have been completed to detect periods for further analysis.	20-Mar
3.	3.1.2	Characterization of organic matter - kerogen extraction and characterization complete	Completed the extraction and 13C NMR analysis of kerogen. Preliminary interpretation included in this report.	21-Mar
4.	3.1.2	Isotopic characterization of produced water and gases - comparison between MIP and Boggess wells and other wells in Marcellus and interpretation.	Complete.	20-Jun
5.	3.1.2	High-pressure and temperature fracture fluid/shale interaction experiments complete.	Complete and ready for publication	21-March
6.	3.1.4	Complete final reservoir	Completed but will continue to refine with new production data any	21-March

		characterization using Boggess 17H pilot well. Compare 17H to MIP 3H	additional well data, and also well monitoring (DTS)	
7.	3.2.1	Methane Audit 14 Completed	Complete	20-Jun
8.	3.4.2	Synthetic data developed for model use	Complete	21-March
9.	3.2.1	Energy Audit Model Completed	Initial data analysis completed, model development continues.	20-Sep
10.	3.1.4	Extend reservoir characterization using logs, completion data and production data to identify good producing stages in Boggess wells.	Delayed due to impacts from COVID-19, including delays in PETREL license renewals. Expect results by June 2021.	21-June

Topic 1 – Geologic Engineering

Approach

The objective of this task is to develop field history-matched reservoir models for the 6 wells drilled and completed in Boggess pad using commercial software CMG-GEM (compositional simulator) and use that for 10 years expected ultimate gas recovery (EUR) predictions. The EUR results obtained from gas production forecasts using history-matched models then were compared with decline curve analysis using multi-segment decline curve, Duong, and stretched exponent techniques obtained using commercial software IHS harmony. Base models for each well in Boggess pad are built using various reservoir rock and fluid properties obtained from well logs and core analysis of Boggess 17H. Initial conditions, trajectories and completions properties of each well collected from completion reports and Hydraulic fracture simulations were reported in our previous quarterly report. The acoustic waterfall maps obtained from Boggess 5H DAS data were used as reference to assign cluster efficiency of all the base models. For history-matching purposes the gas rate is used as constraint and bottom-hole pressure has been history matched. The 10-year EUR forecast is calculated using managed pressure drawdown conducted in a stair step fashion using the average of the last three months' pressure decline rates. Table 1.1 shows the summary of the parameters used to build the base reservoir models. The optimum reservoir parameters are obtained after history matching the reservoir pressure using the rate constraint for each individual well. For history matching the CMG-CMOST software is implemented in which variations of matrix and hydraulic fracturing parameters are used to obtain the best history matched models. Note that in this study, every well is modeled individually and well interference or interactions during completion (frac hits) are not considered.

Table 1.1 Summary of the reservoir properties used for CMG base models

Property	Value	Units	Property	Value	Units
Net Height	95	ft	Fracture Toughness	455	psi*sqrt(in)
Top TVD Marcellus	7880	ft	Young's Modulus	2450000	psi
Bottom TVD Marcellus	7975	ft	Poisson's Ratio	0.18	unitless
Matrix Permeability	400	nd	Pore Pressure Gradient	0.68	psi/ft
Permeability anisotropy	0.1	unitless	Langmuir Volume	240	scf/ton
Matrix Porosity	6.4	%	Langmuir Pressure	670	psia
Natural Fracture Permeability	400	nd	Reservoir Pressure	5400	psi
Natural Fracture Permeability anisotropy	0.1	unitless	Initial Gas Saturation	80	%
Natural Fracture Porosity	0.01	%	Initial Water Saturation	20	%
Natural Fracture density	0.83	Frac/ft	Initial Water Saturation of Hydraulic Fracture	50	%

Results and Discussion

Table 1.2 shows the Boggess wells general information, minimum original gas in place (OGIP), EUR obtained from different decline curve analysis (i.e., Multi-segment, Duong, and stretched exponential) and CMG 10 years EUR forecasts using history matched models. Figures 1 to 6 show the history-match models obtained for each Boggess well and used for 10-year EUR forecasts. As shown in figures 1.1, 1.3 and 1.6 good matches were obtained for Boggess 1H, 5H and 17H, both before and after the shut-in periods. However, Boggess 3H, 9H and 13H show lower quality matches (figures 1.2, 1.4, 1.5). This could be due to the latter group of wells are fully bounded wells and might be impacted by fracture interference that has not been considered in our history matching models. Bohn et al., 2020, using microseismic and fiber optics data have reported the fracture interference (frac-hit) effect during 9H well treatment earlier. The fracture interference effect will be study in the next quarter. Boggess 1H followed by Boggess 17H and Boggess 3H showed the highest EUR in BCF/1000 ft. of lateral length using history matched model.

Table 1.2 Boggess wells analysis summary

Well	B1H	B3H	B5H	B13H	B9H	B17H
Flow Regime	Transient Flow Regime					
Completion design	Geomechanical Spacing			Geometrical Spacing		
TVD	8030	8030	8035	8020	8030	8020
MD	20872	21075	20226	20298	19835	19026
LL	12544	13117	11128	10801	11201	8823
Stages	63	66	56	55	57	45
Pi	5139	5139	5142	5133	5139	5133
Stage Length (ft)	199	199	199	196	197	196
Boundedness	semi-bounded	bounded	bounded	bounded	bounded	semi-bounded
TIL (days)	216	216	216	216	216	215
Min OGIP BCf/1000ft	2.66	2.37	2.28	1.97	2.17	2.66
DCA Multisegment (EUR BCf/1000ft)	0.92	0.89	0.91	0.84	0.91	1.1
DCA Duong (EUR BCf/1000ft)	0.94	0.89	0.88	0.82	0.77	1.14
DCA Stretched exponent (EUR BCf/1000ft)	1.08	0.86	0.83	0.8	0.86	1.1
DCA (averaged) EUR BCf/1000ft	0.98	0.88	0.87	0.82	0.85	1.11
CMG HM model (EUR BCf/1000ft)	1.26	0.92	0.74	0.81	0.82	1.05

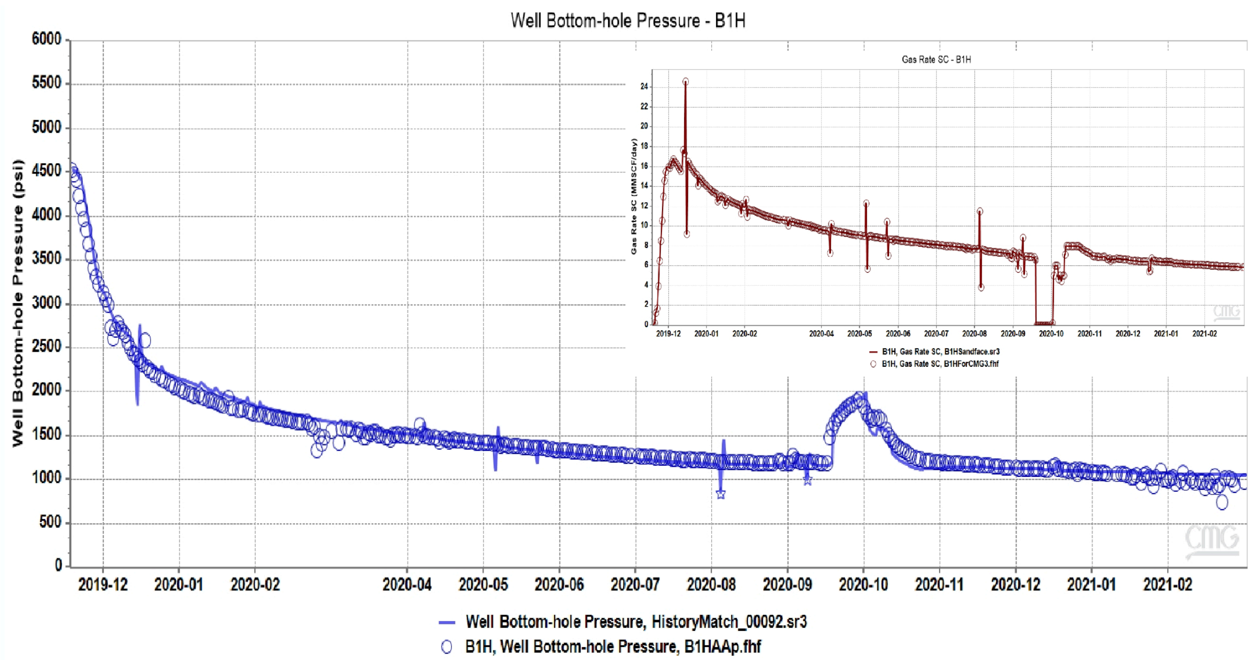

Figure 1.1 Boggess 1H pressure bottom hole pressure history-match in blue and gas rate constraint in red.

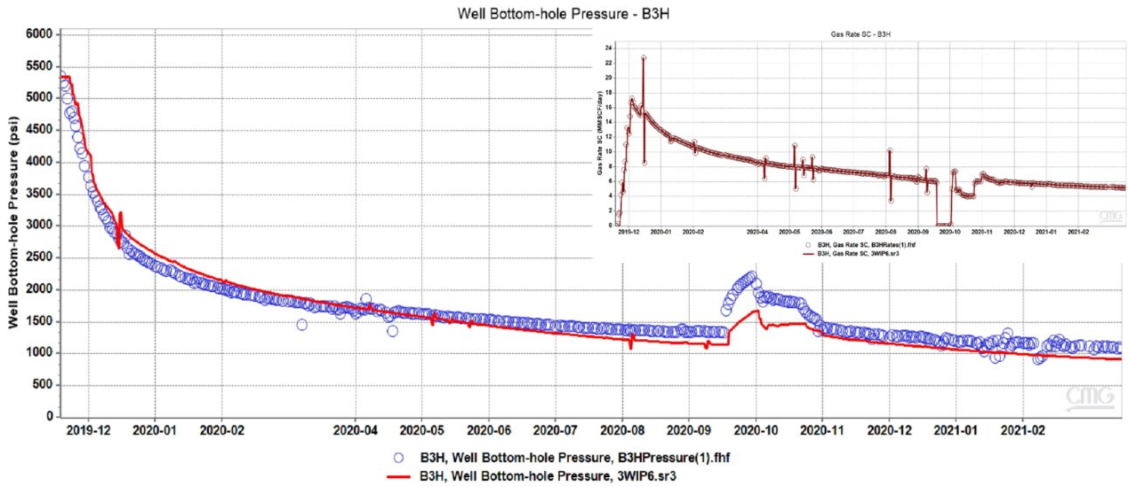

Figure 1.2 Boggess 3H pressure bottom hole pressure history-match in blue and gas rate constraint in red.

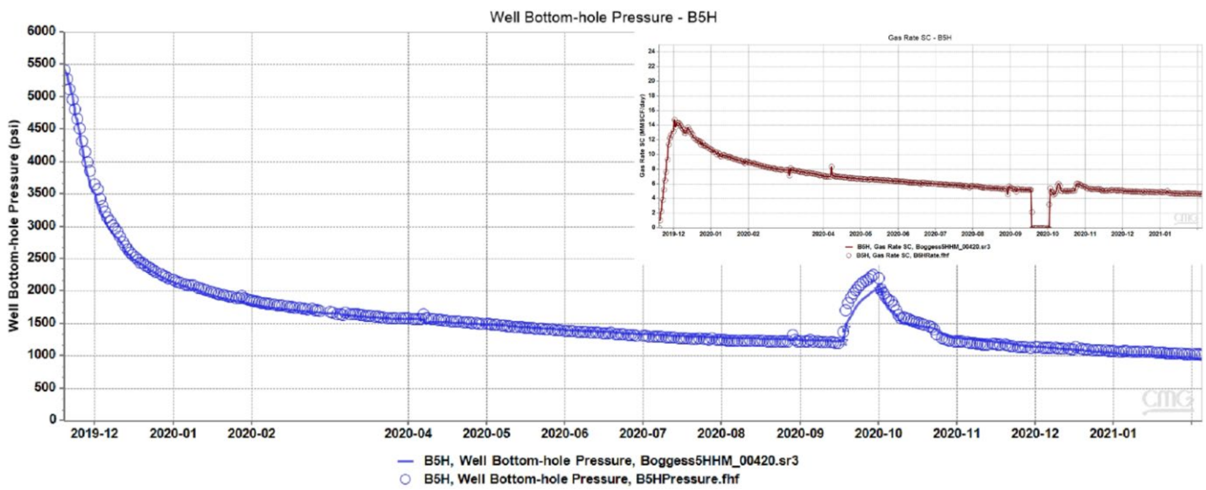

Figure 1.3 Boggess 5H pressure bottom hole pressure history-match in blue and gas rate constraint in red.

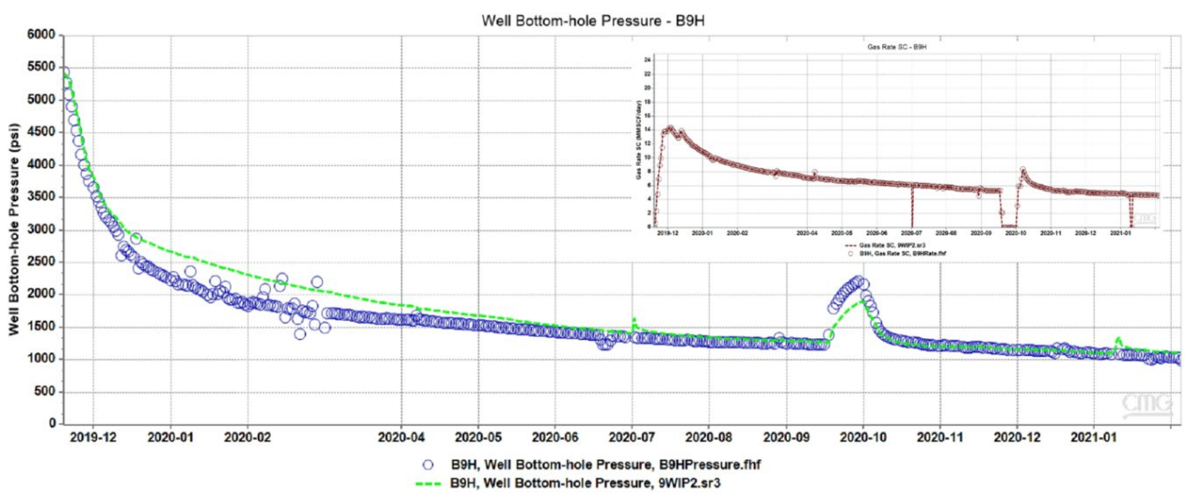

Figure 1.4 Boggess 9H pressure bottom hole pressure history-match in blue and gas rate constraint in red.

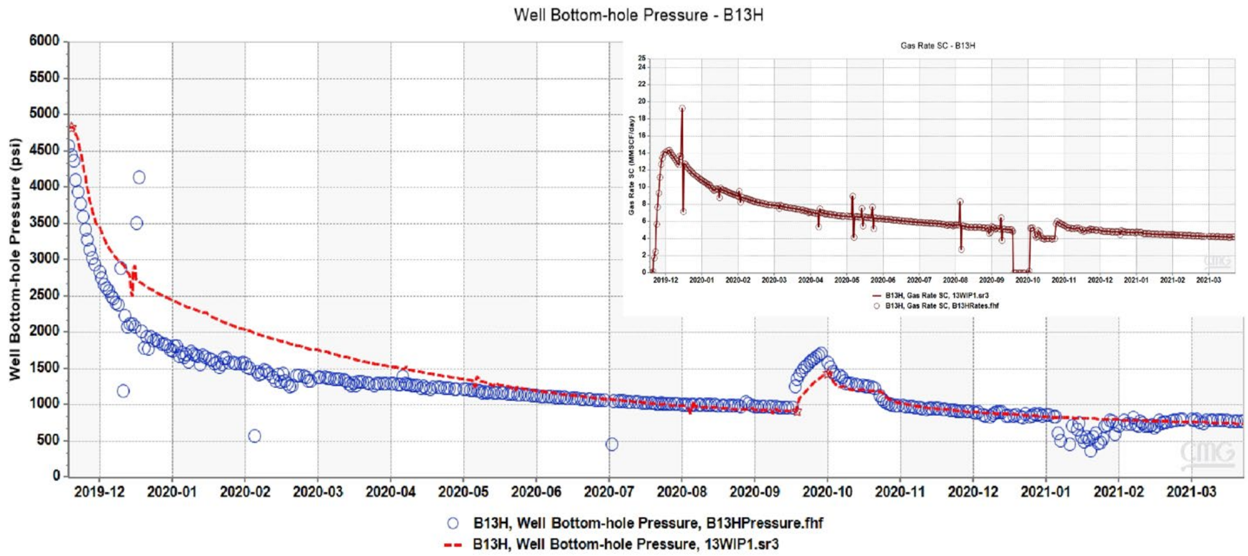

Figure 1.5. Boggess 13H pressure bottom hole pressure history-match in blue and gas rate constraint in red.

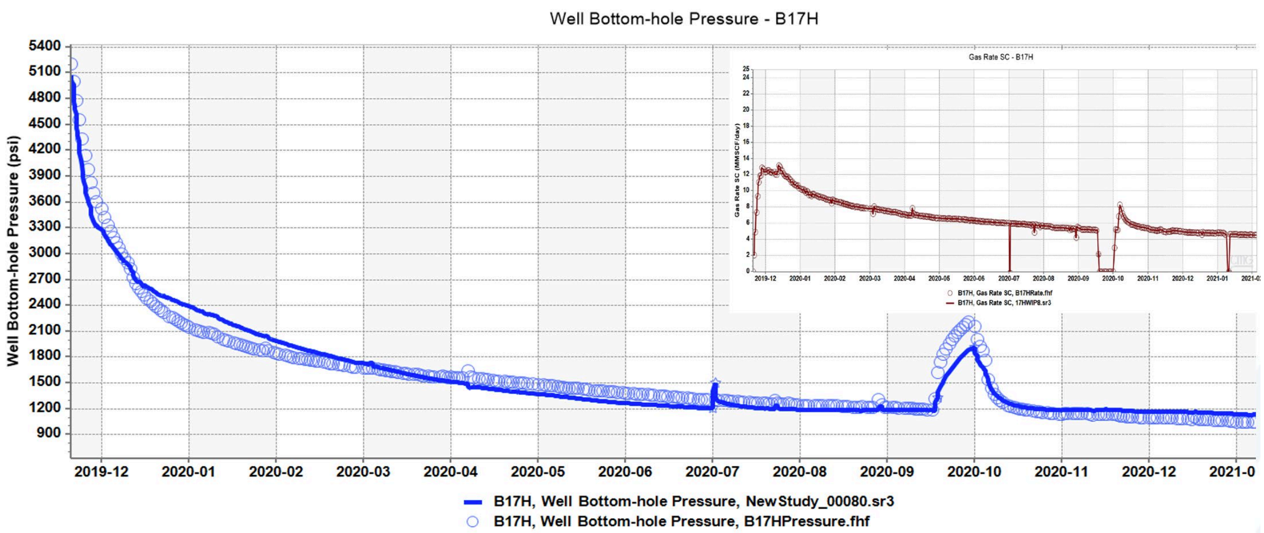

Figure 1.6. Boggess 17H pressure bottom hole pressure history-match in blue and gas rate constraint in red.

Products

All reservoir parameters from the 17H pilot well were used to develop a reservoir characterization and build a history-matched CMG models for individual wells drilled and completed in Boggess pad.

Decline curve analysis was updated based on new gas production and EUR forecasts are obtained using different techniques for each well.

A peer-reviewed paper entitled *Shale Poroelastic Effects on Well Performance Analysis of Shale Gas Reservoirs* was published using the results from MIP wells. The complete citation is listed in Appendix A.

Plan for Next Quarter

1- Sensitivity and economic analysis will be performed to obtain the probabilistic EUR models for each well.
2- Well interference and Frac hit will be investigated using multiple wells scenarios.
3- The effect of shut-in periods on EUR will be investigated.

Topic 2 – Geophysical & Geomechanical

Approach

We have used the core and log data from the pilot wells at the MIP Pad (3H) and the Boggess Pad (17H) and significantly enhanced by the logs in the lateral of the MIP 3H lateral and the LWD in the laterals at the Boggess Pad to develop a reservoir characterization as input to the reservoir simulations. The critical reservoir parameters are summarized in a series of spreadsheets stored on the MSEEL web site. Below are a couple of highlights from this quarter,

Results and Discussion

Completed the petrophysical models for the Boggess 17 and MIP 3 pilot wells using core and logging data. Gas in place calculations were performed for both wells and compared to values derived by Schlumberger. Table 2.1 shows a comparison of all the gas in place values.

Table 2.1. Comparison of gas in place calculations performed by Schlumberger and WVU for the Boggess 17 pilot well to the MIP 3 pilot.

	Schlumberger		WVU	
Zone	MIP 3 GIP	Boggess 17 GIP	MIP 3 GIP	Boggess 17 GIP
	(Bcf/mi^2)	(Bcf/mi^2)	(Bcf/mi^2)	(Bcf/mi^2)
Middlesex to Tully	25	66	49	86
Hamilton to Marcellus	24	35	19	26
Marcellus to Onondaga	91	70	88	90
Total	**140**	**171**	**156**	**202**

We reinterpreted the FracView LWD image data from the Boggess 5H lateral and mapped 6,366 fractures with a primary NNE and ESE orientation (Figure 2.1). This is very similar to the orientation and intensity observed at the MIP 3H with the Schlumberger QuantaGeo. The fractures were loaded in Petrel software in an attempt to build a 3D fracture model (figure 2.2 and 2.3). However, the software is only able to produce stochastic fracture models which do not honor the actual identified fractures. Next quarter we will build a deterministic 3D fracture model using Python.

A log for the Boggess 5H showing LWD GR, fracture intensity log (10 foot bin), fracture intensity log (5 foot bin) and fracture dip tadpoles for stages 5 through 10 was created and a complete image is available on the MSEEL web site (Figure 2.4). The fracture intensity logs in the Boggess 5H lateral well bore were correlated to the comprehensive suite of logs acquired in the Boggess 17 pilot well. Cross plots were created for all pilot logs versus the fracture intensity

(Figure 2.5). Good correlation was found between the spectral gamma ray, specifically the uranium track, and the fracture intensity logs.

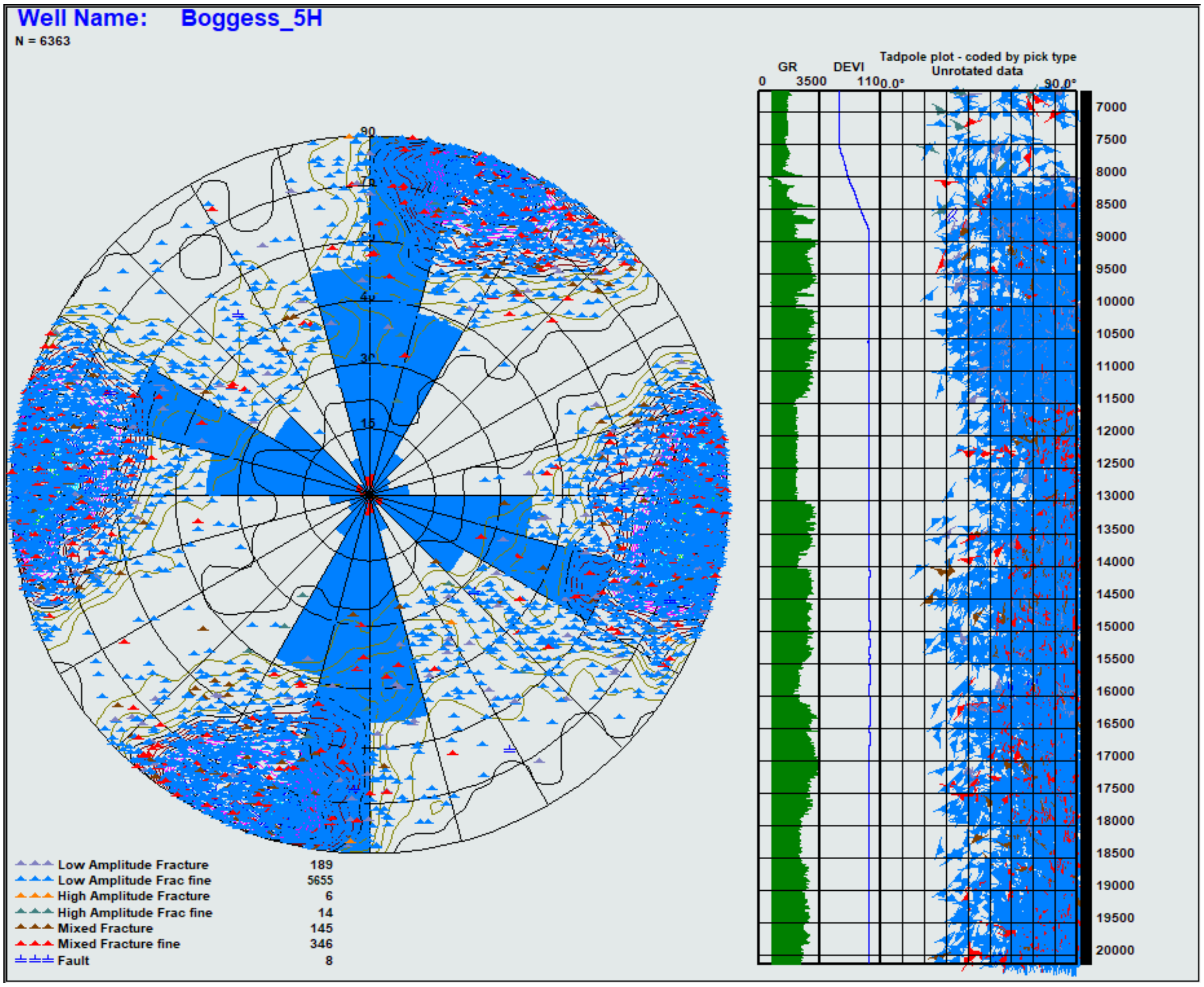

Figure 2.1. Stereonet and tadpole plots of the fractures identified in the Boggess 5H.

