Oil & Natural Gas Technology

DOE Award No.: DE-FE0024297

Quarterly Research Performance Progress Report

(Period ending: 6/30/2016)

Marcellus Shale Energy and Environment Laboratory (MSEEL)

Project Period: October 1, 2014 – September 30, 2019

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Office of Fossil Energy

Quarterly Progress Report

April 1 – June 30, 2016

Executive Summary

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.

This quarter continued to be very active, as the team has started in-depth analysis of the almost four terabytes of data collected during well development. The project team has had several abstracts accepted for the Eastern Section of the American Association of Petroleum Geologists meeting, scheduled for September 25-27, 2016, in Lexington, KY. The abstracts that have been accepted are included in this report as an appendix.

Quarterly Progress Report

April 1 – June 30, 2016

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 third quarter of the FY2016 (April 1 through June 30, 2016).

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.

Topic 1 – Project Management and Planning

Subtopic 1.1. – Project Management

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

This quarter has been very active, as the team has continued analysis of the data collected during well development. Activities this quarter have focused on accelerating some of the planned research tasks and coordination with the US DOE team at NETL.

The project team is tracking four milestones in this budget period.

1. Complete/Stimulate Production Wells (NNE 3H, 5H) – 11/30/2015 (Complete)
    a. Completed with successful gathering of subsurface data from the fiber-optic cable and from advanced logging.

2. Complete Preliminary Analysis of Surface and Subsurface Data – 3/31/2016 (Complete)
    a. Core was received, CT scanned and visually logged, an initial round of samples have been distributed to investigators. Preliminary examination from geomechanical logging and fracture analysis have been completed, but results have raised numerous questions that need to be addressed, including the effectiveness and the direction of fracture stimulation. Analysis of cuttings, produced water and air have been completed and are ongoing during production phase.

3. Complete SEM, XRD and PPAL imaging and Core Analysis – 9/30/2016
    a. Initial results are coming in and will be available this summer. We have taken a very careful approach to calibrate results among labs, including WVU, OSU, NETL and Schlumberger.

4. 3D Fracture Modeling Complete – 12/31/2016.
    a. This is advancing very quickly with the integration of microseismic and fracture logs (see write up for this quarter). Still need to integrate the sonic and temperature data from the fiber-optics. This should be well along by the end of summer.

Subtopic 1.2. – Database Development

Approach

We will use CKAN, open source data portal software (www.ckan.org). This platform is used by NETL-EDX and Data.gov among other organizations and agencies. We will use this platform to store, manage, publish and find datasets.

Results and Discussion

CKAN is up and running and has been used to share data from the existing wells and presentations among research personnel. The MSEEL web site has been enhanced with MSEEL News articles, a time line and with images. We have generated static and dynamic 3D images of the surface and subsurface at the MSEEL site (Figure 1.2)