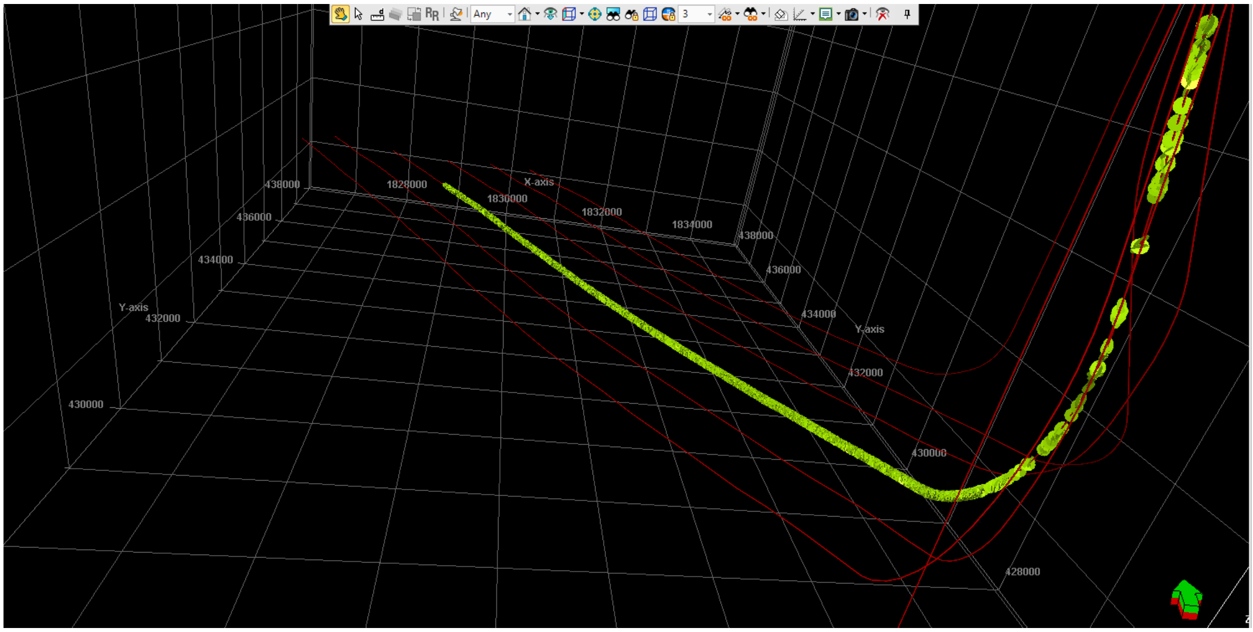

Figure 2.2. Boggess 5H wellbore with fractures displayed as discs in Petrel.

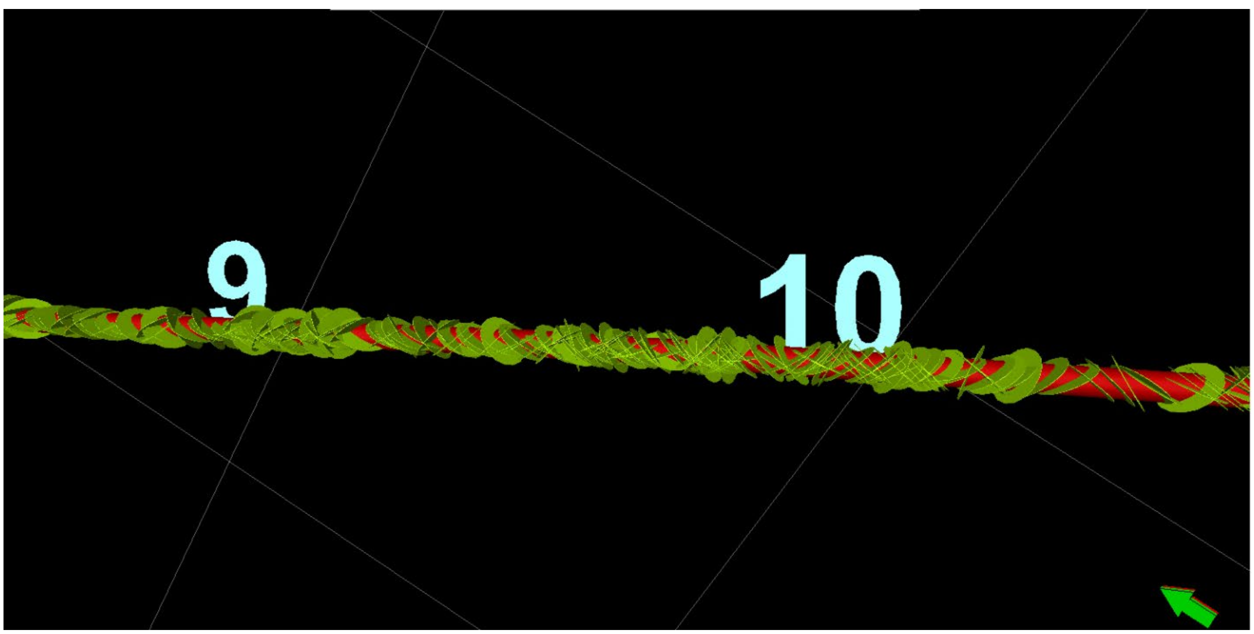

Figure 2.3. Close up view of fractures in Petrel in the Boggess 5H wellbore for stage 9 and 10 showing the variations in fracture intensity along the lateral. Fracture intensity logs were produced from the fracture data for both a 10-foot and 5-foot bin (figure 2.4).

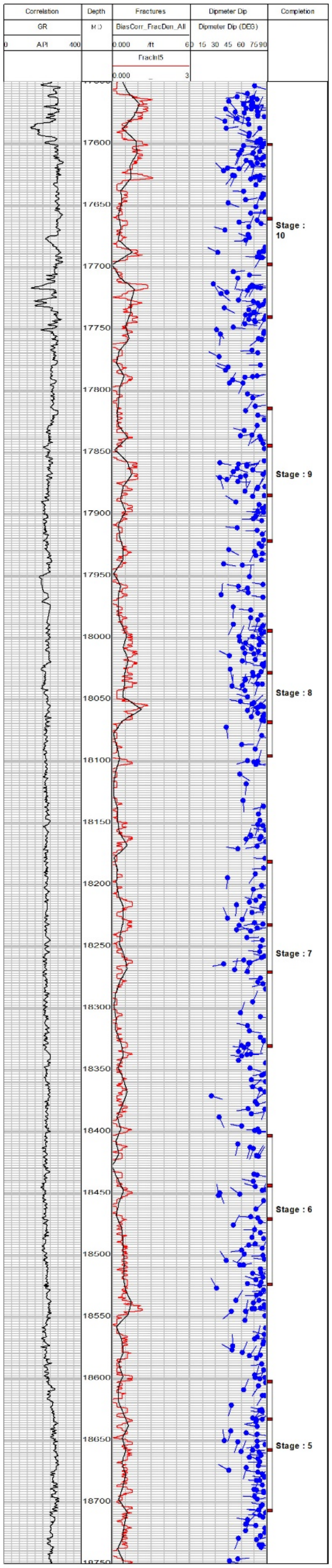

Figure 2.4. Log for the Boggess 5H showing GR, fracture intensity log (10-foot bin), fracture intensity log (5-foot bin) and fracture dip tadpoles covering stages 5 through 10. A complete version is available for download on the MSEEL web site.

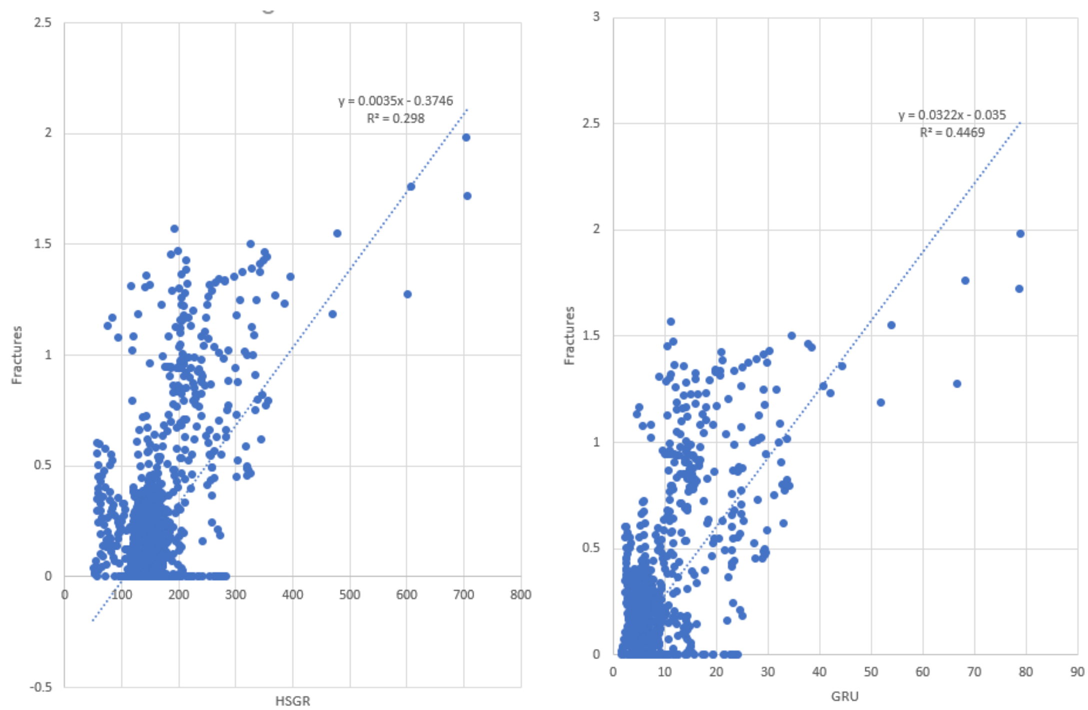

Figure 2.5. Cross plot of fracture intensity log versus (a) spectral gamma ray and the (b) gamma ray – uranium.

The natural fractures have been re-analyzed and interpretation results are treated as true labels. The Python script for exploratory data analysis and showed the fracture distributions are left-skewed (Figure 2.6). Supervised learning method for binary classification task by implementing support vector machine with Python's Scikit-learn. Work is ongoing on validating the fracture intensity dataset to make sure that the measured depth is aligned with raw vibration signals as recorded in FracView's acoustic tool. In addition, different machine learning models will be implemented to improve the prediction accuracy.

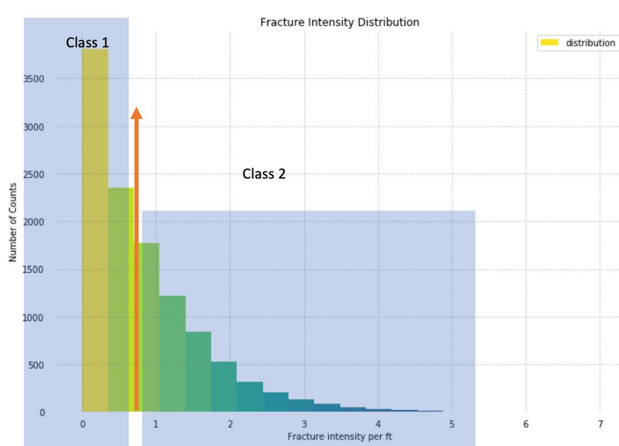

Figure 2.6. Histogram for natural fracture intensity distribution for Boggess 5H.

Facies modelling

Core XRD data and lithoscanner logs for both the Boggess 17 and MIP 3 were used to create facies models for both wells. The ternary diagram for both wells (figure 2.7) show that both wells have similar facies distributions for the Marcellus to Onondaga zone. For the Hamilton to top of Marcellus zone, however, the Boggess is more clay rich than the MIP well. A cross section showing the facies derived from plotting mineralogies derived from Schlumberger's lithoscanner logs (left track) and gas in place (right track in red) (Figure 2.8). Facies are classified using the sCore classification (Gamero, 2012).

NETL has completed their high resolution XRF scanning of the Boggess core and the data has been received.

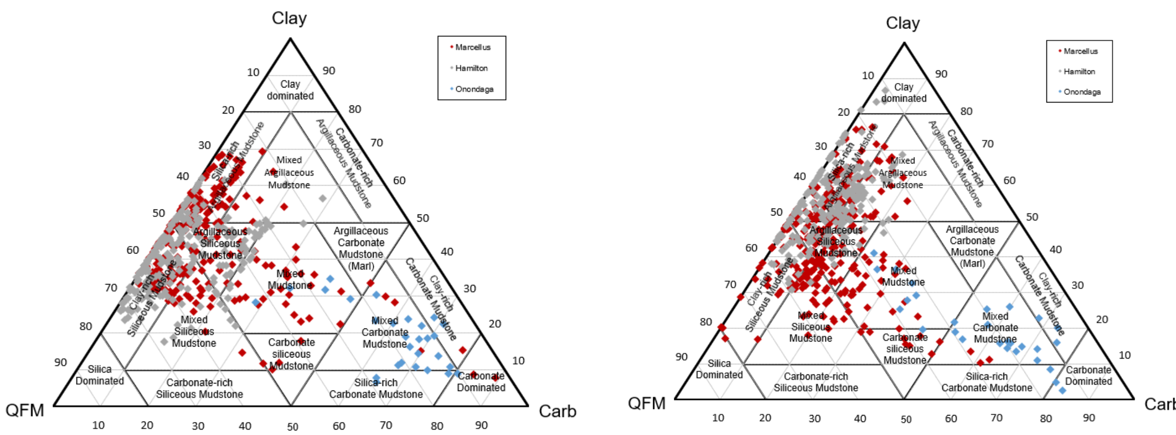

Figure 2.7. Ternary diagrams plotting mineralogy derived from Schlumberger's lithoscanner logs for the (a) Boggess 17 and (b) MIP 3 wells. Marcellus Shale indicated by reddots

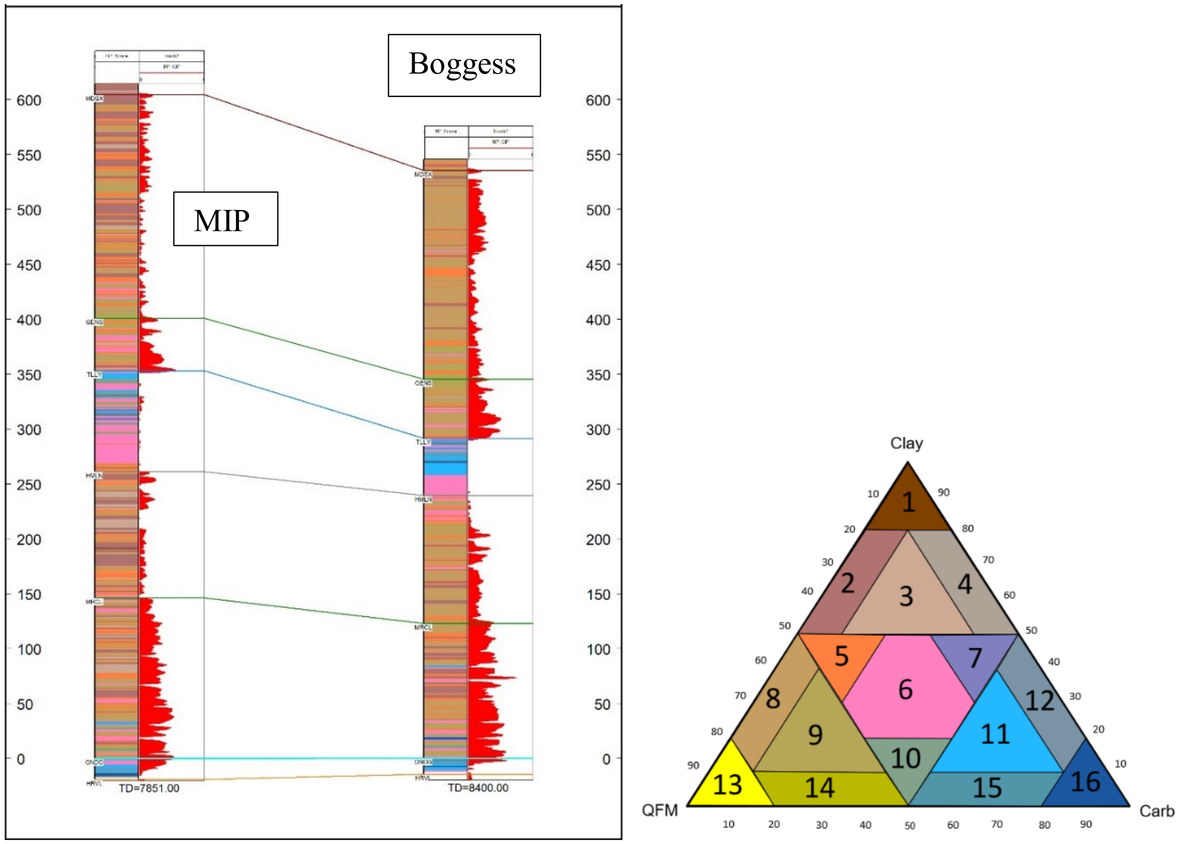

Figure 2.8. Cross section A-A' showing the facies derived from plotting mineralogies derived from Schlumberger's lithoscanner logs (left track) and gas in place (right track in red). Facies are classified using the sCore classification[1].

Products

Reservoir characterization data is summarized in a series of spreadsheets available for download from the MSEEL web site. A publication using data from the MIP Pad entitled *Evaluating proxies for the drivers of natural gas productivity using machine-learning models* appear in Interpretation (Kumar et al., 2021).

Plan for Next Quarter

Analyze LWD FracView image data from the other wells at the Boggess Pad, and create a 3D fracture model using custom software (Python).

Integrate the XRF data received from NETL into the facies modelling.

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[1] Gamero-Diaz, H., Miller, C. and Lewis, R., 2012, sCore: A Classification Scheme for Organic Mudstones Based on Bulk Mineralogy, AAPG Search and Discovery article #40951. Web accessed 21 April 2021. http://www.searchanddiscovery.com/documents/2012/40951diaz/ndx_diaz.pdf

Topic 3 – Deep Subsurface Rock, Fluids, & Gas

Sharma Group MSEEL Report

1. **Characterization of organic matter - kerogen extraction and characterization.** ^{13}C solid-state analysis of the core sample from the producing zone of Boggess 17H to determine its structural parameters is complete. The preliminary interpretation suggests that the Boggess 17H kerogen has 89.8% aromatic carbon, 9.5 % aliphatic carbon, 0.5% carboxyl and amide associated carbon, and 0.2 % carbonyl associated carbons (Fig.1). The molecular structural parameters, lattice structural parameters, and average unit structural model of the kerogen will be determined/built by summer 2021. Further, to determine heterogeneity in kerogen molecular structure, especially within similar maturity and type, the structural parameters and unit kerogen model of Boggess 17H will be compared with available data on kerogen molecular structure from other parts of the Marcellus Shale basin.

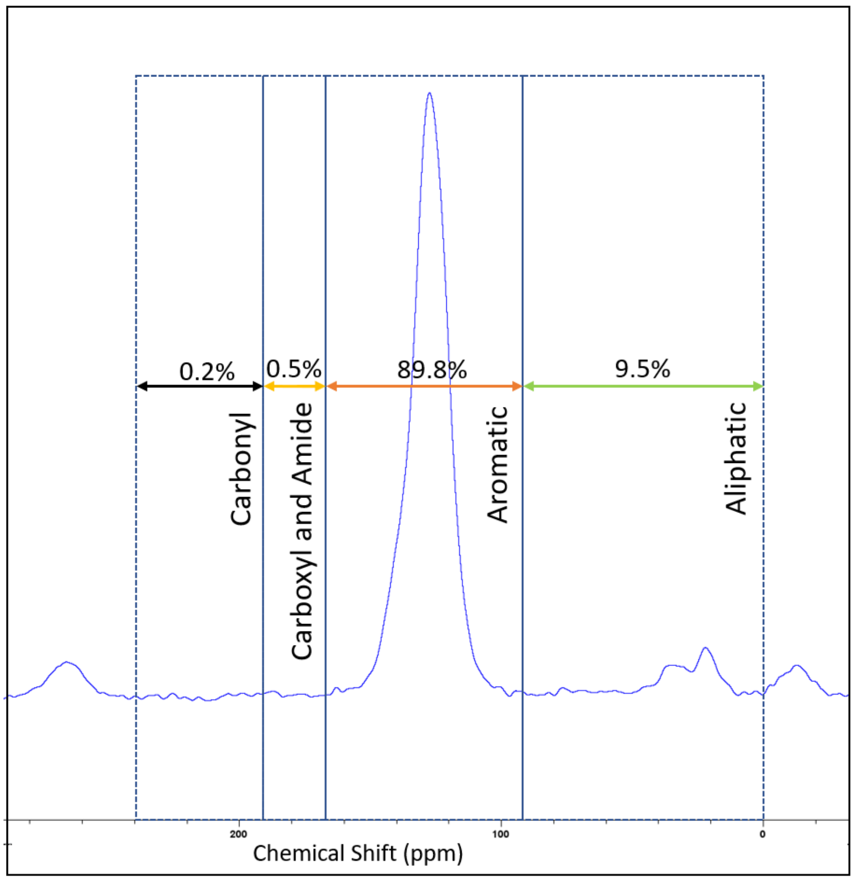


Figure 3.1. 13C solid-state NMR spectra of Boggess 17H kerogen sample.

Deliverables: 1) Determine molecular structural parameters, lattice structural parameters and build an average unit structural model of kerogen by Summer 2021 2) Present key findings in a conference in Summer-Fall 2021.

2. **High-pressure and temperature fracture fluid/shale interaction experiments.** Shale-hydraulic fracturing fluid experiments (HFF) were conducted using core Boggess 17H and synthetic fracturing fluid containing sodium bromate as oxidative breaker. Reacted fluid from the

experiments was analyzed in ICP-MS, ICP-OES to determine the amount of trace elements released. Our analysis show a large release of elements such as B, Mg, Si, K, Fe, and Sr (Fig.3.2) The fluids were also analyzed in IC (ion chromatography) to determine the release of organic acids, major ions (cations and anions). Our analysis show that Shale-HFF released organic acids such as acetate, propionate formate, and oxalate (Fig. 3.3). It also showed the release of cations calcium and anions such as chloride, bromide, nitrite and phosphate (Fig. 3.4). Ions such as ammonium, barium, thiosulfate and iodide were either not detected of present in very low concentrations (Fig. 3.4). To determine the heterogenity and controls on release of trace elements, ions and organics, the results from these experiment will be compared with experimental results conducted on another Marcellus Shale (also at dry gas window).

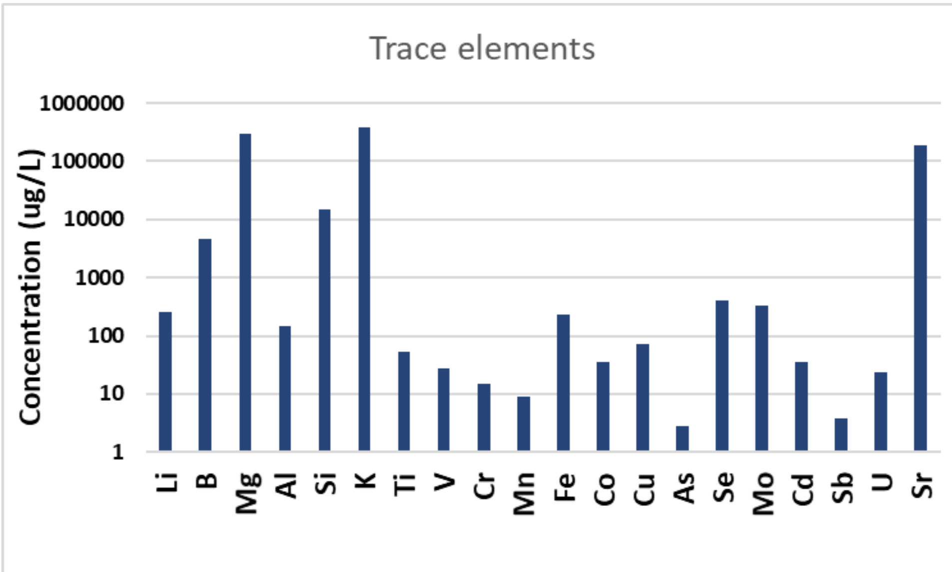


Fig. 3.2 Trace elements analyzed by ICP-MS and IC-OES from Boggess sample reacted with sodium bromate HFF.

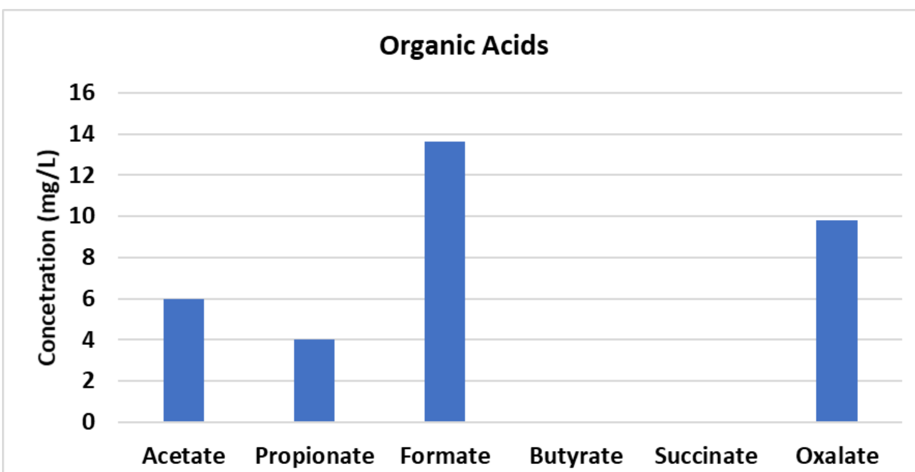


Fig. 3.3 Organic Acids analyzed by IC from Boggess sample reacted with sodium bromate HFF.

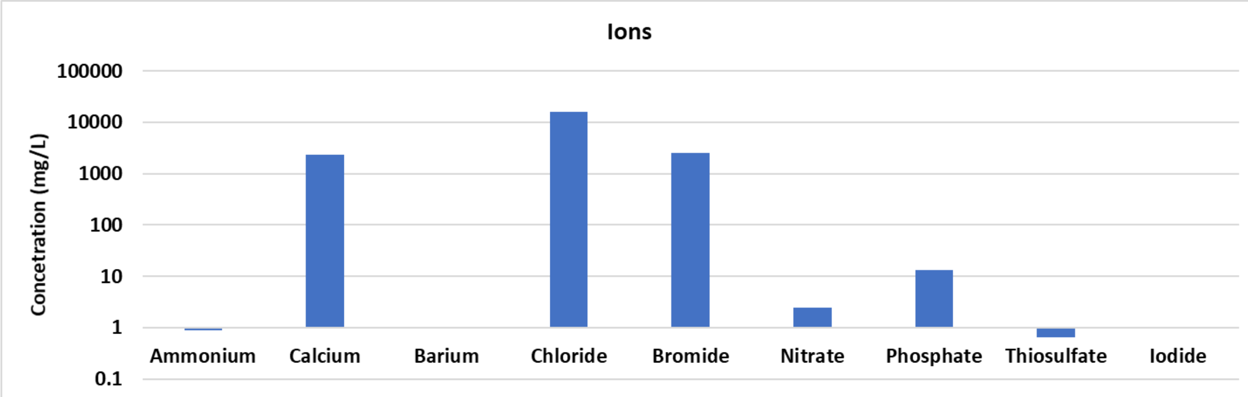


Fig. 3.4 Cations and anions analyzed by IC from Boggess sample reacted with sodium bromate HFF.

Deliverables: 1) Conduct shale-HFF experiments on Marcellus shale derived from different region (similar maturity window) using similar fracturing fluid composition and reaction time in summer 2021 2) Present key findings in a conference in Summer-Fall 2021.

Ohio State Input: MSEEL Fiscal Year 2021

Quarter 2 input (Jan-March 2021)

Mouser Group:

We are slated to collect samples at MSEEL II later this month or early May. The fluids are being used in enrichment bioreactor studies in my lab.

Products (publication)

Aghababaei Shahrestani M, Luek JL, Mouser PJ. Temporal Toxicity in Hydraulic Fracturing Wastewater from Black Shale Natural-Gas Wells in the Appalachian Basin. (2021), *Environmental Science: Processes and Impacts*. DOI:10.1039/D1EM00023C.

https://pubs.rsc.org/en/content/articlepdf/2021/EM/D1EM00023C?page=search

Products (presentations)

Colosimo F, Purvine SO, Kyle JE, Olson HM, Wong AR, Eder EK, Hoyt DW, Callister SJ, Chu RK, and Mouser PJ. (poster). 'Omics analyses of the hydraulically fractured shale isolate Halanaerobium highlights membrane modifications that underpin adaptation under deep subsurface biogeochemical drivers. U.S. Department of Energy, Office of Biological and Environmental Research, 2021 Biological System Sciences Division Principal Investigators' Meetings, Virtual, February 22-25, 2021.

Adhikari J, Colosimo F, Mouser PJ. (poster). Microbial Osmotolerance Mechanisms in Hydraulically Fractured Shale Elucidated Through Metagenomics Analysis. U.S. Department of Energy, Office of Biological and Environmental Research, 2021 Biological System Sciences Division Principal Investigators' Meetings, Virtual, February 22-25, 2021.

Aghababaei M, Luek JL, Colosimo F, Mouser PJ. (oral presentation). Toxicity of hydraulic fracturing wastewater from black shale natural-gas wells influenced by well maturity and chemical additives. ACS annual conference, Virtual, April, 2021.

Cole Group:

On-line and in print now:

Susan A. Welch, Julia M. Sheets, Rebecca A. Daly, Andrea Hanson, Shikha Sharma, Thomas Darrah, John Olesik, Anthony Lutton, Paula J. Mouser, Kelly C. Wrighton, Michael J. Wilkins, Tim Carr, David R. Cole (2021) Comparative geochemistry of flowback chemistry from the Utica/Point Pleasant and Marcellus formations. *Chemical Geology* 564, 120041 doi.org/10.1016/j.chemgeo.2020.120041

Topic 4 – Produced Water and Solid Waste Monitoring

Approach

MIP Site

Over five years into the post completion part of the program, the produced water and solid waste component of MSEEL has continued to systematically monitor changes in produced water quality and quantity. During year one of the study, hydraulic fracturing fluid, flowback, produced water, drilling muds and drill cuttings were characterized according to their inorganic, organic and radiochemistries. In addition, surface water in the nearby Monongahela River was monitored upstream and downstream of the MSEEL drill pad. Toxicity testing per EPA method 1311 (TCLP) was conducted on drill cuttings in both the vertical and horizontal (Marcellus) sections to evaluate their toxicity potential. Sampling frequency has been slowly scaled back following well development. Table 4.1 shows an "X" for sample collection dates. Wells 4H and 6H were brought back online in late 2016. Other blank sample dates in Table 4.1 indicate that samples were not collected, due to lack of availability of produced water from the well(s).

Table 4.3. MIP sampling events are indicated with an "X".

Year	2015		
Day/Month	10-Dec	17-Dec	22-Dec
3H	X		X
4H			
5H	X	X	X
6H			

Year	2016												
Day/Month	6-Jan	20-Jan	3-Feb	2-Mar	23-Mar	20-Apr	18-May	2-Jul	17-Aug	21-Jun	19-Oct	16-Nov	14-Dec
3H	X	X	X		X	X	X	X	X	X	X		X
4H												X	X
5H	X	X	X	X	X	X	X	X	X	X	X	X	
6H												X	X

Year	2017							
Day/Month	13-Jan	14-Feb	13-Mar	7-Apr	5-May	12-Jul	3-Nov	20-Dec
3H	X	X	X	X	X	X	X	X
4H	X	X	X	X	X			
5H		X			X			X
6H	X	X	X	X	X			

Year	2018					
Day/Month	22-Jan	23-Feb	16-May	2-Aug	16-Oct	15-Dec
3H	X	X	X	X		X
4H	X	X	X	X	X	X
5H	X		X		X	X
6H			X	X		

Year	2019							
Day/Month	24-Jan	5-Mar	6-May	13-Jun	18-Sep	21-Oct	21-Nov	30-Dec
3H	X	X	X	X	X	X	X	X
4H	X	X					X	X
5H	X	X	X	X	X	X	X	X
6H		X					X	X

Year	2020									
Day/Month	30-Jan	27-Feb	25-Mar	28-Apr	27-May	30-Jul	5-Oct	26-Oct	24-Nov	30-Dec
3H	X	X	X	X	X	X	X	X	X	X
4H	X	X	X	X	X				X	X
5H		X	X	X	X	X	X	X	X	X
6H	X	X	X	X						X

Year	2021		
Day/Month	27-Jan	26-Feb	25-Mar
3H	X	X	X
4H	X	X	X
5H	X	X	X
6H	X	X	X

Boggess Site

Two control wells; 9H and 17H were selected for solids and aqueous studies at the newly developed Boggess well site.

Tophole was completed in Feb 2019 for 9H and Jan 2019 for 17H. Samples of vertical drilling were not obtained due to completion prior to the start of the Boggess project.

Horizontals were initiated on 19 June 2019 for 17H and 20 May 2019 for 9H (Table 4.2). A drilling mud sample along with depth samples at 8,500ft; 10,000ft; 11,000ft; 13,000ft; and 15,000ft were collected and analyzed for parameters shown in Table 4.3.

Table 4.4. Sample depth and dates for collection of horizontal drilling mud and cutting samples.

Depth/Well	Mud 9H	8500 9H	10000 9H	11000 9H	13000 9H	15000 9H
Date	5/27/2019	5/27/2019	5/28/2019	5/29/2019	5/29/2019	5/30/2019

Depth/Well	Mud 17H	8500 17H	10000 17H	11000 17H	13000 17H	15000H
Date	7/1/2019	7/1/2019	7/1/2019	7/1/2019	7/1/2019	7/1/2019

Table 4.5. Solids analysis list.

Analysis	Method	Units	Parameter
Diesel Range Organics by GC-FID	SW8015M	mg/kg-dry	DRO (C10-C28)
			ORO (C28-C40)
		% Rec	Surr: 4-terphenyl-d14
Gasoline Range Organics by GC-FID	SW8015D	ug/Kg	GRO C6-C10)
		% Rec	Surr: Toluene-d8
Volatile Organic Compounds	SW8260B	ug/kg-dry	Ethylbenzene
			m,p- Xylene
			o- Xylene
			Styrene
			Toluene
			Xylenes total
		% Rec	Surr: 1,2- Dichloroethane-d4
			Surr: 4-Bromofluorobenzene
			Surr: Dibromofluoromethane
			Surr: Tolouene-d8
Radionuclides	EPA 901.1	pCi/g	Potassium-40
			Radium-226
			Radium-228
	9310		Gross Alpha
			Gross Beta
Inorganics	SW9056A	mg/kg-dry	Br
			Cl
			SO4
	SW9034		sulfide
	E353.2		nitrate
	E354.1		nitrite
	A2510M	µS/cm	EC
	SW9045D	units	pH
	A4500-CO2 D	mg/kg-dry	alk bicarb
			alk carb
			alk t
	E365.1 R2.0		TP
	SW6020A		Ag
			Al
			As
			Ba
			Ca
			Cr
			Fe
			K
			Li
			Mg
			Mn
			Na
			Ni
			Pb
			Se
			Sr
			Zn
Moisture	E160.3M	%	Moisture
Chemical Oxygen Demand	E4104 R2.0	mg/kg-dry	COD
Organic Carbon - Walkley-Black	TITRAMETRIC	% by wt-dry	OC-WB
Oil & Grease	SW9071B - OG	mg/kg-dry	O&G

Flowback sampling was initiated on 18 Nov 2019 with weekly collection at 9H and 17H for the first four weeks (Table 4.4). Monthly sampling began following the initial weekly sampling effort. Samples were not collected in June and August 2020.

Table 4.6. Boggess sampling events are indicated with an "X".

Year	2019			
Day/Month	18-Nov	25-Nov	2-Dec	10-Dec
9H	X	X	X	X
17H	X	X	X	X

Year	2020									
Day/Month	30-Jan	27-Feb	25-Mar	28-Apr	27-May	30-Jul	5-Oct	26-Oct	24-Nov	16-Dec
9H	X	X	X	X	X	X	X	X	X	X
17H	X	X	X	X	X	X	X	X	X	X

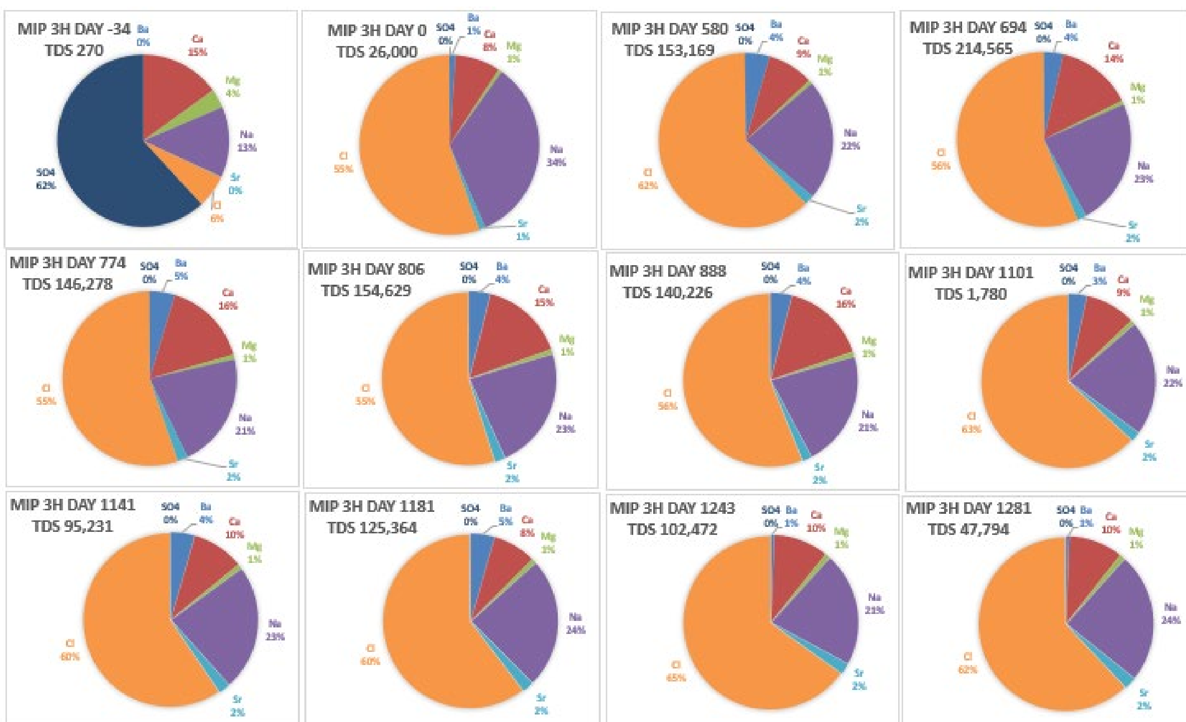
Year	2021		
Day/Month	27-Jan	26-Feb	25-Mar
9H	X	X	X
17H	X	X	X

Results & Discussion

MIP Site

Major ions – trends in produced water chemistry

While makeup water was characterized by low TDS (total dissolved solids) and a dominance of calcium and sulfate ions, produced water from initial flowback is essentially a sodium/calcium chloride water (Figure 4.1).



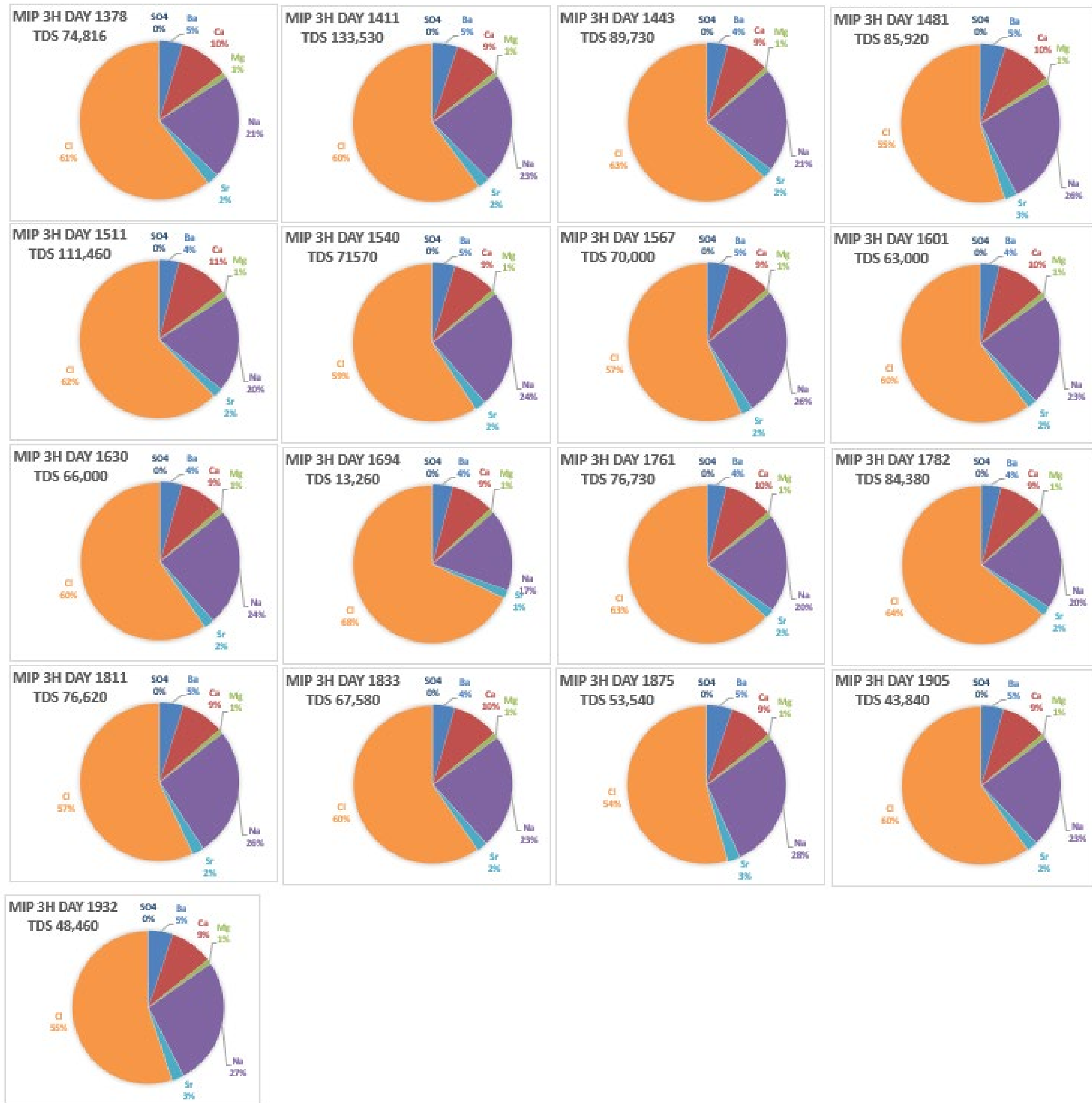


Figure 4.7. Changes in major ion concentrations in produced water from well MIP 3H. Top left Day -34 represents makeup water from the Monongahela River, produced water on the first day (Day 0) and the remainder of pie charts show flowback and produced water on sampling dates through the 1932nd day post-completion.

TDS in wells 3H and 5H increased rapidly over the initial 90 days post-completion, while TDS stabilized between 100,000 and 215,000 mg/L through day 1181(3H). Note that 3H and 5H were both shut-in near day 966 and brought back online before sampling day 1101. Values varied between sampling dates 1101 through day 1411 and again on day 1694, which may reflect additional well closures. Beginning on day 1443, 3H stabilizes between 45,000 and 89,000 mg/L; 5H stabilizes between 120,000 and 186,000 mg/L (Figure 4.2), with the exception of day 1694.

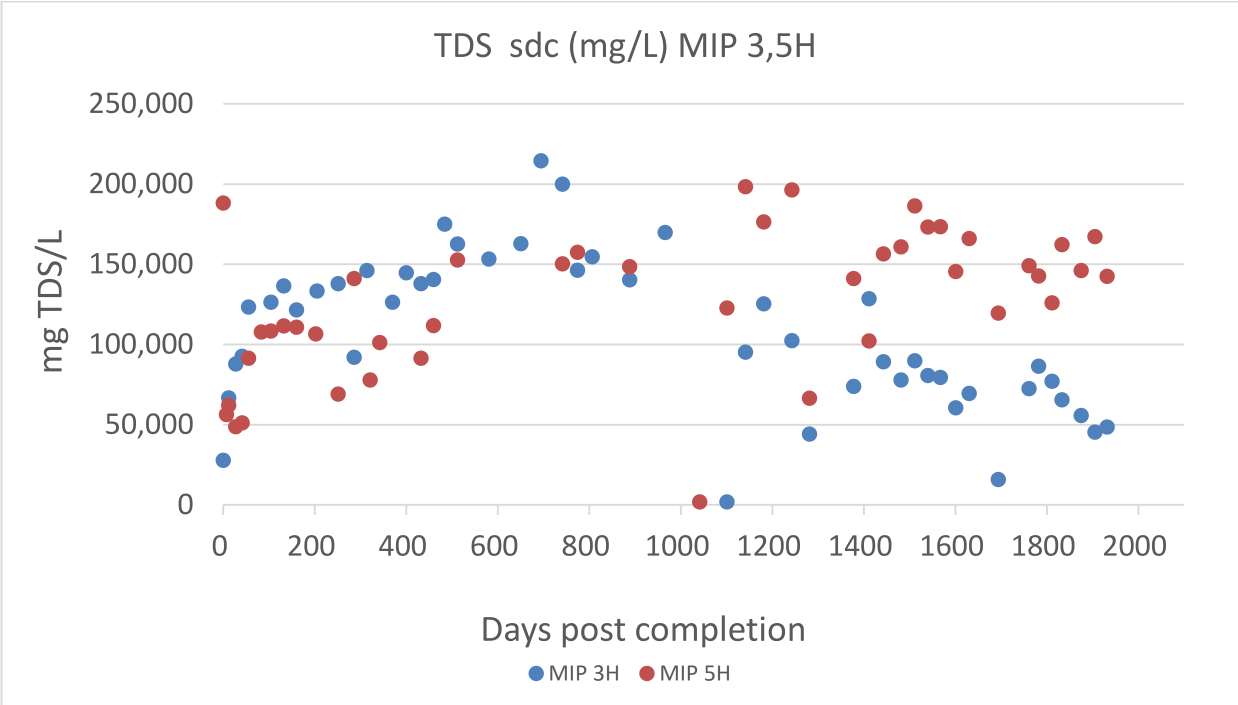


Figure 4.8. Changes in produced water TDS sdc (sum of dissolved constituents) through the first 1932 days post-completion (3,5H).

The older 4H and 6H wells were shut down numerous times during the study period. When wells return online, TDS values increase during subsequent sampling events. TDS ranges at 4H from 50,000 to 150,000 mg/L during times when wells are online and from 30,000 to 150,000 mg/L at 6H (Figure 4.3).

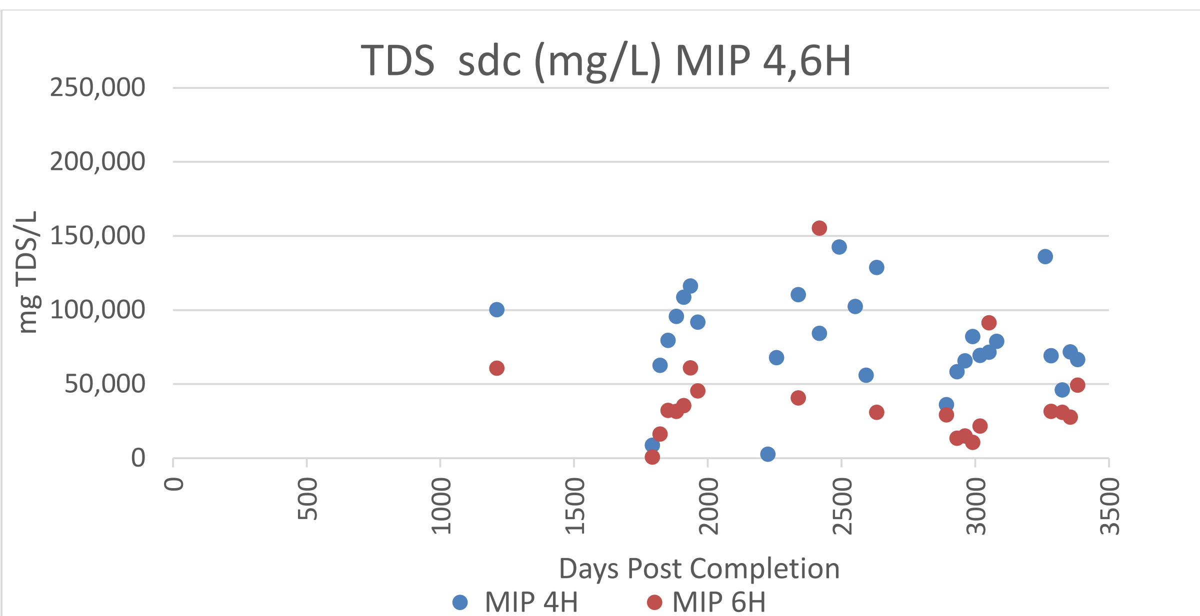


Figure 4.9. Changes in produced water TDS sdc (sum of dissolved constituents) from day 1793 through 3383 days post completion (4,6H).

Water soluble organics

The water-soluble aromatic compounds in produced water: benzene, toluene, ethylbenzene and xylene were never high. With two exceptions at post completion day 314 and 694, benzene has remained below 30 µg/L. This seems to be a characteristic of dry gas geologic units. After five years, benzene has mostly declined below the drinking water standard of 5 µg/L. Toluene ranged between 12 and 31 µg/L, with the exception of day 41. Values have remained below 5 µg/L since day 580 (Figure 4.4).

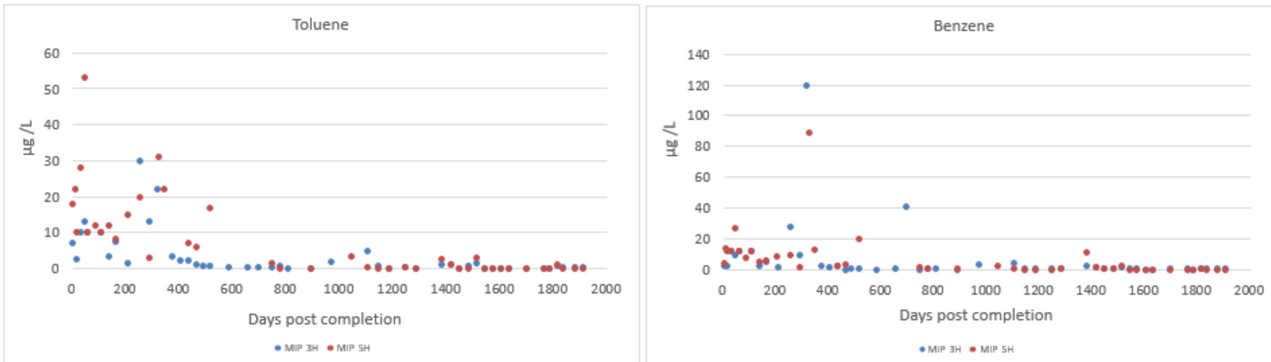


Figure 4.10. Changes in benzene and toluene concentrations. The figure shows data from well both 3H and 5H through day 1833.

Wells 4H and 6H have remained below 5 µg/L for both Toluene and Benzene for the duration of sampling events (Figure 4.5), with the exception of 6H on day 1793 with a toluene value of 5.4 pCi/L.

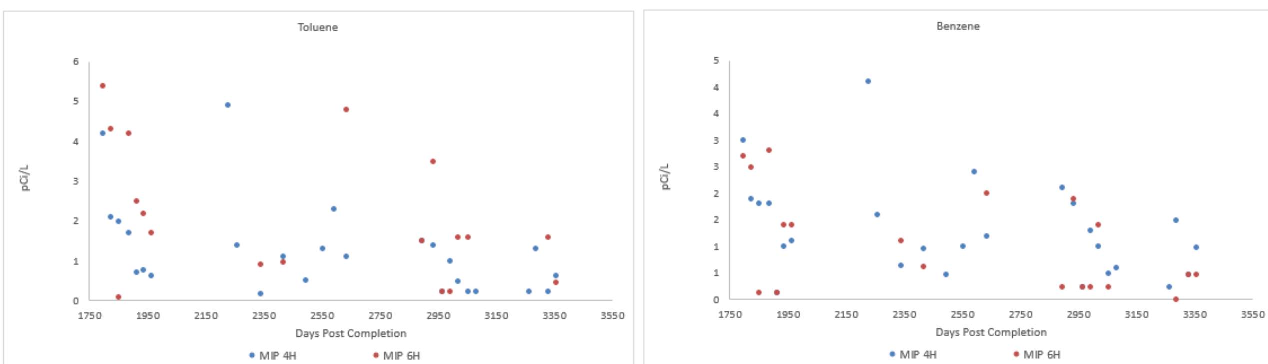


Figure 4.11. Changes in benzene and toluene concentrations. The figure shows data from well both 4H and 6H through day 3383.

Radium isotopes

The radiochemical concentrations were determined by Pace Analytical in Greensburg PA, a state certified analytical lab. Radium concentrations generally increased through 880 days post completion at wells MIP 3H and 5H. Maximum levels of the radium isotopes reached about 22,942 pCi/L at the unchoked 3H well and around 18,809 pCi/L 5H. After returning online prior to day 966, both wells have remained below 16,000 pCi/L through day 1905 (Figure 4.6).

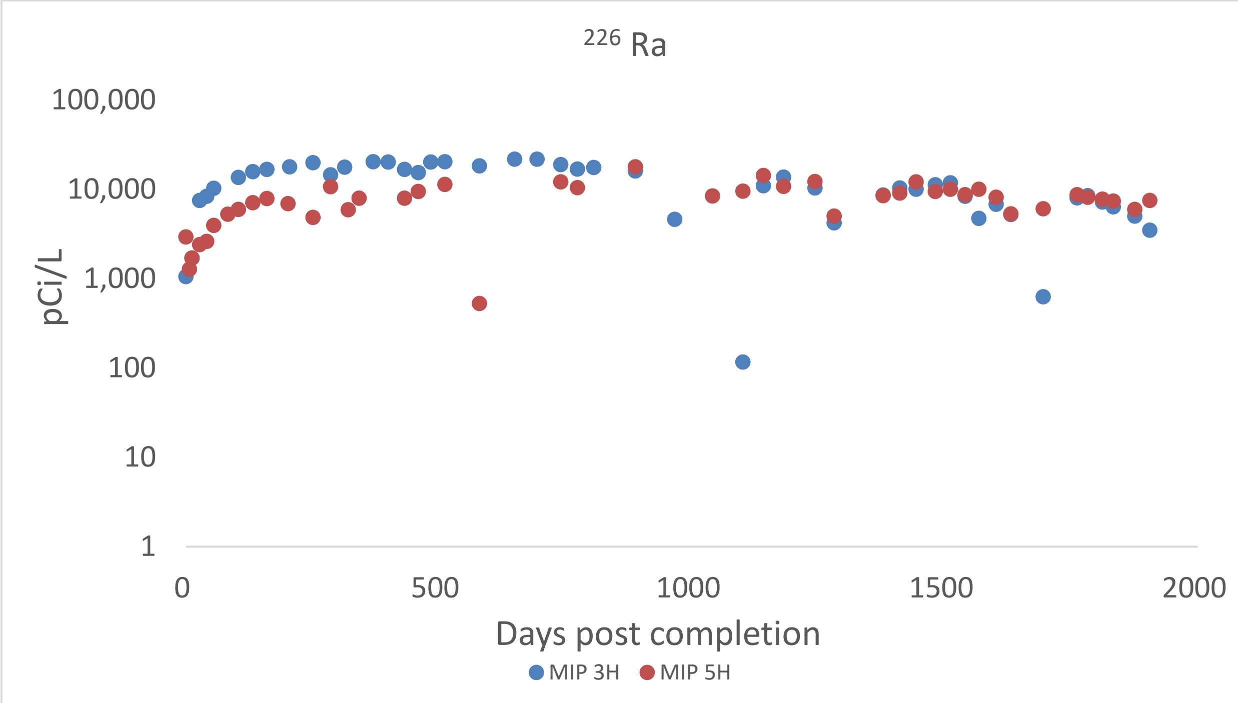


Figure 4.12. The radium isotopes are plotted against days post well completion through day 1905.

Radium concentrations at wells 4H and 6H were below 9,000 pCi/L during all sampling periods. Both wells were choked after day 1963. Well 4H was reopened at day 2225, radium was 58 pCi/L on the first sampling after the reopening and 3719 pCi/L at day 2257, a month later (Figure 4.7) peaked at 5,127 pCi/L then returned to 3,892 pCi/L. The same trend is noted at day 2492 when 4H returned online with 57 pCi/L then peaked at day 2632 with 8,197 pCi/L.

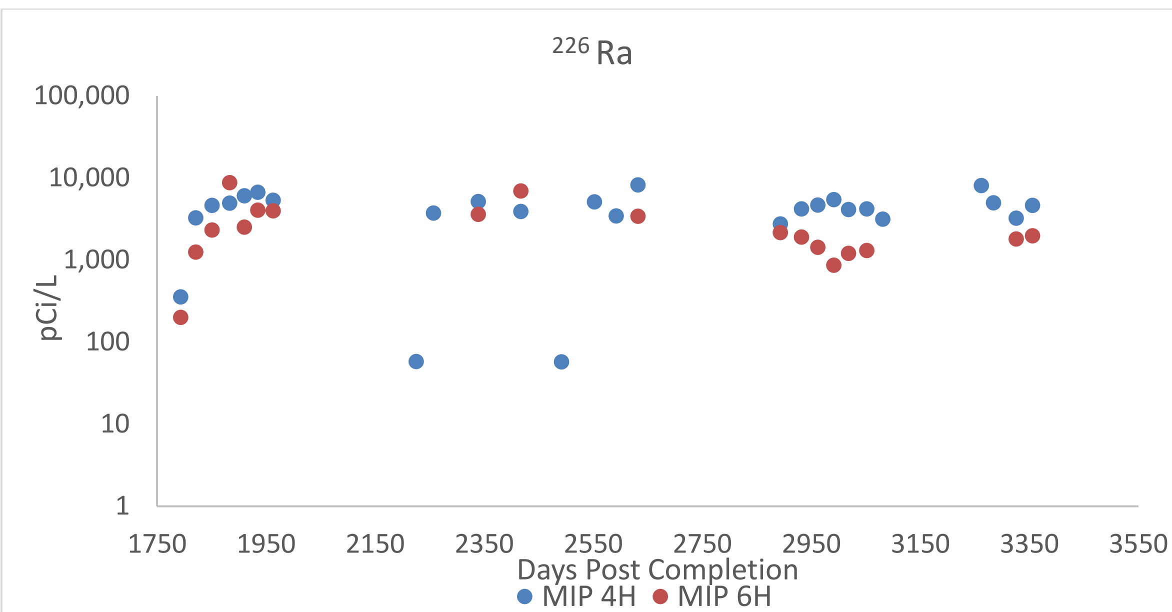


Figure 4.13. The radium isotopes are plotted against days post well completion through day 3356.

Figure 4.8 and Figure 4.9 show the relationship between gross alpha and ^{226}Ra at 3H and 5H through day 1905. Analysis for alpha was not conducted after day 1181.

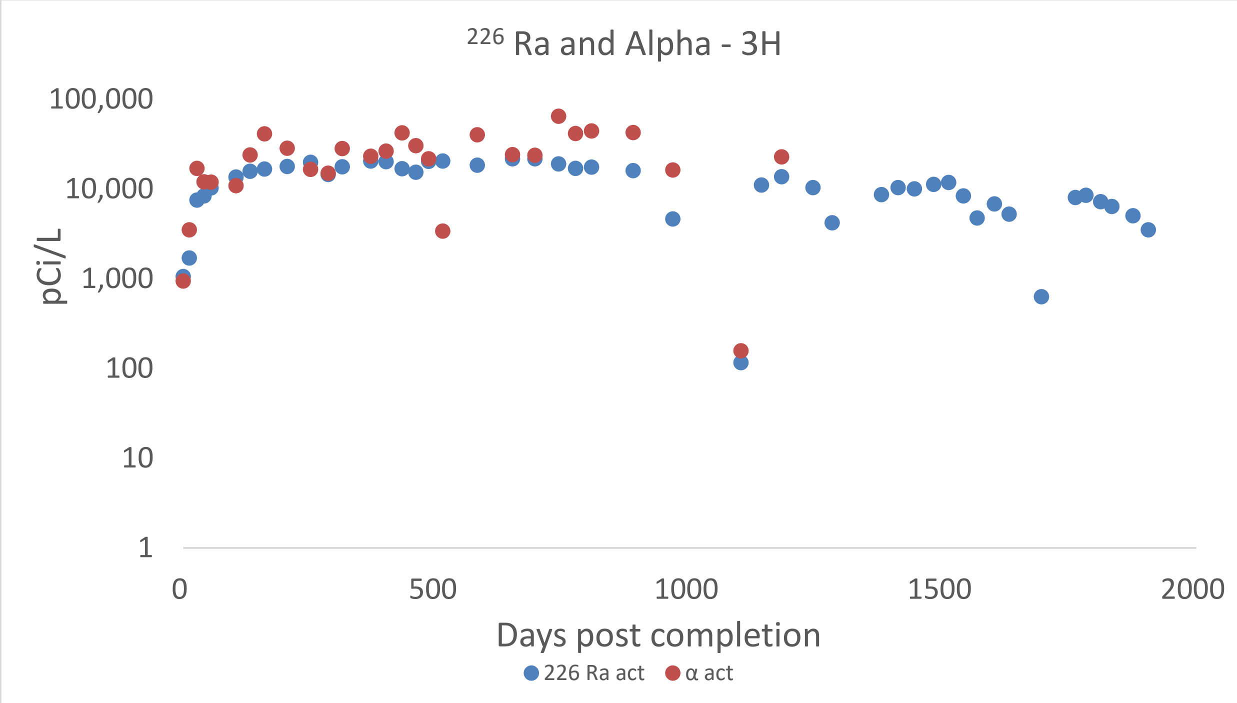


Figure 4.14. The relationship between gross alpha and 226Ra as a function of time post completion at 3H. Note: analysis for alpha was not conducted after day 1181.

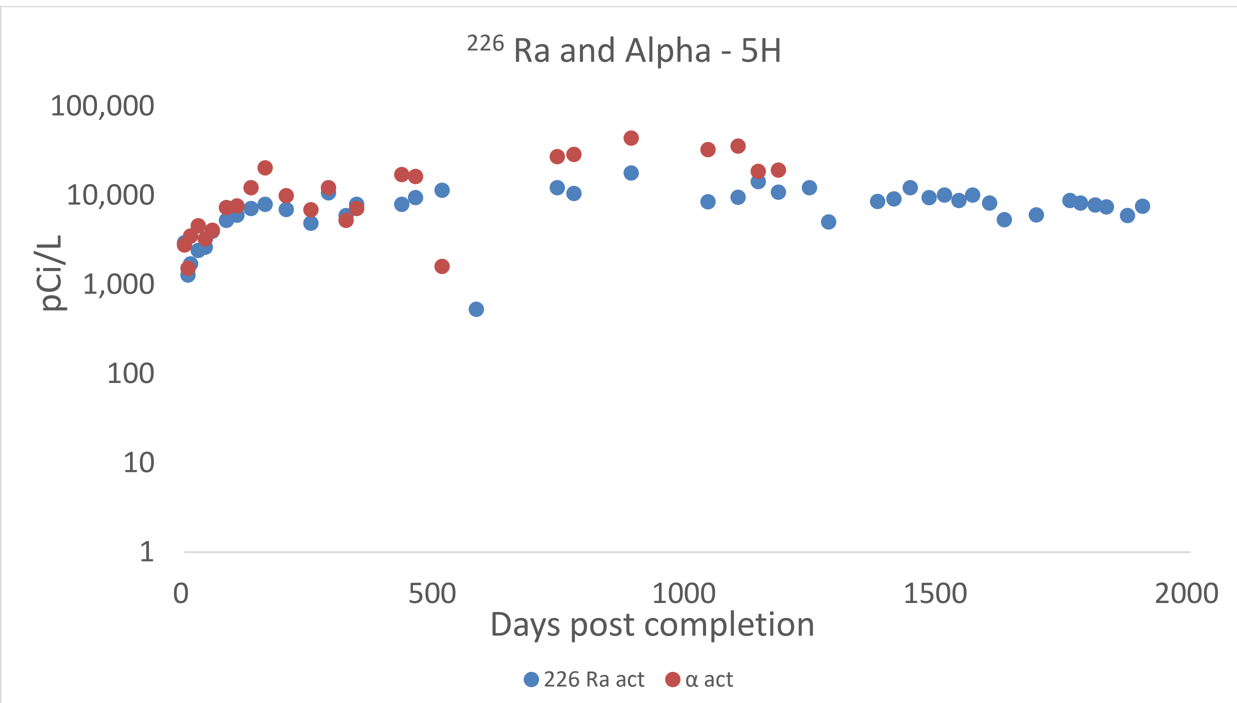


Figure 4.15. The relationship between gross alpha and 226Ra as a function of time post completion at 5H. Note: analysis for alpha was not conducted after day 1181.

The highest values reported in the older wells at 4H and 6H were 17,550 pCi/L gross alpha and 8,197 pCi/L ^{226}Ra, respectively. The relationship between gross alpha and ^{226}Ra for wells 4H and 6H are shown in Figure 4.10 and Figure 4.11. Alpha was not determined after day 2632. Sample volume was not sufficient to perform analysis for radiologicals at 6H on day 3284. Values for Ra^{226} ranged from 1,821 to 3,262 pCi/L with the exception of days 228, 2225, and 2492 when 4H presumably came back online.

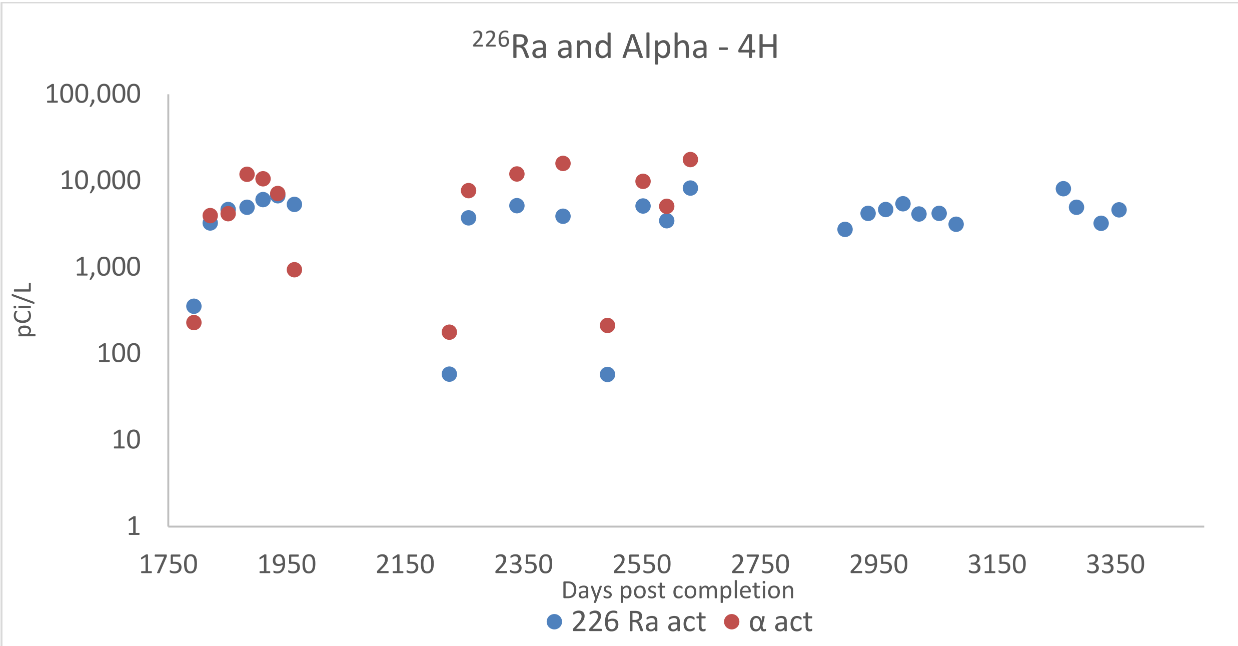


Figure 4.16. The relationship between gross alpha and 226Ra as a function of time post completion at 4H. Note: analysis for alpha was not conducted after day 2632.

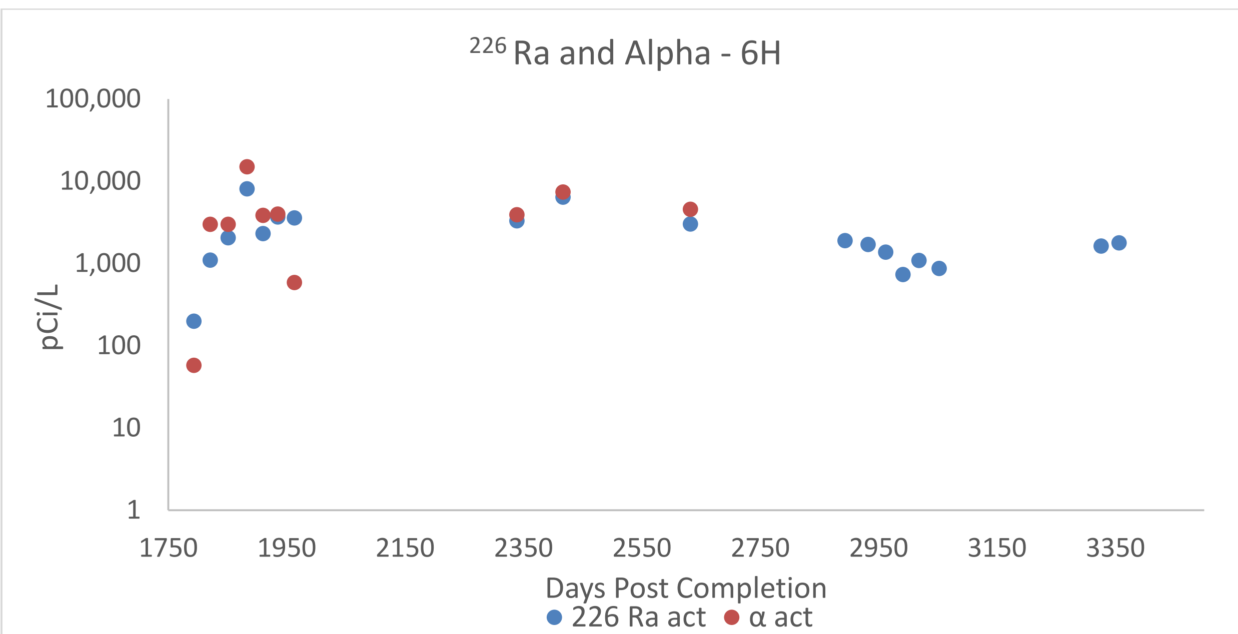


Figure 4.17. The relationship between gross alpha and 226Ra as a function of time post completion at 6H. Note: analysis for alpha was not conducted after day 2632.

Boggess Well

The drilling mud and drill cutting samples were prepared using USEPA method SW3050. The resulting extracts were then analyzed using ICPMS. Method SW3050B uses both hydrochloric acid, nitric acid and hydrogen peroxide. It is used to identify components of the solid matrix that are may become mobile. It does not normally break down a rock's alumino-silicate structure. The acids would dissolve any carbonates and the peroxide would oxidize pyrites which are abundant in the Marcellus formation. This accounts for the high concentrations of Ca, Mg and Fe. Presumably most sulfates generated during pyrite oxidation would precipitate as gypsum, barite and strontianite given the abundance of Ca, Ba and Sr in Marcellus formation fluids.

Solids

Drilling muds and cuttings were collected from 9H at depth intervals of 8,500ft; 10,000ft; 11,000ft; 13,000ft; and 15,000ft. Parameters (e.g. alk, Al, Ba, Ca, Cl, Fe, K, Mg, Mn, Na, and Sr) are shown in Figure 4.12. Drill cuttings from 9H are predominately calcium (Ca) and iron (Fe). The full list of solids parameters and methods are shown in Figure 4.3.

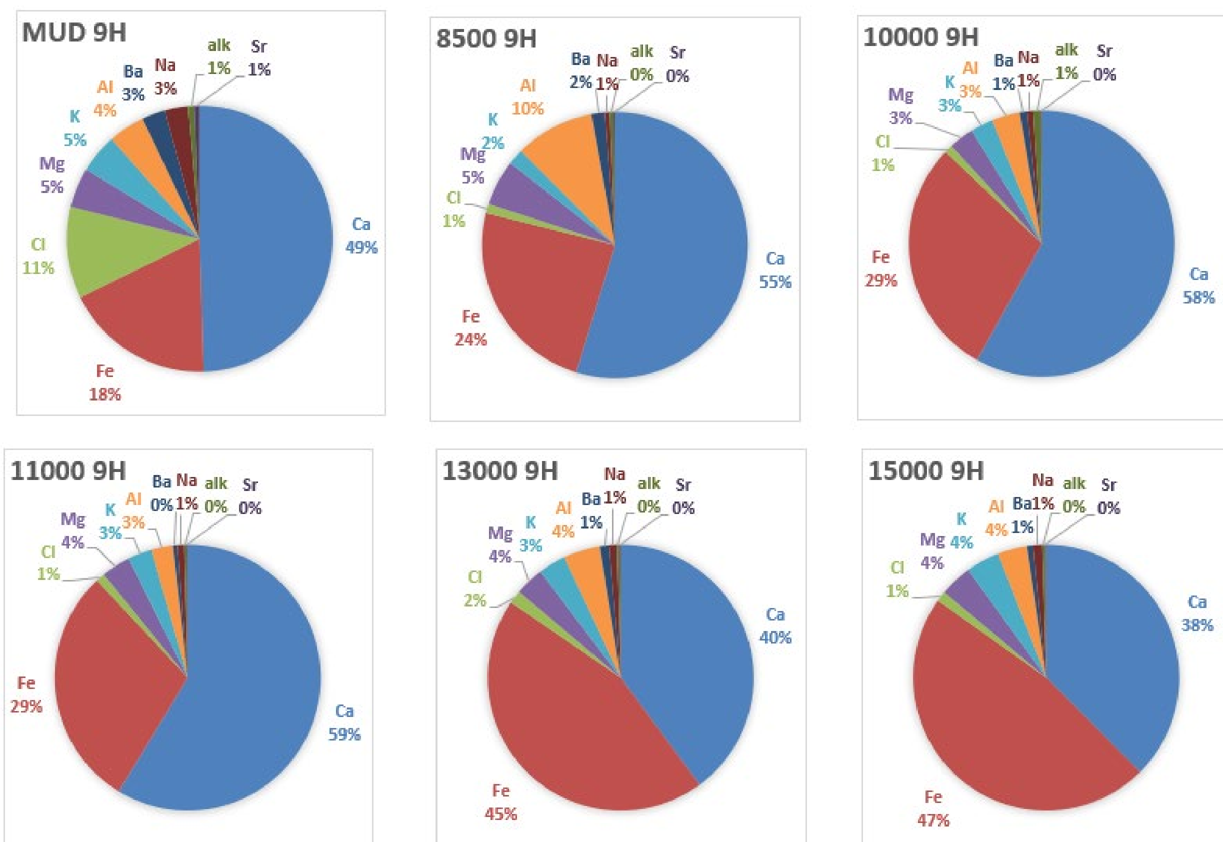


Figure 4.18. Anions/cations of drilling mud and cutting solids from 9H.

Figure 4.13 depicts parameters for drilling mud and cuttings from 17H. Shallower depths showed more variability in chemical composition in 17H in comparison to 9H. Deeper depths were predominately iron and calcium.

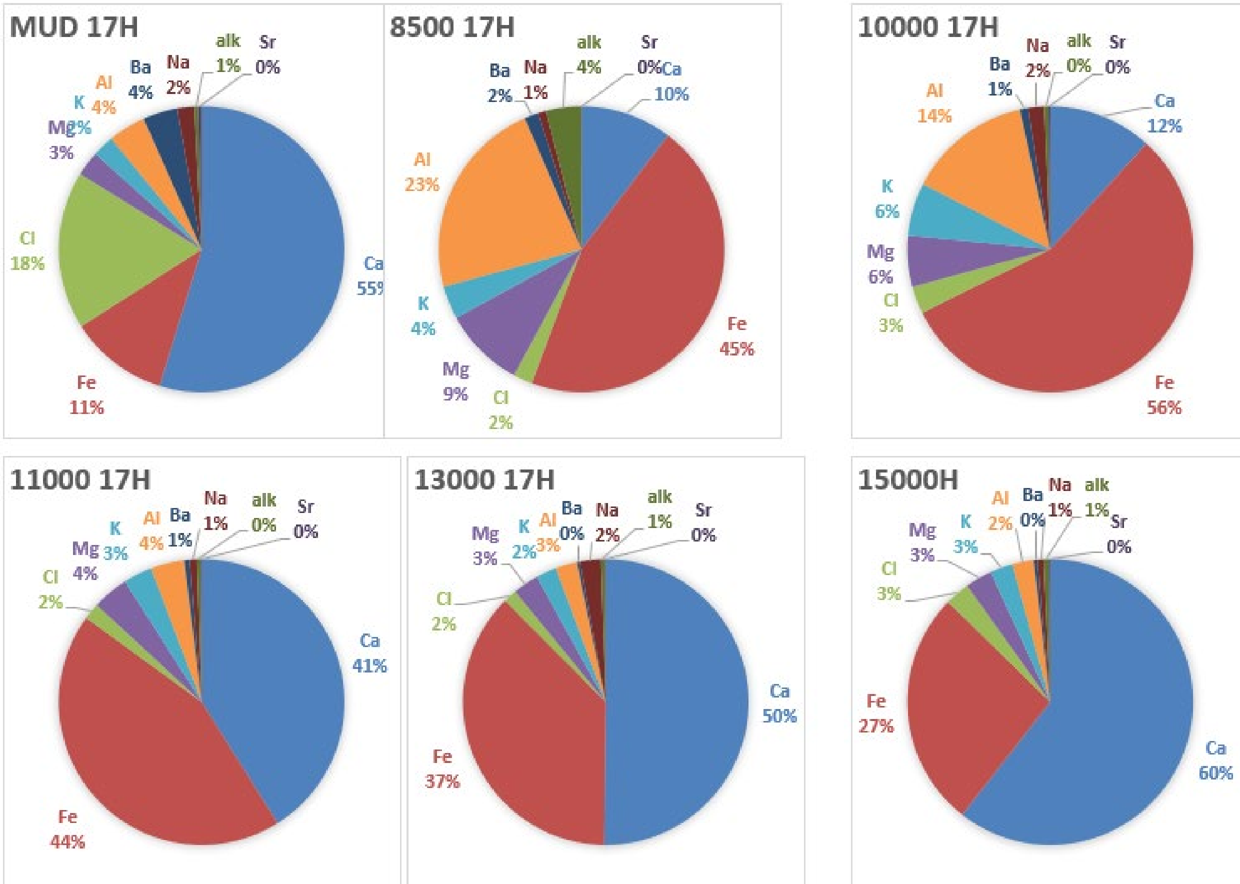


Figure 4.19. Anions/cations of drilling mud and cuttings solids from 17H.

Figure 4.14 and Figure 4.15 depict combined radium 226 and 228 of solids in drilling mud and cuttings solids from 9H and 17H.

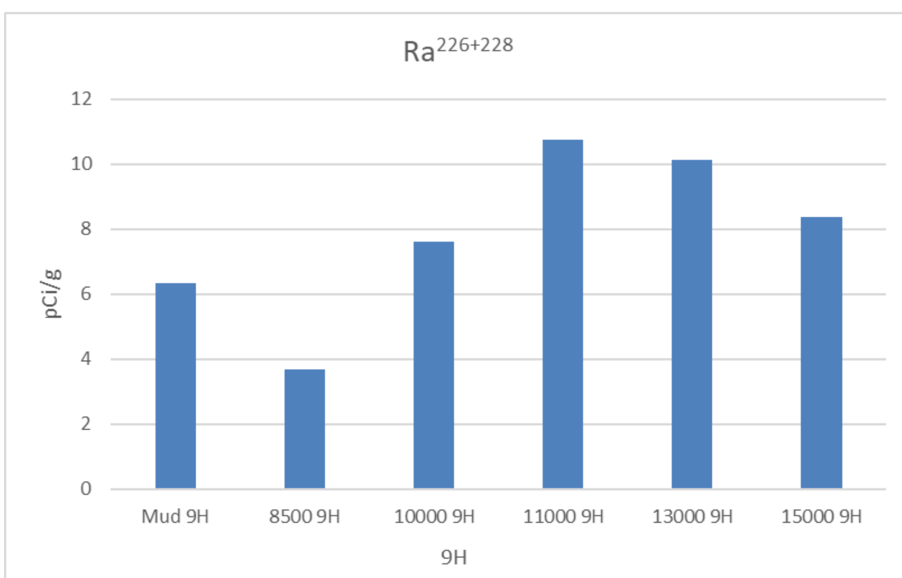


Figure 4.20. 9H Combined radium 226 and 228 for drilling mud and cuttings solids.

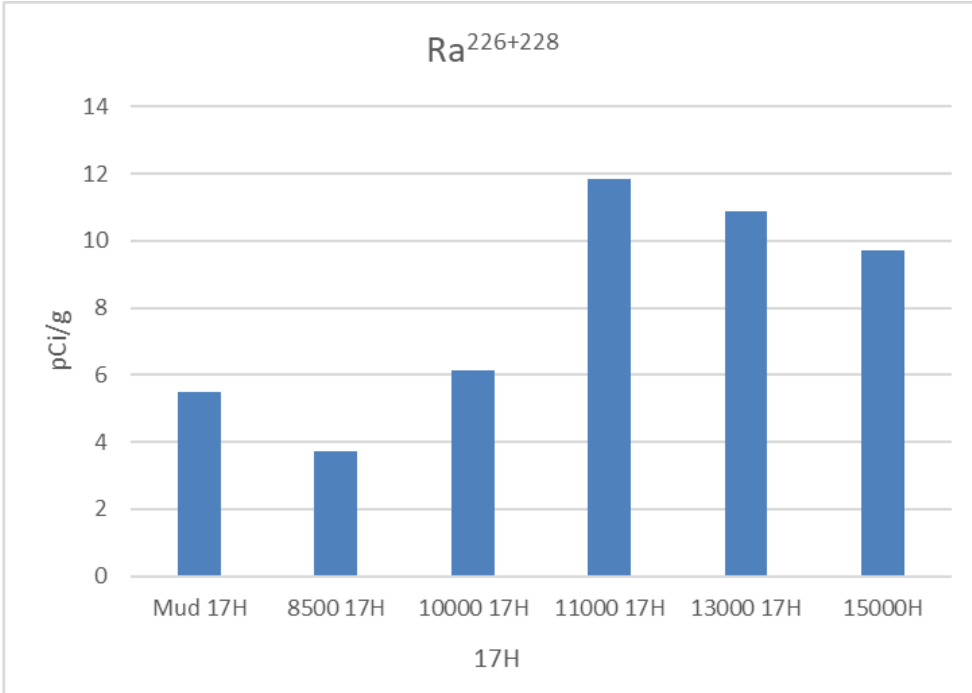


Figure 4.21. 17H Combined radium 226 and 228 for drilling mud and cuttings solids.

For comparison purposes, solids radium analysis from MIP 5H and 3H are shown in Figure 4.16 and Figure 4.17. In all wells analyzed, 3H and 5H from MIP along with 9H and 17H at Boggess, combined radium 226 and 228 remained below 12 pCi/g.

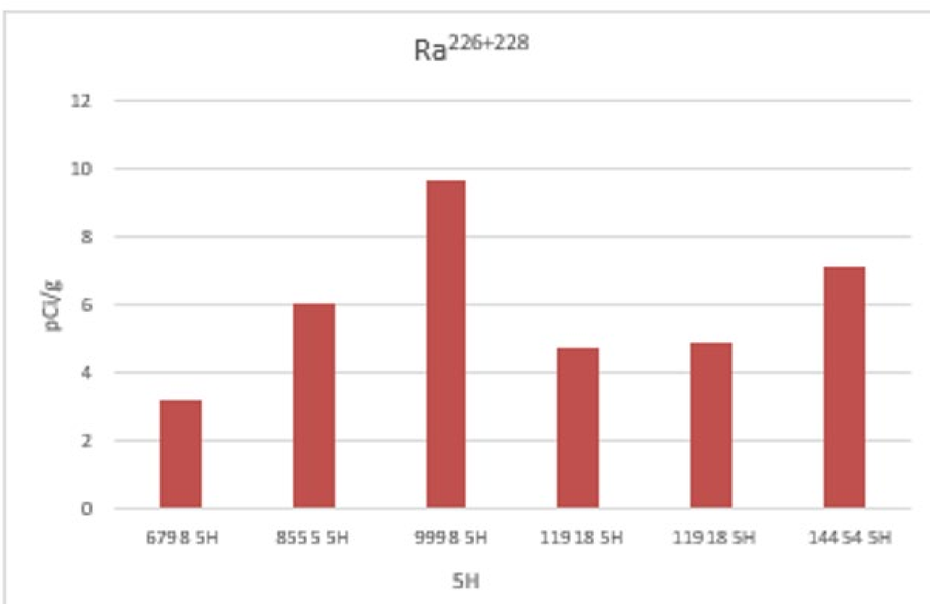


Figure 4.22. Combined Ra 226 + 228 for 5H MIP site.

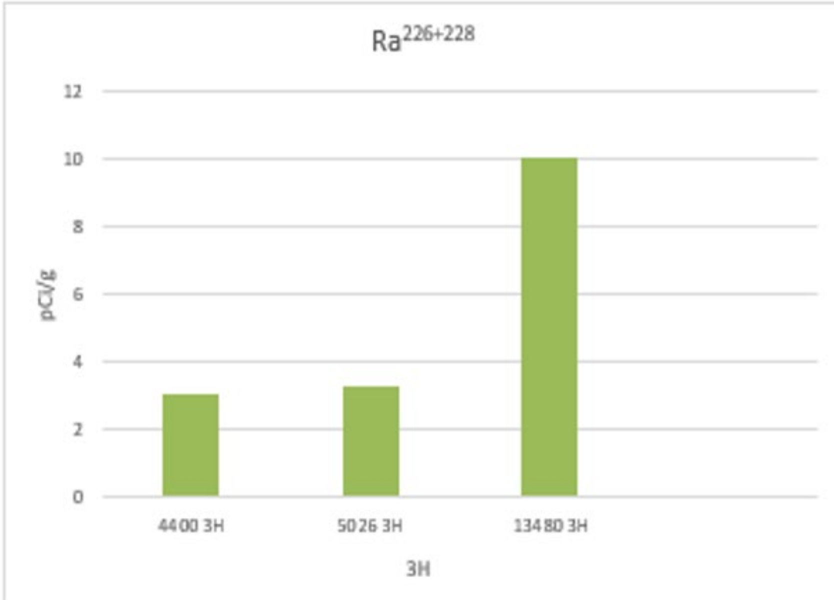


Figure 4.23. Combined Ra 226 + 228 for 3H MIP site.

Major ions – trends in produced water chemistry

While makeup water was characterized by low TDS and a dominance of calcium and sulfate ions, produced water from initial flowback is essentially a sodium/calcium chloride water as noted in the earlier discussion regarding results from MIP. Preliminary results from days 0-493 at Boggess 9H and 17H are consistent with earlier results from MIP (Figure 4.18 and Figure 4.19).

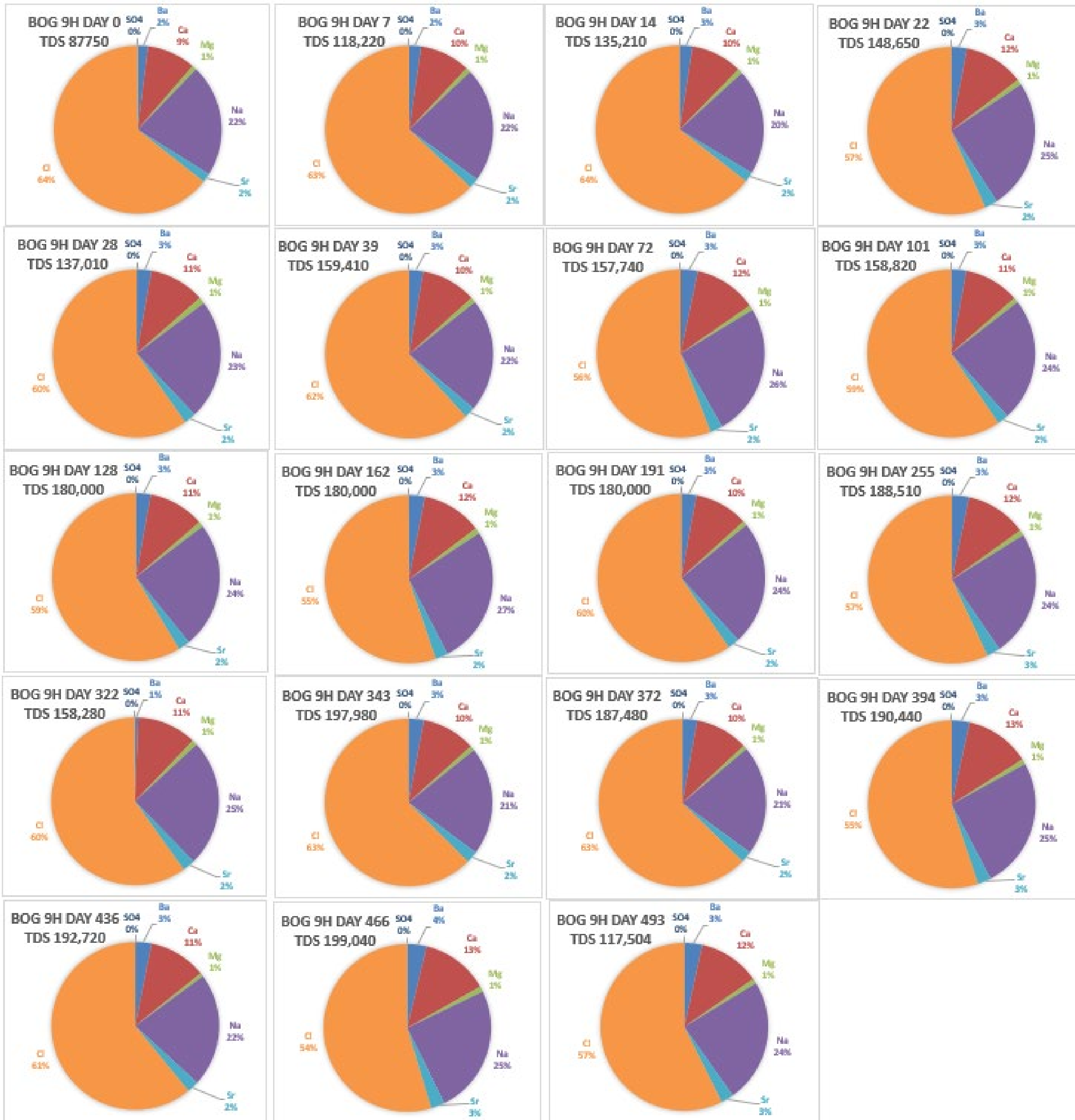


Figure 4.24. Major ion concentrations in produced water from wells Boggess 9H.

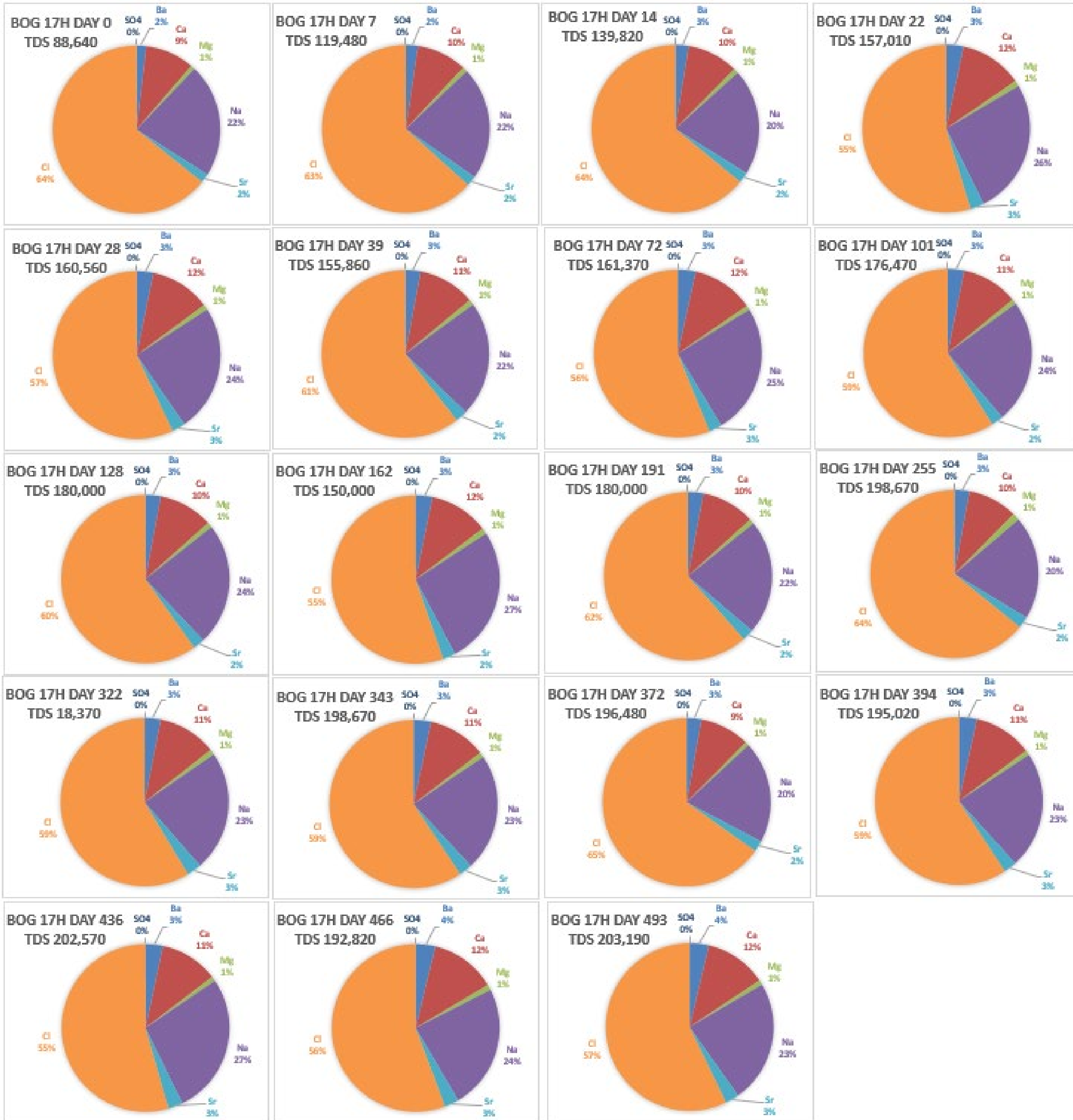


Figure 4.25. Major ion concentrations in produced water from wells Boggess 17H.

Preliminary TDS (sdc) at Boggess 9H and 17H show a slight upward trend between days 0 and 493 with an exception of day 322 (Figure 4.20 and Figure 4.21). Benzene was 19 µg/L (Figure 4.22) and Toluene was 23 µg/L (Figure 4.23) on day 322 at 17H, which could indicate well stimulation occurred prior to sample collection, resulting in low TDS. As with MIP wells, benzene and toluene at Boggess 9H and 17H remain below 5 pCi/L (with the exception of well stimulation near day 322).

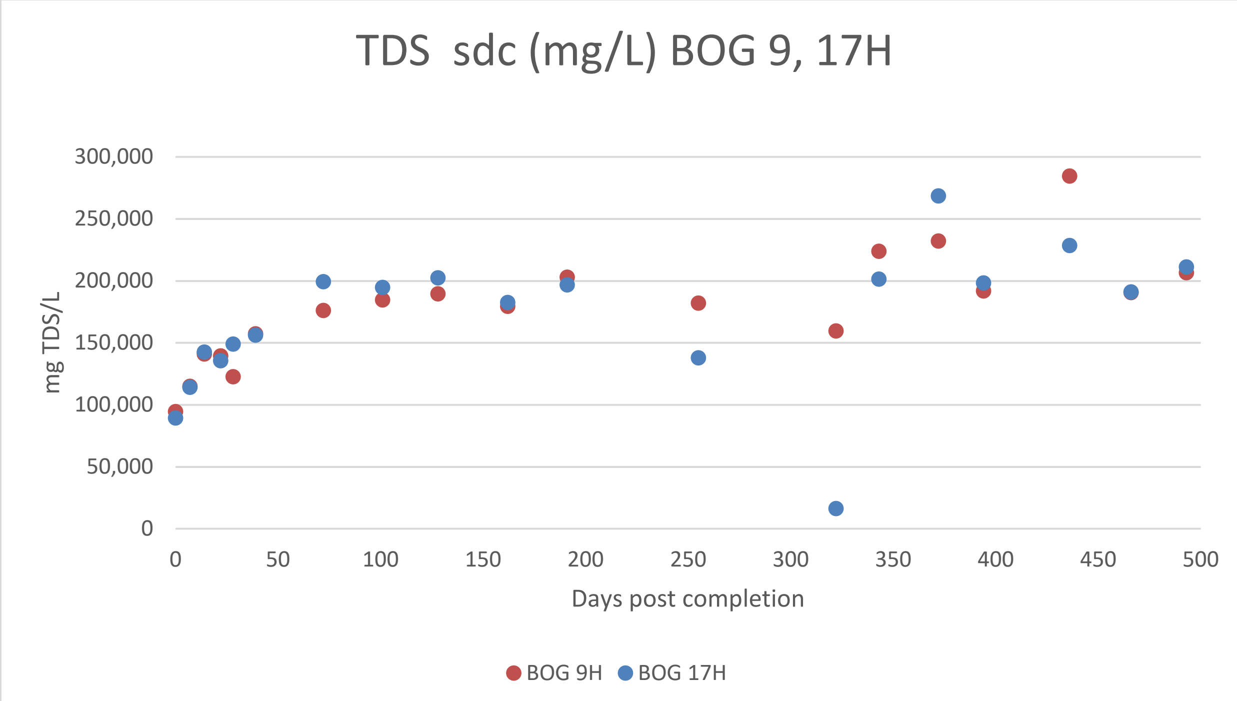


Figure 4.26. TDS (sdc) at Boggess 9H and 17H; days 0-493

Radium concentrations were below 23,000 pCi/L at both 9H and 17H at 466 days post completion (Figure 4.21).

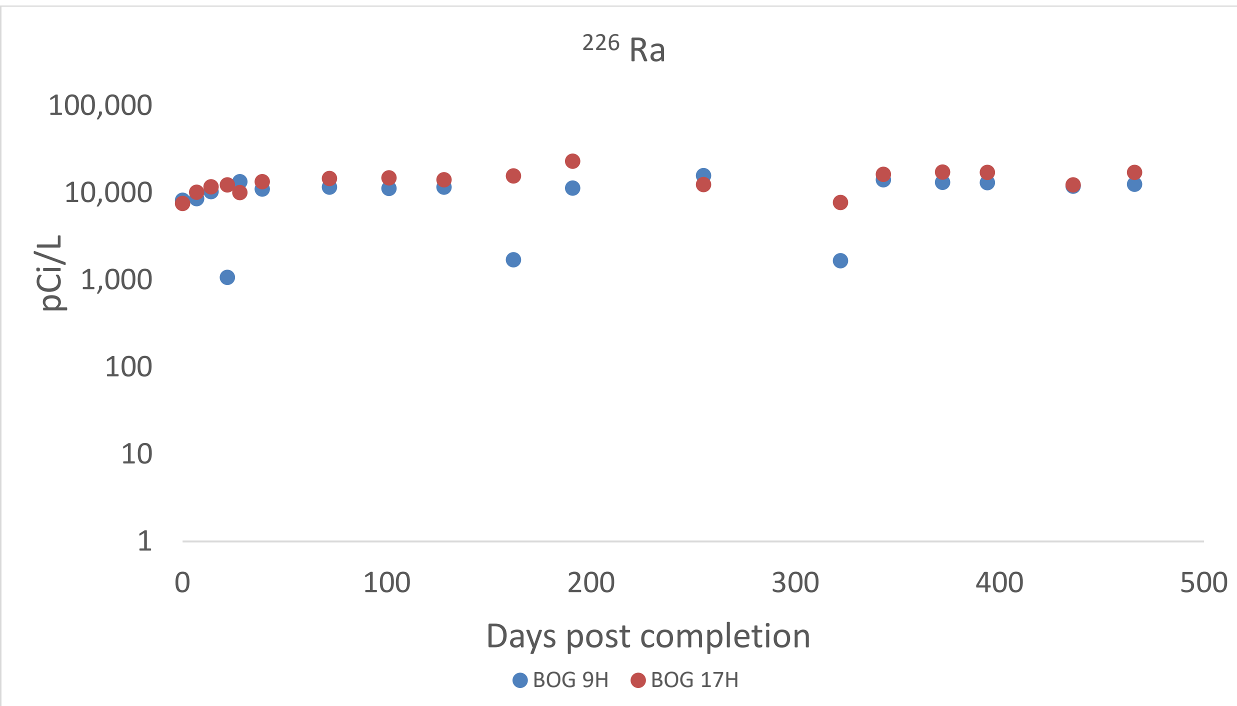


Figure 4.27. The radium isotopes are plotted against days post well completion at Boggess 9H and 17H; days 0-466.

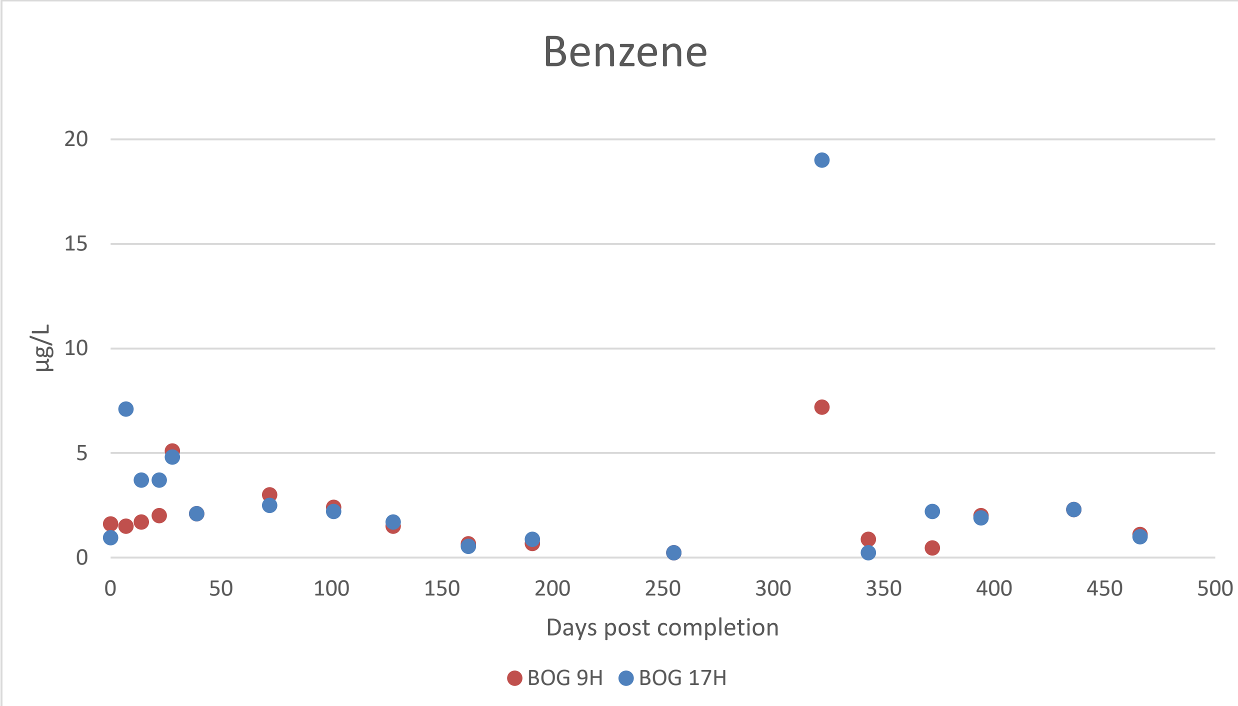


Figure 4.28. Benzene (µg/L) at BOG 9H and 17H through day 466.

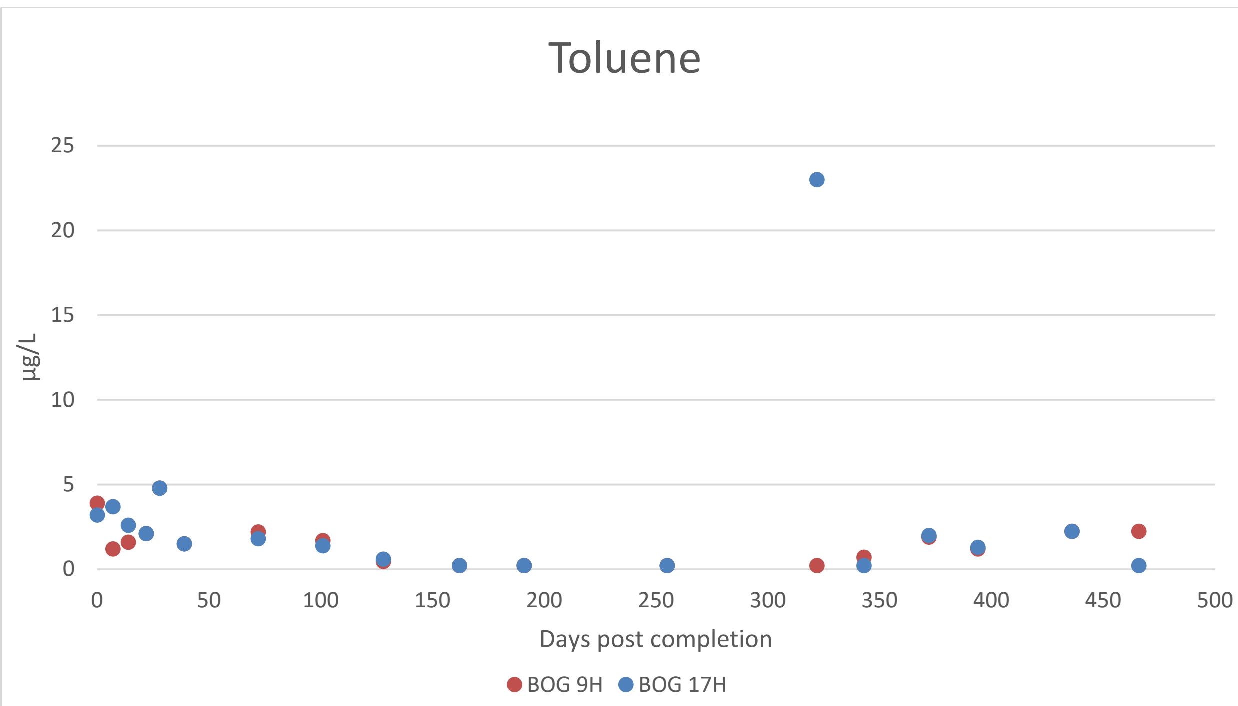


Figure 4.29. Toluene (µg/L) at BOG 9H and 17H through day 466.

Products

None for this quarter.

Plan for Next Quarter

We will continue monthly sampling at MIP and analyze flowback/produced water (FPW) from MIP 3H, 4H, 5H and 6H if they are online.

We will continue sampling produced water at Boggess Pad control wells 9H and 17H on a monthly basis. Following the same protocols used at MIP wells, we will continue to characterize their inorganic, organic and radio chemistries.

Topic 5 – Environmental Monitoring: Air & Vehicular

Approach

The Environmental Monitoring Team completed 17 methane audits at MSEEL from November 2016 through November 2020. Audits utilized a custom full flow sampler (FFS) to accurately quantify methane emissions detected from manually scanning equipment using a handheld methane detector. The FFS utilized both methane specific spectroscopy and newly available methane and ethane spectrometers. The goal of these audits was to better understand the long-term temporal variations of methane emissions associated with unconventional gas sites. The first six audits showed high variability as highlighted in a brief ACS OMEGA publication. These data were used to augment a proposal to the National Science Foundation (NSF) to enable additional research focused on improving the understanding of methane emissions through indirect methane monitoring and quantification. This research enabled the development of a Mobile Eddy Covariance Tower (MECT) that was developed and verified off-site at the WVU Reedsville Farm. Once baseline data were completed, the MECT was located at MSEEL. The MECT collected all necessary data using state-of-the-art equipment to evaluate two indirect quantification techniques: EPA Other Test Method 33A (OTM 33A) and Eddy Covariance (EC). The MECT was deployed at MSEEL from November 2019 through November 2020. The MECT collected data nearly continuously over the course of the year and was onsite during the last six methane audits. The accurate direct quantification results were compared with a subset of nearly concurrent results from the MECT and OTM 33A and EC. Results varied greatly and as a part of the additional research through NSF the EMT examined a Taguchi Optimized OTM 33A, and machine learning to combined OTM 33A and EC measurements to improve accuracy and reduce uncertainty. The machine learning techniques evaluated were MLP NN and random forest (RF) regression.

In addition to completing research focused on methane emissions from the first MSEEL 1.0 site, the EMT also completed an energy audit during the drilling of an unconventional well. Unfortunately, the data were not collected at the Boggess pad, but the EMT worked with NNE and drilling operators to collect energy audit data from another well site in Monongalia County. The energy audit focused on collecting additional engine activity data from the drilling rig, in addition to boiler activity – including temperatures and fuel flow rates. Boilers are required in cold regions or during cold seasons to provide steam heat throughout the rig to prevent liquid freezing and provide human comfort. The EMT team hypothesized that a combined heat and power (CHP) approach could be utilized during cold seasons or in cold regions to reduce fuel consumption and recovery waste heat from the prime movers – diesel engines or dedicated natural as engines. In addition, with these new data, we recognized that operators are also examining drill rig hybridization to reduce fuel consumption, reduce emissions, and improve efficiency. Models were created to assess various CHP systems for diesel and natural gas engines and in combination with a hybrid energy management system (HEMS). Reduced order modeling was performed using

Simulink and a chemical engineering software commonly used to assess heat exchanger effectiveness – CHEMCAD. Data were also compared to currently available waste heat recovery steam generators that could be easily modified for deployment at well sites.

All proposed measurements, data collection efforts, and modeling have been completed for both of these major research areas. An MS and PhD student have completed draft thesis and dissertations on these topics for final defense this summer. Two new publications have been submitted and some additional journal or conference publications will likely be developed in the final months of the overall program. Brief summary results and discussion for both efforts are presented in the following section.

Results and Discussion

Methane Emissions

The results of the 17 direct quantification efforts had been reported but are presented again in Figure 5.1. This new version includes color coding to show audits that were conducted at or after the deployment of the MECT. As reminder, the results of direct quantifications tended to match with spatially collect data in literature. Emissions varied temporally from a low of 0.078 kg/hr to a maximum of 43.4 kg/hr. The mean emissions were skewed by two likely "super-emitter" conditions during Audits 7 and 8. The mean emissions were 4.25 kg/hr, however the geometric mean was only 0.82 kg/hr.

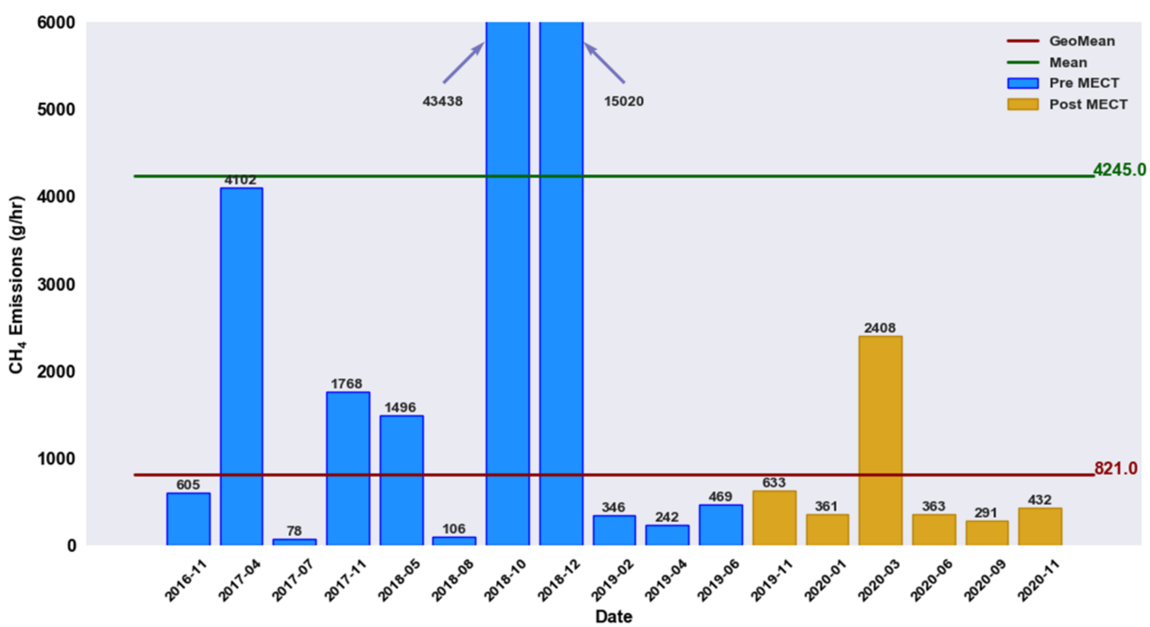


Figure 5.1. Summary of audits – methane mass emissions.

We previously reported on the throughput normalized methane emissions (TNME) for the days of the specific audits. Methane losses were as low was 0.002% and as high as 2.361%. The average TNME was 0.169% while the geometric mean was only 0.017%. In our submitted ACS OMEGA publications, we examined two alternative approaches to estimate the TNME over the 4-year period (1517 days) – both using daily reported site production values.

The first approach applied each audit result over the entire population of production days. This approach provided a population of 24,772 daily estimates. In this case, the mean TNME was 0.117% and 70% of projections were less than 0.05%.

The second approach utilized a Monte Carlo (MC) analysis. For this approach, audit data were separated into five categories of leaks and leak counts, EGPU, tank, and other emissions rates. Cubic spline fits were assigned to describe each category distribution. Distributions were randomly sampled 10^4 times to create a new pool of total daily emissions. Then an emissions rate was randomly sampled and applied to a real daily production value. This created a population of TNME values that was then bootstrapped 10^4 times with replacement. The average TNME was 0.093% with a 95% confidence interval of 0.081 to 0.106%.

As highlighted in Figure 5.1 the MECT was deployed for about a year and collected data during six audits. Table 5.1 provides the overall summary of data collected by MECT during the field campaign.

Table 5.1. Breakdown of available periods from MSEEL.

Period Attribute	**All**	**Audit**
Total Possible	35,364	1147
Valid EC and OTM	25,256	670
±45° Wind Direction (Valid Set)	10,404	245
QC CH4 Flux < 2	8018	184
OTM 33A DQI < 10	2314	28
Daytime (EddyPro)	5774	170

The audit conducted during September of 2020 had a total site emissions rate of 0.1 g/s, however, there were no valid periods within 24 hours of the audit measurements and therefore it was not analyzed here. There was a total of 245 valid periods distributed among the remaining five audits. The EC method requires a footprint analysis to enable flux emissions to be converted to mass rate emissions for comparison with audits and OTM 33A. Unfortunately, both common methods did not provide a valid footprint for days of audits or days within +/- 1 day of audits.

As part of the NFS project, optimization and machine learning were used to develop a new Taguchi optimized OTM 33A and NN and RF methods. The NN and RF methods were developed such that all input/output data from OTM 33A and EC could be used – regardless of EC footprint validity. Figure 5.2 presents a summary results from the conventional OTM 33A, the Taguchi optimized OTM 33A and the NN and RF models. The boxes encapsulate the lower and upper quartiles, the whiskers extend to the 5^{th} and 95^{th} percentiles, the blue dashed lines represent the means, and the red dotted lines represent the medians. Data outside of the 5^{th} and 95^{th} percentiles are not presented. The solid and dotted gray lines represent the weighted median and mean of the MECT audits, respectively. These values were calculated using all accepted periods within ±24 hours of an audit and assigning them the values of the audit. The standard deviation of the estimates from the Taguchi OTM were on average 24% less than those of the default OTM. The NN and RF reduced the standard deviation of estimates by 53% and 87%, compared to the Taguchi OTM estimates.

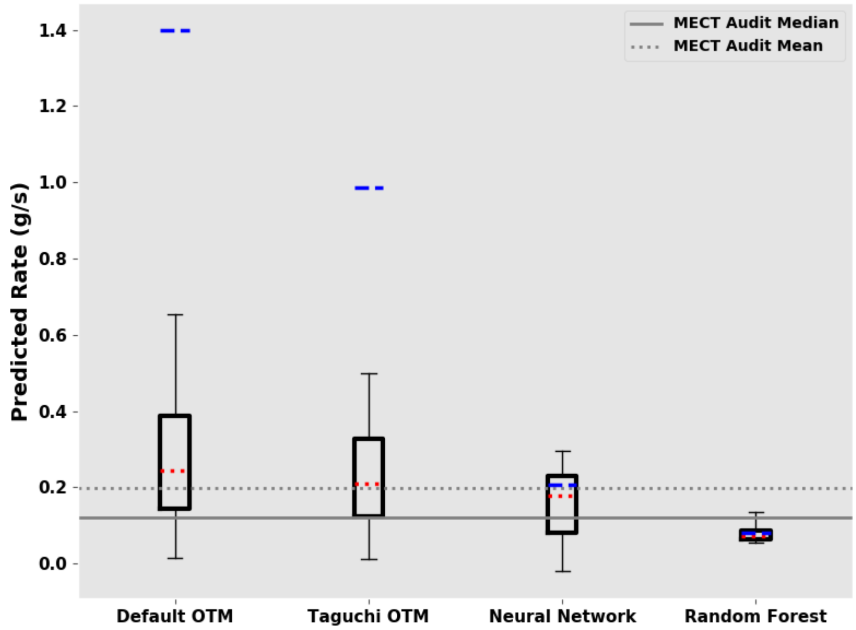


Figure 5.2. Box and whisker of audit comparisons.

The RMSEs of the respective methods are presented in Table for each individual audit. The Taguchi OTM RMSE was 24% less on average than the default OTM RMSE, across the five valid audits. The NN reduced the RMSE of 4 of the 5 estimates compared to the Taguchi OTM results. The NN performed poorly on the 2020-01 audit, causing an increase in RMSE of 187% over the Taguchi OTM estimate. However, across all audits it reduced the RMSE by an average of 9% and across the four audits that it did improve the average percent reduction was 58%. The RF produced a lower RMSE than the Taguchi OTM estimate across all audits by an average of 49%. The RF produced a lower RMSE than the NN on 3 of the 5 estimates.

Table 5.2. Comparison of method RMSEs of MSEEL audits.

Information			RMSE (g/s)			
Audit Date	**Site Emissions (g/s)**	**Count (#)**	**Default OTM**	**Taguchi OTM**	**Random Forest**	**Neural Network**
2019-11	0.17	78	0.13	0.11	0.10	0.071
2020-01	0.10	19	0.064	0.041	0.035	0.12
2020-03	0.67	32	0.91	0.86	0.59	0.51
2020-06	0.08	50	0.28	0.21	0.021	0.08
2020-09	0.10	0	-	-	-	-
2020-11	0.12	66	19.94	12.01	0.05	0.84
All		245	10.36	6.24	0.22	0.48

Energy Audits

Our analysis focused on a combined heat power (CHP) approach to improve the utilization factor (UF) of fossil energy consumed during development. Engine activity, boiler fuel consumption, and exhaust gas temperatures were recorded during winter drilling of an entire well in the Marcellus shale. Four characteristic activity cycles were extracted from recorded activity to represent four energy consumption scenarios. Exhaust and jacket water heat exchangers (E-HEX, JW-HEX) were designed and simulated, and results were analyzed in 0-D models for the four case scenarios. A 584-kWh hybrid energy management system (HEMS) was also designed and simulated into the model as another method to reduce fossil energy fuel consumption during well development. To assess the potential energy savings – field data were utilized to create four activity or energy cycles. Four different setups were analyzed over the four characteristic cycles defined before. These setups are high horsepower diesel engine with CHP (HHPDE-CHP), dedicated natural gas engines with CHP (DNGE-CHP), and HHPDE-CHP and DNGE-CHP with HEMS. Table 5.3 presents a summary of the energy demand during the four energy cycles.

Table 5.3. **Energy cycles with energy demand by rig engines and boiler. 2E1HR = 2 engines, 1 hour, 3E1HR = 3 engines 1 hour, TP1HR = transient profile, 1 hr, 24HR = equivalent full day.**

Cycle	**Rig's Energy Demand**	**Boiler's Energy Demand**	**Boiler's Average Instant Demand**
Name	**MJ**	**MJ**	**kW**
2E1HR	4895	2619	727.5
3E1HR	5238	2339	649.7
TP1HR	2884	2388	663.3
24HR	104,437	60,760	703.2

Heat exchanger design was assisted by CC-THERM software, a sub-program to the CHEMCAD® suite developed by Chemstations. Both exhaust heat exchangers (E-HEX) and jacket-water heat exchangers (JW-HEX) could be analyzed with this program. Heat exchangers were selected to be automatically sized and designed complying with ASME and TEMA standards. Boilers usually provide saturated steam at pressures around 110 psi; therefore, the E-HEX design was intended to match the boiler's pressure and temperature output. The variable was designed to be the water inlet input. Saturated steam distribution lines are equipped with steam traps that redirect saturated and condensed water to a day tank that functions as a recovery feedwater system that feeds the boiler. The heat distribution system was not intended to be redesigned but to assist/replace the boiler with a set of heat exchangers. Therefore, steam distribution design and specifications must be met for the design. Day tank water was selected as a water inlet for the E-HEX design. Since the boiler steam output has a fixed pressure, the water temperature returned to the day tank is nearly constant, only being affected by ambient temperature. Water inlet temperature (day tank temperature) was assumed to be constant at the average temperature recorded during boiler usage (70 °C). E-HEX and JW-HEX types were selected to be shell-and-tube due to its popularity in steam generation applications in industries such as combined cycle power plants and its ability to handle high pressures and flows. Table 5.4 presents the summary design parameters for the E-HEX for the HHPDE and DNGE.

Table 5.4. Exhaust HEX design parameters from CHEMCAD, performance data mapped into Simulink Models.

E-HEX	HHPDE E-HEX	DNGE E-HEX
Shell Diameter (m)	2.1	2.4
Tube Length (m)	2.4	3.0
Number of Tubes	5557	7508
Effective Transfer Area (m2)	798.3	1352.4
U (W/m2°C)	30.2	21.5
Tube O.D. (cm)	1.91	1.91
Tube I.D. (cm)	1.56	1.56

The energy modeling in Simulink showed that the E-HEX could recover all heat necessary to replace the boiler when designed for the DNGE rigs. However, only some cycles could the boiler be eliminated for HHPDE. As such, the software was used again with activity data collected from the field to design a JW-HEX for the HHPDE. Table 5.5 shows the heat recovery results for the combined CHP system for HHPDE. With both E-HEX and JW-HEX the CHP approach could eliminate boiler consumption. Table 5.6 shows the heat recovery results for the CHP system for DNGE (E-HEX only). With a CHP approach with DNGE – again the boiler could be eliminated.

Table 5.5. CHP Heat Recovery Results for HHPDE.

Cycle	HHPDE E-HEX+JW-HEX Heat Recovered	HHPDE E-HEX+JW-HEX Heat Recovered-Demanded
Name	**MJ**	**%**
2E1HR	5494	210
3E1HR	5589	239
TP1HR	2612	109
24HR	106,919	176

Table 5.6. CHP Heat Recovery Results for DNGE.

Cycle	DNGE E-HEX Heat Recovered	DNGE E-HEX Heat Recovered-Demanded
Name	**MJ**	**%**
2E1HR	4081	156
3E1HR	4368	187
TP1HR	2404	101
24HR	87,079	143

Finally, we assessed the benefits of a HEMS in addition to operation as CHP systems. To assess this, we defined utilization factor (UF) as opposed to thermal efficiency of the engine alone. UF was defined as the useful engine work, additional energy saved by the HEMS, and heat recovered divided by the total fuel energy suppled to the energy scenarios from the models. Table 5.7 shows the results for HHPDE HEMS and CHP systems. The average UF for the baseline HHPDE was 35.7% on average and increased to 38.2% with the HEMS. The average further improved to 61.1% for the case where the boiler was eliminated. In addition, the model examined additional energy recovery beyond that demanded by the boiler over the limited weather conditions during data collection. These data are highlighted in the last column.

Table 5.7. Utilization factor (UF) Results for HHPDE CHP System.

Cycle	HHPDE Hybrid Without CHP System UF	HHPDE-CHP Hybrid System UF limited by Heat Required	HHPDE-CHP Hybrid System Potential UF
		E-HEX+JW-HEX	E-HEX+JW-HEX
Name	**%**	**%**	**%**
2E1HR	37.3	57.2	76.7
3E1HR	38.8	56.2	77.5
TP1HR	39.2	71.6	77.7
24HR	37.6	59.5	75.6
Average	38.2	61.1	76.9

Table 5.8 shows the results for DNGE HEMS and CHP systems. The average UF for the baseline DNGE was 19.0% on average and increased to 20.8% with the HEMS. The average further improved to 33.2% for the case where the boiler was eliminated. In addition, the model examined additional energy recovery beyond that demanded by the boiler over the limited weather conditions during data collection. These data are highlighted in the last column.

Table 5.8. Utilization factor (UF) Results for DNGE HEMS and CHP systems.

Cycle	DNGE Hybrid System Without CHP System UF	DNGE-CHP Hybrid System UF Limited by Heat Required	DNGE-CHP Hybrid System Potential UF
		E-HEX	E-HEX
Name	**%**	**%**	**%**
2E1HR	**20.2**	**31.0**	**38.2**
3E1HR	**21.1**	**30.5**	**38.7**
TP1HR	**21.2**	**38.7**	**41.2**
24HR	**20.7**	**32.7**	**38.2**
Average	**20.8**	**33.2**	**39.1**

Products

- Johnson, D., and Heltzel, R., "On the Long-Term Temporal Variations in Methane Emissions from an Unconventional Natural Gas Well Site," **2021**, Submitted to *ACS OMEGA*, Reviewed and Revision Submitted.
- Dranuta, D., and Johnson, D., "Analysis on Combined Heat and Power and Combined Heat and Power and Hybrid Power Systems for Unconventional Drilling Operations," **2021**, Submitted to *ASME International Combustion Engine Division Fall Technical Conference* – ICEF2021-67492. Under Review.

Plan for Next Quarter

- Diego Dranuta Thesis Defense – Energy Audit Based
- Robert Heltzel Dissertation Defense – MSEEL 1.0 and NSF Based
- Develop additional publication based on MSEEL/NSF machine learning findings

Topic 6 – Water Treatment

This task is complete and will not be updated in future reports.

Topic 7 – Database Development

Approach

In December, we met the self-imposed deadline of adding the Boggess data to the web site one year after initial product. All MSEEL data from the MIP and Boggess pads are online and available to researchers via the ***Get Data*** link (FTP) (Figures 7.1, 7.2 and 7.3). We continue to add new data, summaries and interpretations and will work to improve the navigation and performance for obtaining the data. The website has been updated to include new navigation and adding the latest production for both the MIP and Boggess pads (Figure 7.4).

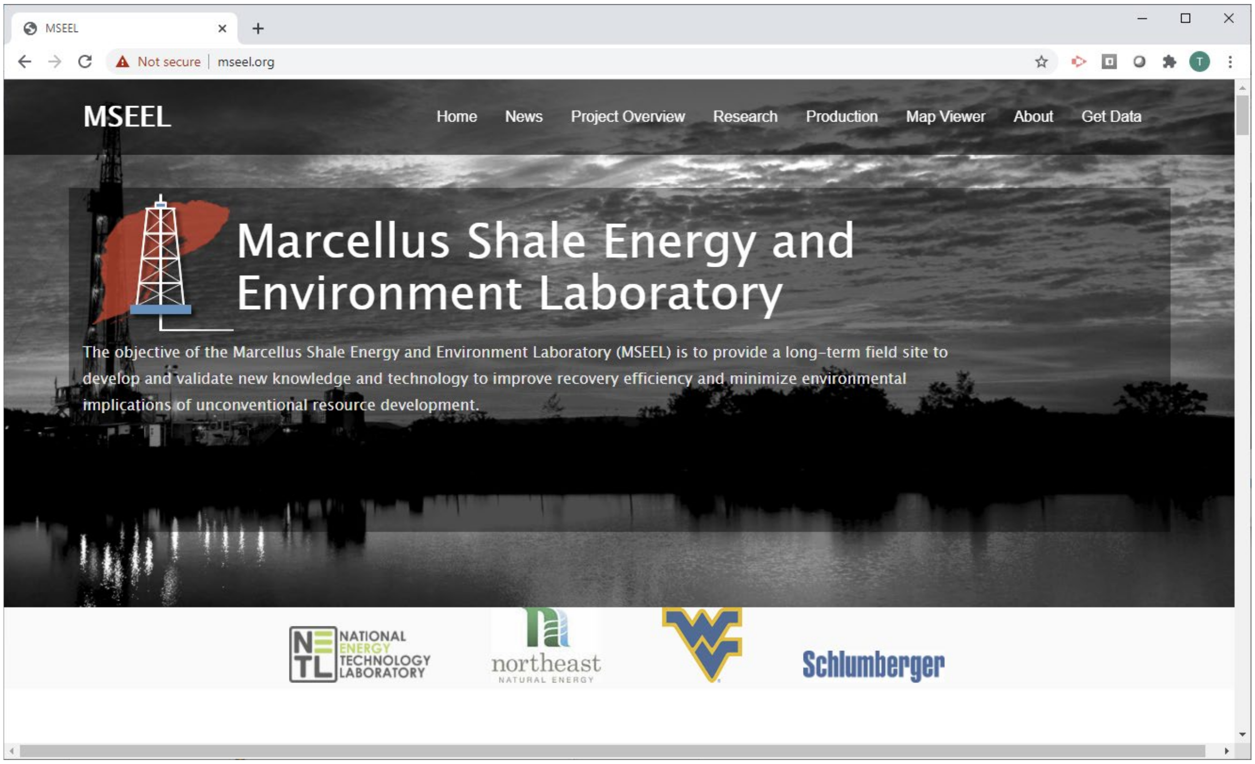


Figure 7.1. MSEEL website at http://mseel.org/.

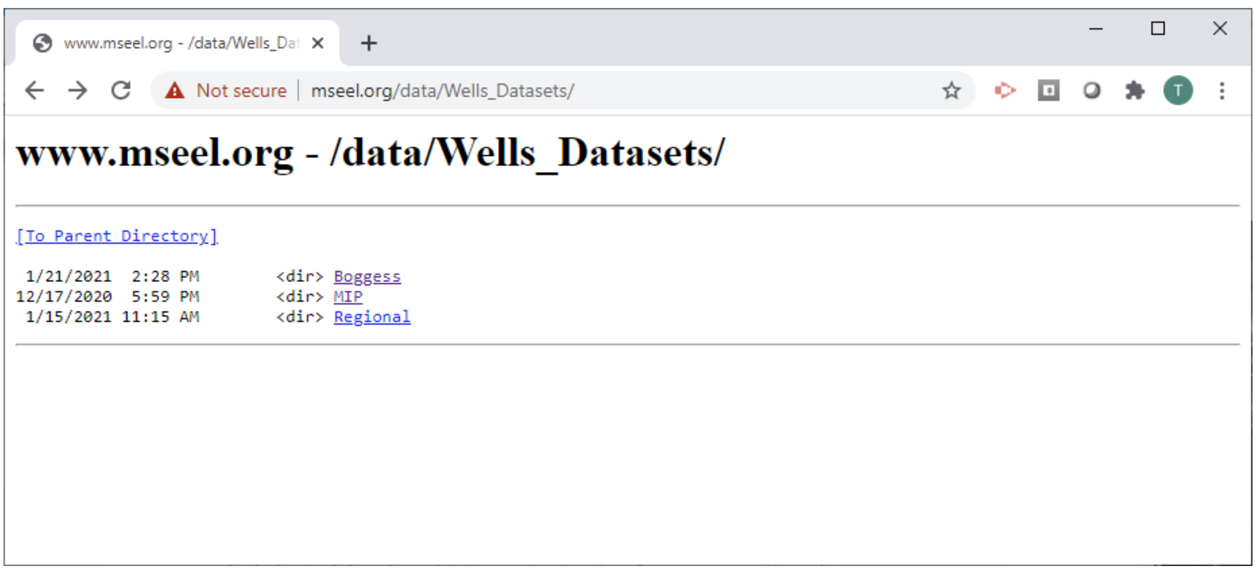


Figure 7.2. All data generated by the MSEEL project is available for download at http://mseel.org/.

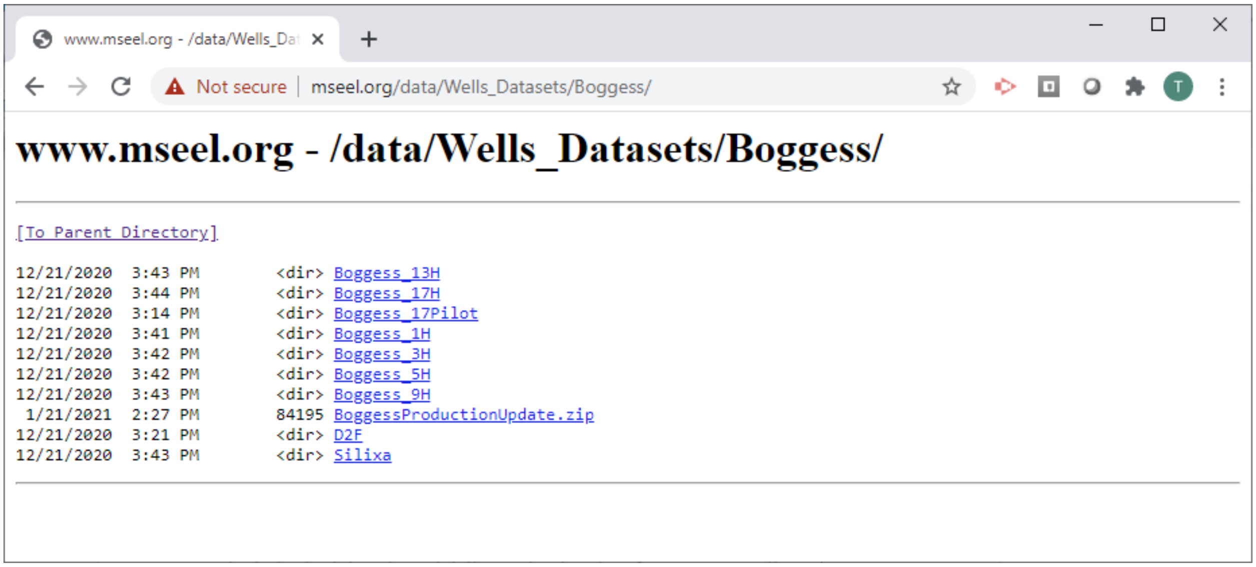


Figure 7.3. Example of data files from the Boggess Pad now available for download at http://mseel.org/.

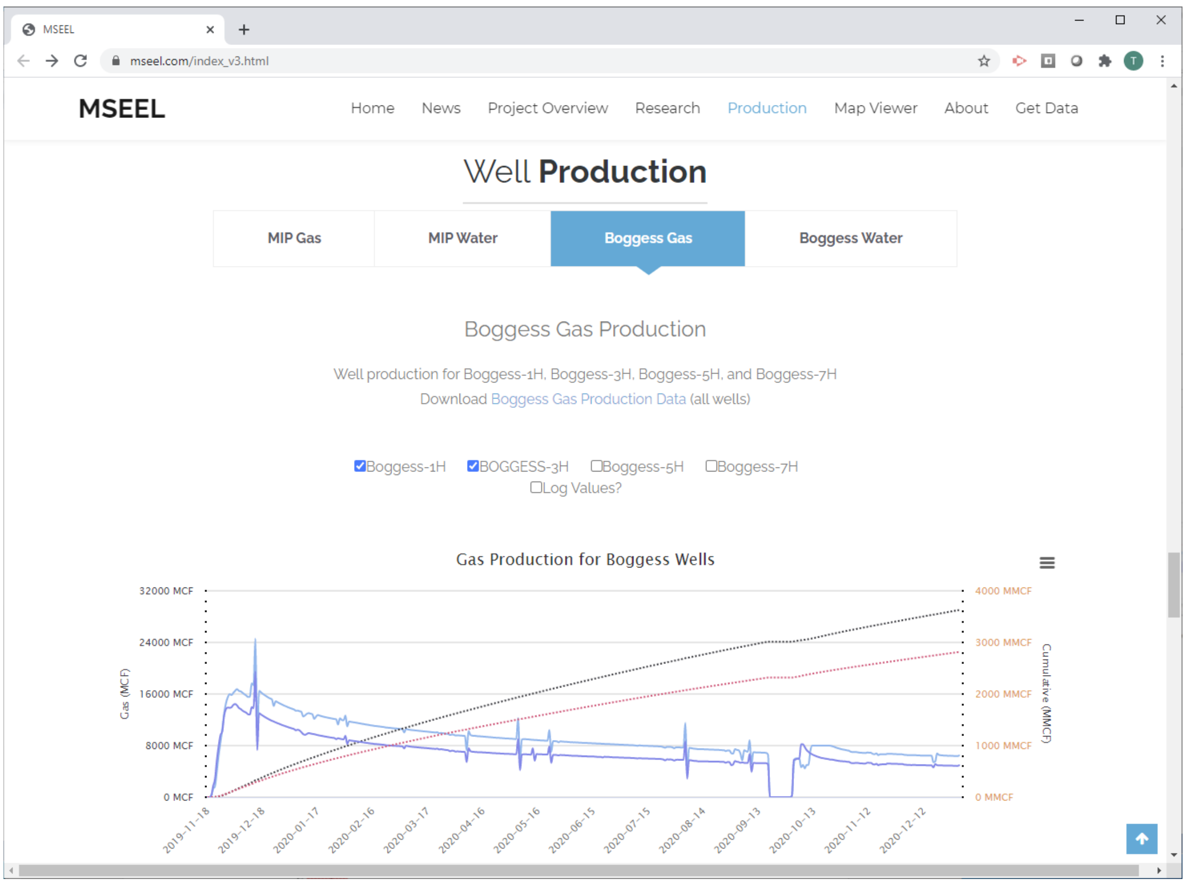


Figure 7.4. Production plots with new navigation to show gas and water production from both the MIP Pad and the Boggess Pad. Gas and water production have been updated through the end of the quarter are available at http://mseel.org/. Addition detailed production data (e.g., pressure etc.) are also available as spreadsheets (such as BoggessProductionUpdate.zip from the Get Data section, Figure 7.3).

Results & Discussion

Quality controlled production data are now available at http://mseel.org/.

We continue to work to improve online access to the very large primarily DAS datasets. The DAS data are currently stored in the internal server (fiber (\\157.182.4.208)(Z:)). System responses are slow since the data files are large. For example, the computer freezes and idles for about 10 minutes just to open one level of data folder. **Figure 7.5** shows the result of opening multiple levels of folder from the root directory, which could take more than one hour. To test the file transfer from internal server to ftp site, a Python code was written that automates the transfer of 2GB data to local desktop without accessing the data folders manually. The process of copying 2GB files over the Internet to desktop then uploading to ftp site takes about one hour. An improvement but continue to work on this issue. We discussed large dataset transfer with WVU IT personnel and will work with others (e.g., EDX) to improve access to these extremely large datasets.

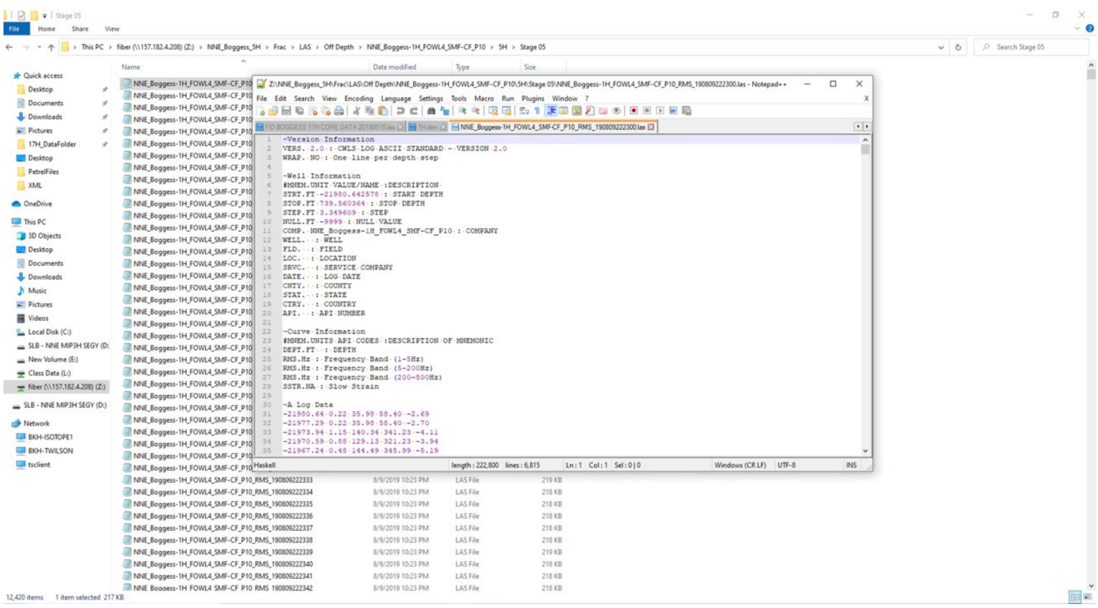


Figure 7.5. DAS data example located on fiber server.

Products

Web site enhanced and updated.

Plan for Next Quarter

Working on summarizing the operational data collection and integration in order to provide a user guide to the Boggess pad digital gas field. Data analytics and visualization would be performed in order to improve data quality. Figure 7.6 shows the outline for summarizing both the structured and unstructured data files.

Will contact EDX personnel to transfer MSEEL data and discuss access to the very large DAS data sets. Process DTS data from Boggess Pad.

Part 1. Well drilling history

- 1.a. Well trajectory
- 1.b. Bit sub introduction
- 1.c. Common drilling parameters measured from surface

Part 2. Different well logs and the usage

- 2.a. A table to summarize the well logs and tools
- 2.b. Measured vs. Interpreted well logs

Part 3. Completion data summary

- 3.a. Timeline for the starting time for each stage
- 3.b. Quantification of fluids, chemicals and proppants injected

Part 4. Real-time well production data acquisition from SCADA system

- 4.a. Flow rates
- 4.b. Pressure measurements

Figure 7.6: Outline for Boggess pad operational data summary.

Topic 8 – Economic and Societal

<u>This task is complete and will not be updated in future reports.</u>

Cost Status

Year 1

Start: 10/01/2014 End: 09/30/2019

Baseline Reporting Quarter

	Q1 (12/31/14)	Q2 (3/31/15)	Q3 (6/30/15)	Q4 (9/30/15)
Baseline Cost Plan	(From 424A, Sec. D)			
(from SF-424A)				
Federal Share	$549,000		$3,549,000	
Non-Federal Share	$0.00		$0.00	
Total Planned (Federal and Non-Federal)	$549,000		$3,549,000	
Cumulative Baseline Costs				
Actual Incurred Costs				
Federal Share	$0.00	$14,760.39	$237,451.36	$300,925.66
Non-Federal Share	$0.00	$0.00	$0.00	$0.00
Total Incurred Costs - Quarterly (Federal and Non-Federal)	$0.00	$14,760.39	$237,451.36	$300,925.66
Cumulative Incurred Costs	$0.00	$14,760.39	$252,211.75	$553,137.41
Uncosted				
Federal Share	$549,000	$534,239.61	$3,296,788.25	$2,995,862.59
Non-Federal Share	$0.00	$0.00	$2,814,930.00	$2,814,930.00
Total Uncosted - Quarterly (Federal and Non-Federal)	$549,000	$534,239.61	$6,111,718.25	$5,810,792.59

Start: 10/01/2014 End: 09/30/2019

Baseline Reporting Quarter

	Q5 (12/31/15)	Q6 (3/31/16)	Q7 (6/30/16)	Q8 (9/30/16)
Baseline Cost Plan	(From 424A, Sec. D)			
(from SF-424A)				
Federal Share	$6,247,367		$7,297,926	
Non-Federal Share	2,814,930		$4,342,480	
Total Planned (Federal and Non-Federal)	$9,062,297	$9,062,297.00	$11,640,406	
Cumulative Baseline Costs				
Actual Incurred Costs				
Federal Share	$577,065.91	$4,480,939.42	$845,967.23	$556,511.68
Non-Federal Share	$0.00	$2,189,863.30	$2,154,120.23	$0.00
Total Incurred Costs - Quarterly (Federal and Non-Federal)	$577,065.91	$6,670,802.72	$3,000,087.46	$556,551.68
Cumulative Incurred Costs	$1,130,203.32	$7,801,006.04	$10,637,732.23	$11,194,243.91
Uncosted				
Federal Share	$5,117,163.68	$636,224.26	$1,004,177.30	$447,665.62
Non-Federal Share	$2,814,930.00	$625,066.70	($1,503.53)	($1,503.53)
Total Uncosted - Quarterly (Federal and Non-Federal)	$2,418,796.68	$1,261,290.96	$1,002,673.77	$446,162.09

Start: 10/01/2014
End: 09/30/2019

Baseline Reporting Quarter

Baseline Reporting Quarter	Q9 (12/31/16)	Q10 (3/31/17)	Q11 (6/30/17)	Q12 (9/30/17)
Baseline Cost Plan	(From 424A, Sec. D)			
(from SF-424A)				
Federal Share				$9,128,731
Non-Federal Share				$4,520,922
Total Planned (Federal and Non-Federal)				$13,649,653
Cumulative Baseline Costs				
Actual Incurred Costs				
Federal Share	$113,223.71	$196,266.36	$120,801.19	$1,147,988.73
Non-Federal Share	$0.00	$0.00	$0.00	$0.00
Total Incurred Costs - Quarterly (Federal and Non-Federal)	$113,223.71	$196,266.36	$120,801.19	$1,147,988.73
Cumulative Incurred Costs	$11,307,467.62	$11,503,733.98	$11,624,535.17	$12,772,523.90
Uncosted				
Federal Share	$334,441.91	$138,175.55	$17,374.36	$700,190.63
Non-Federal Share	($1,503.53)	($1,503.53)	($1,503.53)	$176,938.47
Total Uncosted - Quarterly (Federal and Non-Federal)	$332,938.38	$136,672.02	$15,870.83	$877,129.10

Start: 10/01/2014 End: 09/30/2019

Baseline Reporting Quarter

	Q13 (12/31/17)	Q14 (3/31/18)	Q15 (6/30/18)	Q16 (9/30/18)
Baseline Cost Plan	(From 424A, Sec. D)			
(from SF-424A)				
Federal Share				$11,794,054
Non-Federal Share				$5,222,242
Total Planned (Federal and Non-Federal)				$17,016,296.00
Cumulative Baseline Costs				
Actual Incurred Costs				
Federal Share	$112,075.89	$349,908.08	$182,207.84	$120,550.20
Non-Federal Share	$0.00	$31,500.23	$10,262.40	$4,338.00
Total Incurred Costs - Quarterly (Federal and Non-Federal)	$112,075.89	$381,408.31	$192,470.24	$124,888.20
Cumulative Incurred Costs	$12,884,599.79	$13,266008.10	$13,458,478.34	$13,583,366.54
Uncosted				
Federal Share	$588,114.74	$238,206.66	$55,998.82	$2,600,771.62
Non-Federal Share	$176,938.47	$145,438.24	$135,175.84	$832,157.84
Total Uncosted - Quarterly (Federal and Non-Federal)	$765,053.21	$383,644.90	$191,174.66	$3,432,929.46

Start: 10/01/2014 End: 09/30/2019

Baseline Reporting Quarter

	Q17 (12/31/18)	Q18 (3/31/19)	Q19 (6/30/19)	Q20 (9/30/19)
Baseline Cost Plan	(From 424A, Sec. D)			
(from SF-424A)				
Federal Share			$15,686,642.00	
Non-Federal Share			$9,180,952.00	
Total Planned (Federal and Non-Federal)			$24,867594.00	
Cumulative Baseline Costs				
Actual Incurred Costs				
Federal Share	$80,800.03	$133,776.98	$714,427.48	$1,136,823.21
Non-Federal Share	$4,805.05	$130,449.21	$4,099,491.20	$334,919.08
Total Incurred Costs - Quarterly (Federal and Non-Federal)	$85,605.08	$264,226.19	$4,813,918.68	$1,471,742.29
Cumulative Incurred Costs	$13,668,971.62	$13,933,197.81	$18,747,116.49	$20,218,858.78
Uncosted				
Federal Share	$2,519,971.59	$2,386,194.61	$5,564,355.13	$4,427,531.92
Non-Federal Share	$827,352.79	$696,903.58	$412,612.38	$221,203.30
Total Uncosted - Quarterly (Federal and Non-Federal)	$3,347,324.38	$3,083,098.19	$5,976,967.51	$4,948,735.22

Start: 10/01/2014

End: 09/30/2020

Baseline Reporting Quarter	Q21 (12/31/19)	Q22 (3/31/20)	Q23 (6/30/20)	Q24 (9/30/20)
Baseline Cost Plan	(From 424A, Sec. D)			
(from SF-424A)				
Federal Share				
Non-Federal Share				
Total Planned (Federal and Non-Federal)				
Cumulative Baseline Costs				
Actual Incurred Costs				
Federal Share	$3,098,337.44	$735,358.08	$159,437.40	$276,916.50
Non-Federal Share	$3,163,776.74	$750,301.90	$0.00	$163,643.13
Total Incurred Costs - Quarterly (Federal and Non-Federal)	$6,262,114.18	$1,485,659.98	$159,437.40	$440,559.63
Cumulative Incurred Costs	$26,480,972.96	$27,966,632.94	$28,126,070.34	$28,566,629.97
Uncosted				
Federal Share	$1,629,041.48	$893,683.40	$734,246.00	$1,079,195.50
Non-Federal Share	-$2,942,573.44	-$3,692,875.34	-$3,692,875.34	-$3,856,518.47
Total Uncosted - Quarterly (Federal and Non-Federal)	-$1,313,531.96	-$2,799,191.94	-$2,958,629.34	-$2,777,322.97

Start: 10/01/2014

End: 09/30/2021

Baseline Reporting Quarter

	Q25 (12/31/20)	Q26 (3/31/21)	Q27 (6/30/21)	Q28 (9/30/21)
Baseline Cost Plan	(From 424A, Sec. D)			
(from SF-424A)				
Federal Share				
Non-Federal Share				
Total Planned (Federal and Non-Federal)				
Cumulative Baseline Costs				
Actual Incurred Costs				
Federal Share	$191,315.03	$262,527.46		
Non-Federal Share	$90,883.68	$28,358.30		
Total Incurred Costs - Quarterly (Federal and Non-Federal)	$282,198.71	$290,885.76		
Cumulative Incurred Costs	$28,848,828.68	$29,139,714.44		
Uncosted				
Federal Share	$887,880.47	$625,353.01		
Non-Federal Share	-$3,947,402.15	-$3,975,760.45		
Total Uncosted - Quarterly (Federal and Non-Federal)	-$3,059,521.68	-$3,350,407.44		

APPENDIX A – Scientific Journal Submissions Supported By MSEEL

Scientific Journals and Associated Media
Aghababaei Shahrestani M, Luek JL, Mouser PJ. Temporal Toxicity in Hydraulic Fracturing Wastewater from Black Shale Natural-Gas Wells in the Appalachian Basin. (2021), *Environmental Science: Processes and Impacts*. DOI:10.1039/D1EM00023C. https://pubs.rsc.org/en/content/articlepdf/2021/EM/D1EM00023C?page=search
Kumar, A., Harbert, W., Hammack, R., Zorn, E., Alex Bear, A., & Carr,T. Evaluating proxies for the drivers of natural gas productivity using machine learning models, 2021, Interpretation, online preprint https://doi.org/10.1190/int-2020-0200.1
Fathi, E.; Belyadi, F.; Jabbar, B. Shale Poroelastic Effects on Well Performance Analysis of Shale Gas Reservoirs. Fuels 2021, 2, 130–143. https://doi.org/10.3390/fuels2020008
Susan A. Welch, Julia M. Sheets, Rebecca A. Daly, Andrea Hanson, Shikha Sharma, Thomas Darrah, John Olesik, Anthony Lutton, Paula J. Mouser, Kelly C. Wrighton, Michael J. Wilkins, Tim Carr, David R. Cole (2021) Comparative geochemistry of flowback chemistry from the Utica/Point Pleasant and Marcellus formations. *Chemical Geology* 564, 120041 doi.org/10.1016/j.chemgeo.2020.120041
Evans MV, Sumner A, Daly RA, *Luek JL, Plata D, Wrighton KC, Mouser PJ. Hydraulically fractured natural-gas well microbial communities contain genomic (de)halogenation potential. (2019). *Environmental Science & Technology* Letters, 6, (10), 585-591.
The manuscript from Nixon et al. was published in mSphere. S.L. Nixon, R.A. Daly, M.A. Borton, L.M. Solden, S.A. Welch, D.R. Cole, P.J. Mouser, M.J. Wilkins, K.C. Wrighton. Genome-resolved metagenomics extends the environmental distribution of the Verrucomicrobia phylum to the deep terrestrial subsurface. mSphere. DOI: 10.1128/mSphere.00613-19
Sharma, S., Agrawal, V., & Akondi, R. N. 2020. Role of biogeochemistry in efficient shale oil and gas production. *Fuel,* 259, 116207.
We have worked with LANL to generate a conference paper for the spring meeting of the Association for the Advancement of Artificial Intelligence (March 23-25) at Stanford University. The paper is entitled Physics-informed Machine Learning for Real-time Unconventional Reservoir Management
Sharma, S. Agrawal, V., Akondi R. 2019. Role of Biogeochemistry in efficient shale oil and gas production. Fuel. https://doi.org/10.1016/j.fuel.2019.116207
Phan T., Hakala A., Sharma S. 2019. Application of geochemical signals in unconventional oil and gas reservoir produced waters towards characterizing in situ geochemical fluid-shale reactions. International Journal of Coal Geology (in review)
Akondi, R., Sharma S., Texler, R., Pfifnner S. (2019). Effects of Sampling and Long-Term Storage on Microbial Lipid Biomarker Distribution in Deep Subsurface Marcellus Shale Cores. Geomicrobiology (in review)
Agrawal, V. and Sharma, S. 2019. Are we modelling properties of unconventional shales correctly? Fuel (in review)
Evans, Morgan, Andrew J. Sumner, Rebecca A. Daly, Jenna L. Luek, Desiree L. Plata, Kelly C. Wrighton, and Paula J. Mouser, 2019, Hydraulically Fractured Natural-Gas Well Microbial Communities Contain Genomic Halogenation and Dehalogenation Potential, Environmental Science and Technology Letters, online preprint, 7p., DOI: 10.1021/acs.estlett.9b00473.

Song, Liaosha, Keithan Martin, Timothy R. Carr, Payam Kavousi Ghahfarokhi, 2019, Porosity and storage capacity of Middle Devonian shale: A function of thermal maturity, total organic carbon, and clay content, Fuel 241, p. 1036-1044, https://doi.org/10.1016/j.fuel.2018.12.106 .
Akondi, R., Sharma S., Texler, R., Pfifnner S. (2019). Effects of Sampling and Long Term Storage on Microbial Lipid Biomarker Distribution in Deep Subsurface Marcellus Shale Cores. Frontiers in Microbiology *(in review)*.
Johnson, D., Heltzel, R., and Oliver, D., "Temporal Variations in Methane Emissions from an Unconventional Well Site," *ACS Omega*, 2019. DOI: 10.1021/acsomega.8b03246.
Evans MV, Daly RA, *Luek JL, Wrighton KC, **Mouser PJ.** (Accepted with revisions). Hydraulically fractured natural-gas well microbial communities contain genomic (de)halogenation potential. *Environmental Science & Technology Letters*.
Plata DL, Jackson RB, Vengosh A, **Mouser PJ.** (2019). More than a decade of hydraulic fracturing and horizontal drilling research. *Environmental Sciences: Processes & Impacts* 21 (2), 193-194.
Pilewski, J., S. Sharma, V. Agrawal, J. A. Hakala, and M. Y. Stuckman, 2019, Effect of maturity and mineralogy on fluid-rock reactions in the Marcellus Shale: Environmental Science: Processes & Impacts, doi:10.1039/C8EM00452H.
Phan, T. T., J. A. Hakala, C. L. Lopano, and S. Sharma, 2019, Rare earth elements and radiogenic strontium isotopes in carbonate minerals reveal diagenetic influence in shales and limestones in the Appalachian Basin: Chemical Geology, v. 509, p. 194–212, doi: 10.1016/j.chemgeo.2019.01.018.
Booker AE, Hoyt DW, Meulia T, Eder E, Nicora CD, Purvine SO, Daly RA, Moore JD, Wunch K, Pfiffner SM, Lipton MS, Mouser PJ, Wrighton KC, and Wilkins MJ (2019) Deep Subsurface Pressure Stimulates Metabolic Plasticity in Shale-Colonizing *Halanaerobium*. *Applied and Environmental Microbiology*. doi:10.1128/AEM.00018-19
Kavousi Ghahfarokhi, P., Wilson, T.H., **Carr, T.R.**, Kumar, A., Hammack, R. and Di, H., 2019. Integrating distributed acoustic sensing, borehole 3C geophone array, and surface seismic array data to identify long-period long-duration seismic events during stimulation of a Marcellus Shale gas reservoir. Interpretation, *7*(1), pp. SA1-SA10. https://doi.org/10.1190/INT-2018-0078.1.
Borton MA, Daly RA, O'Banion B, Hoyt DW, Marcus DN, Welch S, Hastings SS, Meulia T, Wolfe RA, Booker AE, Sharma S, Cole DR, Wunch K, Moore JD, Darrah TH, Wilkins MJ, and Wrighton KC (2018) Comparative genomics and physiology of the genus Methanohalophilus, a prevalent methanogen in hydraulically fractured shale. *Environmental Microbiology*. doi: 10.1111/1462-2920.14467
Booker AE, Hoyt DW, Meulia T, Eder E, Nicora CD, Purvine SO, Daly RA, Moore JD, Wunch K, Pfiffner S, Lipton MS, Mouser PJ, Wrighton KC, and Wilkins MJ. Deep subsurface pressure stimulates metabolic flexibility in shale-colonizing *Halanaerobium*. Submitted to *Applied and Environmental Microbiology*. In review.
Additionally since the last report, the team's shale virus paper has been published in *Nature Microbiology*. Citation provided below:
Daly RA, Roux S, Borton MA, Morgan DM, Johnston MD, Booker AE, Hoyt DW, Meulia T, Wolfe RA, Hanson AJ, Mouser PJ, Sullivan MB, Wrighton KC, and Wilkins MJ (2018) Viruses control dominant bacteria colonizing the terrestrial deep biosphere after hydraulic fracturing. *Nature Microbiology*. doi: 10.1038/s41564-018-0312-6
Johnson, D., Heltzel, R.*, Nix, A., and Barrow, R.*, "Development of Engine Activity Cycles for the Prime Movers of Unconventional, Natural Gas Well Development," *Journal of the Air and Waste Management Association*, 2016. DOI: 10.1080/10962247.2016.1245220.

Johnson, D., Heltzel, R.*, Nix, A., Clark, N., and Darzi, M.*, "Greenhouse Gas Emissions and Fuel Efficiency of In-Use High Horsepower Diesel, Dual Fuel, and Natural Gas Engines for Unconventional Well Development," *Applied Energy*, 2017. DOI: 10.1016/j.apenergy.2017.08.234.
3.) **Johnson, D.**, Heltzel, R.*, Nix, A., Clark, N., and Darzi, M.*, "Regulated Gaseous Emissions from In-Use High Horsepower Drilling and Hydraulic Fracturing Engines," *Journal of Pollution Effects and Control*, 2017. DOI: 10.4176/2375-4397.1000187.
Johnson, D., Heltzel, R.*, Nix, A., Darzi, M.*, and Oliver, D.*, "Estimated Emissions from the Prime-Movers of Unconventional Natural Gas Well Development Using Recently Collected In-Use Data in the United States," *Environmental Science and Technology*, 2018. DOI: 10.1021/acs.est.7b06694.
Johnson, D., Heltzel, R.*, Nix, A., Clark, N., and Darzi, M.*, "In-Use Efficiency of Oxidation and Threeway Catalysts Used In High-Horsepower Dual Fuel and Dedicated Natural Gas Engines," *SAE International Journal of Engines*, 2018. DOI: 10.4271/03-11-03-0026.
Luek JL, Hari M, Schmitt-Kopplin P, **Mouser PJ,** Gonsior M. (2018). Organic sulfur fingerprint indicates continued injection fluid signature 10 months after hydraulic fracturing. *Environmental Science: Processes & Impacts*. Available in advance at doi: 10.1039/C8EM00331A.
Evans MV, Panescu J, Hanson AJ, Sheets J, Welch SA, Nastasi N, Daly RA, Cole DR, Darrah TH Wilkins MJ, Wrighton KC, **Mouser PJ.** (*in press*, 2018), Influence of *Marinobacter* and *Arcobacter* taxa on system biogeochemistry during early production of hydraulically fractured shale gas wells in the Appalachian Basin. *Frontiers of Microbiology*.
"Economic Impacts of the Marcellus Shale Energy and Environment Laboratory" has been released by the WVU Regional Research Institute,
Panescu J, Daly R, Wrighton K, Mouser, PJ. (2018). Draft Genome Sequences of Two Chemosynthetic Arcobacter Strains Isolated from Hydraulically Fractured Wells in Marcellus and Utica Shales. Genome Announcements, 6 (20), e00159-18. doi:10.1128/genomeA.00159-18.
University of Vermont seminar, Department of Civil and Environmental Engineering. The Role of Microbial Communities in Hydraulically Fractured Shale Wells and Produced Wastewater, 4/2018.
Gordon Research Conference, Environmental Sciences: Water. The Outsiders: Microbial Survival and Sustenance in Fractured Shale, 6/2018.
Ziemkiewicz, P.F. and He, Y.T. 2015. Evolution of water chemistry during Marcellus shale gas development: A case study in West Virginia. Chemosphere 134:224-231.
*"*Candidatus *Marcellius: a novel genus of Verrucomicrobia discovered in a fractured shale ecosystem."* To be submitted to Microbiome journal. This research is led by a visiting post-doc, Sophie Nixon, in the Wrighton laboratory.
"Genomic Comparisons of Methanohalophilus *and* Halanaerobium *strains reveals adaptations to distinct environments."* This work is led by two graduate students: Mikayla Borton in the Wrighton lab and Anne Booker in the Wilkins lab.
Agrawal V and Sharma S, 2018. Molecular characterization of kerogen and its implications for determining hydrocarbon potential, organic matter sources and thermal maturity in Marcellus Shale. Fuel 228: 429–437.
Agrawal V and Sharma S, 2018. Testing utility of organogeochemical proxies to assess sources of organic matter, paleoredox conditions and thermal maturity in mature Marcellus Shale. Frontiers in Energy Research 6:42.

M.A. Borton, D.W. Hoyt, S. Roux, R.A. Daly, S.A. Welch, C.D. Nicora, S. Purvine, E.K. Eder, A.J. Hanson, J.M. Sheets, D.M. Morgan, S. Sharma, T.R. Carr, D.R. Cole, P.J. Mouser, M.S. Lipton, M.J. Wilkins, K.C. Wrighton. Coupled laboratory and field investigations resolve microbial interactions that underpin persistence in hydraulically fractured shales. *Proceedings of the National Academy of Sciences*. June 2018, 201800155; DOI: 10.1073/pnas.1800155115.
R.A. Daly, S. Roux, M.A. Borton, D.M. Morgan, M.D. Johnston, A.E. Booker, D.W. Hoyt, T. Meulia, R.A. Wolfe, A.J. Hanson, P.J. Mouser, M.B. Sullivan, K.C. Wrighton, M.J. Wilkins. Viruses control dominant bacteria colonizing the terrestrial deep biosphere after hydraulic fracturing. *Nature Microbiology.* (in revision)
R.A. Daly, K.C. Wrighton, M.J. Wilkins. Characterizing the deep terrestrial subsurface microbiome. In R. Beiko, W. Hsiao, J. Parkinson (Eds.), *Microbiome analysis: methods and protocols,* Methods in Molecular Biology. Clifton, NJ: Springer Protocols. (in press)
*"*In vitro *interactions scaled to* in situ *conditions: microorganisms predict field scale biogeochemistry in hydraulically fractured shale."* Review comments have been
"Comparison of Methanohalophilus *strains reveals adaptations to distinct environments."* Invited to submit to Frontiers in Microbiology special topic edition Geobiology in the Terrestrial Subsurface, to be submitted June 2018. An undergraduate researcher, Bridget O'Banion in the Wrighton lab, led this research.
Marcellus Shale model stimulation tests and microseismic response yield insights into mechanical properties and the reservoir DFN. Interpretation. 50p. published December 4, 2017, Interpretation, Society Exploration Geophysicists https://doi.org/10.1190/int-2016-0199.1 Thomas H. Wilson , Tim Carr , B. J. Carney , Malcolm Yates , Keith MacPhail , Adrian Morales , Ian Costello , Jay Hewitt , Emily Jordon , Natalie Uschner , Miranda Thomas , Si Akin , Oluwaseun Magbagbeola , Asbjoern Johansen , Leah Hogarth , Olatunbosun Anifowoshe , and Kashif Naseem,
Akondi R, Trexler R, Pfiffner SM, Mouser PJ, Sharma S 2017. Modified Lipid Extraction Method for Deep Subsurface Shale. Frontiers in Microbiology https://doi.org/10.3389/fmicb.2017.01408
the paper was submitted to the Journal Interpretation. The journal submission is titled Marcellus Shale model stimulation tests and microseismic response yield insights into mechanical properties and the reservoir DFN
Johnson, D., Heltzel, R., Nix, A., and Barrow, R., "Development of Engine Activity Cycles for the Prime Movers of Unconventional, Natural Gas Well Development," Journal of the Air and Waste Management Association, 2016. DOI: 10.1080/10962247.2016.1245220
Preston County Journal: http://www.theet.com/news/local/wvu-project-setting-the-standard-for-researching-oil-and-gas/article_25e0c7d0-279d-59c1-9f13-4cbe055a1415.html
The statesman: http://www.thestatesman.com/news/science/fracking-messiah-or-menace/81925.html
Nova Next article: http://www.pbs.org/wgbh/nova/next/earth/deep-life/
NPR interview: http://www.wksu.org/news/story/43880
Midwest Energy News : http://midwestenergynews.com/2015/11/17/researchers-study-microbes-living-in-shale-and-how-they-can-impact-drilling/
McClatchyDC News: "Could deep earth microbes help us frack for oil?"S. Cockerham http://www.mcclatchydc.com/news/nation-world/national/article29115688.html

APPENDIX B – Conference Papers/Presentations MSEEL

Conference Paper/Presentation
Agrawal, V., S. Sharma, N. Mahlstedt 2019, Determining the type, amount and kinetics of hydrocarbons generated in a Marcellus shale maturity series. Eastern Section AAPG 48th Annual Meeting in Columbus, OH.
Carney BJ, Carr TR, Hewitt J, Vagnetti R, Sharma S, Hakala A. 2019. Progress and Findings from "MSEEL 1" and the Transition to "MSEEL 2": Creating Value from a Cooperative Project. Annual Eastern Section AAPG Meeting, Columbus, Ohio.
Phan TT, Hakala JA, Lopano C L, & Sharma S. 2019. Rare earth elements and radiogenic strontium isotopes in carbonate minerals reveal diagenetic influence in shales and limestones in the Appalachian Basin. GAC-MAC-IAH conference, Quebec City, Quebec, Canada.
Ferguson, B., Sharma, S., Agrawal, V., Hakala, A., 2019. Investigating controls on mineral precipitation in hydraulically fractured wells. Geological Society of America Annual Meeting, Phoenix, (GSA), Annual meeting, Phoenix, Arizona.
Akondi R, Sharma S. 2019. Microbial Signatures of Deep Subsurface Shale Biosphere. Geological Society of America (GSA), Annual meeting, Phoenix, Arizona.
Carr, Timothy R. MSEEL Seismic Attribute Application of Distributed Acoustic Sensing Data, presentation at 53rd US Rock Mechanics / Geomechanics Symposium, 2019 American Rock Mechanics Association (ARMA) Annual Meeting, New York City, NY.
Agrawal, V., S. Sharma, N. Mahlstedt 2019, Determining the type, amount and kinetics of hydrocarbons generated in a Marcellus shale maturity series. Eastern Section AAPG 48th Annual Meeting in Columbus, OH
Evans M, Luek J, Daly R, Wrighton KC, **Mouser PJ**. (2019). Microbial (de)halogenation in hydraulically fractured natural-gas wells in the Appalachian Basin. ACS annual conference, Orlando, FL, Mar 31-Apr 4, 2019.
Luek J, Murphy C, Wrighton KC, **Mouser PJ.** (2019). Detection of antibiotic and metal resistance genes in deep shale microbial community members. ACS annual conference, Orlando, FL, Mar 31-Apr 4, 2019.
Kumar, A., E. V. Zorn, R. Hammack, and W. Harbert, 2017a, Seismic monitoring of hydraulic fracturing activity at the Marcellus shale energy and environment laboratory (MSEEL) Site, West Virginia: Presented at the Unconventional Resources Technology Conference, Paper 2670481.
Tufts University, Dept. of Civil and Environmental Engineering. Microbial Survival and Sustenance in Fractured Shale 10/2018.
University of New Hampshire, Dept. of Earth Science. Microbial Survival and Sustenance in Fractured Shale 09/2018.
GSA conference in Indianapolis, Indiana. 2019
AAPG 2019, San Antonio, Texas.
Agrawal, V., Sharma, S., 2018. New models for determining thermal maturity and hydrocarbon potential in Marcellus Shale. Eastern Section AAPG 47th Annual Meeting in Pittsburgh, WV
Eastern Section SPE and AAPG by Yixuan Zhu and T. R, Carr entitled Estimation of "Fracability" of Marcellus Shale: A Case Study from the MIP3H in Monongalia County, WV, USA. The paper will be presented in Pittsburgh, PA during the meeting (October 9-11)

Kelly Wrighton -19th Annual Microbiology Student Symposium, University of California Berkeley, April 28, 2018
Kelly Wrighton - ASM Microbe, Atlanta, Georgia, June 9, 2018
Mouser PJ**,** Heyob KM, Blotevogel J, Lenhart JJ, Borch T (2018). Pathways and Mechanisms for Natural Attenuation of Nonionic Surfactants in Hydraulic Fracturing Fluids if Released to Agricultural Soil and Groundwater. ACS annual conference, New Orleans, LA, Mar 19-22, 2018.
Hanson AJ, Lipp JS, Hinrich K-U, Mouser PJ (2018). Microbial lipid biomarkers in a Marcellus Shale natural gas well: From remnant molecules to adapted communities. ACS annual conference, New Orleans, LA, Mar 19-22, 2018
University of Maine, Department of Biology and Ecology. Biodegradation of Organic Compounds in the Hydraulically Fractured Shale Ecosystem, 2/2018.
"*Top-down and bottom-up controls on* Halanaerobium *populations in the deep biosphere*." Poster presentation at the Department of Energy's Joint Genome Institute 'Genomics of Energy and Environment Meeting', San Francisco, CA, March 2018. A researcher, Rebecca Daly, in the Wrighton lab, led this work.
Sharma S, Wilson T, Wrighton, K, Borton M & O'Banion. 2017 Can introduction of hydraulic fracturing fluids induce biogenic methanogenesis in the shale reservoirs? Annual American Geophysical Union Conference, Dec 11-15, New Orleans, LA.
Booker AE, Borton MA, Daly R, C. Nicora, Welch S, Dusane D, Johnston M, Sharma S et. al., 2017. Potential Repercussions Associated with Halanaerobium Colonization of Hydraulically Fractured Shales. Annual American Geophysical Union Conference, Dec 11-15, New Orleans, LA.
Mouser P. *Colorado State University, Civil and Environmental Engineering* and *CSU Water Center*, From the Land Down Under: Microbial Community Dynamics and Metabolic processes influencing organic additives in black shales, 11/2017.
Presentation at ISES (International Society for Exposure Science), Raleigh, NC Oct. 16th, 2017 on "Techniques for Estimating Community Exposure from Hydraulic Fracturing Operations
Kavousi, Payam, **Timothy R**. **Carr,** Robert J Mellors, Improved interpretation of Distributed Acoustic Sensing (DAS) fiber optic data in stimulated wells using seismic attributes, [S33B-0865] presented at December 2017 Fall Meeting, AGU, New Orleans, LA, 11-15,https://agu.confex.com/agu/fm17/meetingapp.cgi/Paper/282093
Mellors Robert J, Christopher Scott Sherman, Frederick J Ryerson, Joseph Morris, Graham S Allen, Michael J Messerly, **Timothy Carr**, Payam Kavousi, Modeling borehole microseismic and strain signals measured by a distributed fiber optic sensor, [S33B-0869] presented at 2017 Fall Meeting, AGU, New Orleans, LA, 11-15, https://agu.confex.com/agu/fm17/meetingapp.cgi/Paper/264800
Song, Liaosha and **Timothy R. Carr**, Microstructural Evolution of Organic Matter Pores in Middle Devonian Black Shale from West Virginia and Pennsylvania, USA, SEPM – AAPG Hedberg Research Conference, Mudstone Diagenesis, Santa Fe, New Mexico, October 16-19. http://www.searchanddiscovery.com/pdfz/abstracts/pdf/2017/90283hedberg/abstracts/ndx_song.pdf.html

Carr, Timothy R., The Importance of Field Demonstration Sites: The View from the Unconventional Resource Region of the Appalachian Basin (Invited), [H21K-06] presented at 2017 Fall Meeting, AGU, New Orleans, LA, 11-15 Dec. https://agu.confex.com/agu/fm17/meetingapp.cgi/Paper/242523
Ghahfarokhi, P. K., Carr, T., Song, L., Shukla, P., & Pankaj, P. (2018, January 23). Seismic Attributes Application for the Distributed Acoustic Sensing Data for the Marcellus Shale: New Insights to Cross-Stage Flow Communication. Society of Petroleum Engineers, doi:10.2118/189888-MS.
Presentation of paper at 2017 Annual International SEG meeting: The paper *titled "Relationships of brittleness index, Young's modulus, Poisson's ratio and high TOC for the Marcellus Shale, Morgantown, West Virginia"* by Thomas H. Wilson*, Payam Kavousi, Tim Carr, West Virginia University; B. J. Carney, Northeast Natural Energy LLC; Natalie Uschner, Oluwaseun Magbagbeola and Lili Xu, Schlumberger, was presented at the annual SEG meeting, this past September in Houston, TX.
Thomas H. Wilson and Tim Carr, West Virginia University; B. J. Carney, Jay Hewitt, Ian Costello, Emily Jordon, Northeast Natural Energy LLC; Keith MacPhail, Oluwaseun Magbagbeola, Adrian Morales, Asbjoern Johansen, Leah Hogarth, Olatunbosun Anifowoshe, Kashif Naseem, Natalie Uschner, Mandy Thomas, Si Akin, Schlumberger, 2016, Microseismic and model stimulation of natural fracture networks in the Marcellus Shale, West Virginia: SEG International Exposition and 86th Annual Meeting, 3088-3092, https://doi.org/10.1190/segam2016-13866107.1.
Sharma S 2017. Shale Research at Marcellus Shale Energy and Environment laboratory. 23rd Annual CNSF Exhibition, May 16, Rayburn House, Washington DC.
Elsaig, M., Black, S., Aminian, K., and S. Ameri, S.: "Measurement of Marcellus Shale Properties," SPE-87523, SPE Eastern Regional Conf., Lexington, KY, October 2017.
El Sgher, M., Aminian, K., and S. Ameri: "The Impact of Stress on Propped Fracture Conductivity and Gas Recovery in Marcellus Shale," SPE-189899, SPE Hydraulic Fracturing Technology Conf., Woodlands, TX, January 2018.
Ebusurra, M.: "Using Artificial Neural Networks to Predict Formation Stresses for Marcellus Shale with Data from Drilling Operations." MS Thesis, Petroleum & Natural Gas Engineering, West Virginia University, August 2017.
M. El Sgher, K. Aminian, S. Ameri: "The impact of the hydraulic fracture properties on gas recovery from Marcellus Shale," SPE 185628, SPE Western Regional Conf., Bakersfield, California, April 2017.
Elsaig, M., Aminian, K., Ameri, S. and M. Zamirian: "Accurate Evaluation of Marcellus Shale Petrophysical Properties," SPE-**Error! Reference source not found.**84042, SPE Eastern Regional Conf., Canton, OH, September 2016.
Filchock, J.J., Aminian, K. and S. Ameri: "Impact of Completion Parameters on Marcellus Shale Production," SPE-184073, SPE Eastern Regional Conf., Canton, OH, September 2016.
Tawfik Elshehabi and H. Ilkin Bilgesu: "Well Integrity and Pressure Control in Unconventional Reservoirs: A Comparative Study of Marcellus and Utica Shales," SPE 184056, SPE Eastern Regional Conf., Canton, OH, September 2016

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The presentation was made at the annual SEG convention in Dallas (see http://library.seg.org/doi/pdf/10.1190/segam2016-13866107.1) and the paper was submitted to the Journal Interpretation. The journal submission is titled Marcellus Shale model stimulation tests and microseismic response yield insights into mechanical properties and the reservoir DFN
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Marcellus Shale Energy and Environment Laboratory (MSEEL): Subsurface Reservoir Characterization and Engineered Completion; Presenter: Tim Carr; West Virginia University (2670437)
Depositional environment and impact on pore structure and gas storage potential of middle Devonian organic rich shale, Northeastern West Virginia, Appalachian Basin; Presenter: Liaosha Song, Department of Geology and Geography, West Virginia University, Morgantown, WV, (2667397)
Seismic monitoring of hydraulic fracturing activity at the Marcellus Shale Energy and Environment Laboratory (MSEEL) site, West Virginia; Presenter: Abhash Kumar, DOE, National Energy Technology Laboratory (2670481)
Geomechanics of the microseismic response in Devonian organic shales at the Marcellus Shale Energy and Environment Laboratory (MSEEL) site, West Virginia; Presenter: Erich Zorn, DOE, National Energy Technology Laboratory (2669946)
Application of Fiber-optic Temperature Data Analysis in Hydraulic Fracturing Evaluation- a Case Study in the Marcellus Shale; Presenter: Shohreh Amini, West Virginia University (2686732)
The Marcellus Shale Energy and Environmental Laboratory (MSEEL): water and solid waste findings-year one; Presenter: Paul Ziemkiewicz WRI, West Virginia University (2669914)
Role of organic acids in controlling mineral scale formation during hydraulic fracturing at the Marcellus Shale Energy and Environmental Laboratory (MSEEL) site; Presenter: Alexandra Hakala, National Energy Technology Laboratory, DOE (2670833)

MSEEL Water and Waste Findings - RPSEA Onshore Workshop
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Sharma S., 2016. Unconventional Energy Resources: A view from the Appalachian Basin. US Embassy Berlin, Germany 25 May 2016.
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On July 20, 2016, Paul Ziemkiewicz, Task 5a lead investigator gave a presentation titled: WVU – Northeast Natural Energy Marcellus Hydraulic Fracture Field Laboratory Environmental Research Update at the WVU/PTTC/NETL/RPSEA Onshore Technology WorkshopAppalachian Basin Technology in Canonsburg, PA.
Abstract entitled "Addressing Health Issues Associated with Air Emissions around UNGD Sites" by Michael McCawley, Travis Knuckles, Maya Nye and Alexandria Dzomba accepted for the 2016 Eastern Section – American Association of Petroleum Geologists' meeting in Lexington, Kentucky on September 27, 2016.
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Application of voltammetric techniques towards iron and sulfur redox speciation in geologic fluids from coal and shale formations, American Chemical Society Fall Meeting 2016 Philadelphia, PA.
Phan, T.T., Hakala, J.A. 2016. Contribution of colloids to major and trace element contents and isotopic compositions (Li and Sr) of water co-produced with natural gas from Marcellus Shale. American Chemical Society Fall Meeting 2016 Philadelphia, PA.
Environmentally Friendly Drilling Conference on 11/15/2015 by Sunil Moon and Michael McCawley, Diesel Traffic Volume Correlates with Ultrafine Particle Concentrations but not PM2.5.
Agrawal V, Sharma S , Chen R, Warrier A, Soeder D, Akondi R. 2015. Use of biomarker and pyrolysis proxies to assess organic matter sources, thermal maturity, and paleoredox conditions during deposition of Marcellus Shale. Annual Geological Society of America Meeting, Baltimore, MD, November 1-4.
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Mouser, PJ, Daly, RA, Wolfe, R. and Wrighton, KC (2015). Microbes living in unconventional shale during energy extraction have diverse hydrocarbon degradation pathways. Oral presentation presented at 2015 Geological Society of America Annual Conf. Baltimore, MD, Nov 1-4.
Sharma S and Wilson T. 2015. Isotopic evidence of microbe-water-rock interaction in Shale gas produced waters. Annual Geological Society of America Meeting, Baltimore, MD, November 1-4.
Sharma S, Chen R, Agrawal V. 2015 Biogeochemical evidences of oscillating redox conditions during deposition of organic-rich intervals in the middle Devonian Marcellus Shale. Annual Geological Society of America Meeting, Baltimore, MD, November 1-4.
Trexler RV, Pfiffner SM, Akondi R, Sharma S, Mouser PJ.(2015) Optimizing Methods for Extracting Lipids from Organic-Rich Subsurface Shale to Estimate Microbial Biomass and Diversity. Poster session presented at: 2015 Geological Society of America Annual Meeting. 2015 Nov 1-4; Baltimore, MD.
Wrighton, KC; Daly, R; Hoyt, D; Trexler, R; MacRae, J; Wilkins, M; Mouser, PJ (2015), Oral presentation at the American Geophysical Union Annual Meeting. Something new from something old? Fracking stimulated microbial processes. Presentation# B13K-08. San Francisco, CA, Dec 14-18, 2015.
Mouser, P, The Impact of Fracking on the Microbiology of Deep Hydrocarbon Shale, American Society for Microbiology (ASM) Annual Conference, New Orleans, LA, May 30-June 2, 2015.
Wrighton et al, Drivers of microbial methanogenesis in deep shales after hydraulic fracturing. American Society of Microbiology. New Orleans, LA. May 30-June 2, 2015.
Daly et al, Viral Predation and Host Immunity Structure Microbial Communities in a Terrestrial Deep Subsurface, Hydraulically Fractured Shale System. American Society of Microbiology. New Orleans, LA.

APPENDIX C – Special MSEEL Sessions

Paper prepared for presentation at the Unconventional Resources Technology Conference (URTeC) held in Denver, Colorado, USA, 22-24 July 2019, 10 pages, DOI 10.15530/urtec-2019- 415.
Odegaarden, Natalie and Timothy Carr, Vein Evolution due to Thermal Maturation of Kerogen in the Marcellus Shale, Appalachian Basin, Paper presented at the Annual Meeting of the Geological Society of America 22-25 September 2019 Phoenix, AZ.
URTeC (URTeC: 2902641) for presentation in Houston (July) by Payam Kavousi Ghahfarokhi, Timothy Carr, Shuvajit Bhattacharya, Justin Elliott, Alireza Shahkarami and Keithan Martin entitled A Fiber-optic Assisted Multilayer Perceptron Reservoir Production Modeling: A Machine Learning Approach in Prediction of Gas Production from the Marcellus Shale. 2019
8/15/2017 - Coordinate and hold MSEEL session at URTEC 2017 (Scheduled 8/30/2017; Completed 8/30/2017)
4/30/2017 - Conduct preliminary analysis of production log data and present to DOE. (Completed and being worked into a new reservoir simulation – Review meeting held at WVU
26 Jul 2017: URTeC, Austin, TX, Manuscript attached
27 Sep 2017: Marcellus Shale Coalition, Shale Insight,
SPE-184073, SPE Eastern Regional Conf., Canton, OH, September 2016.
2016 SEG meeting in Dallas
2014 American Geophysical Union (AGU) Fall Meeting in December 2014 to discuss next steps in the project. At AGU, we hosted a special session on Biogeochemistry of Deep Shale,

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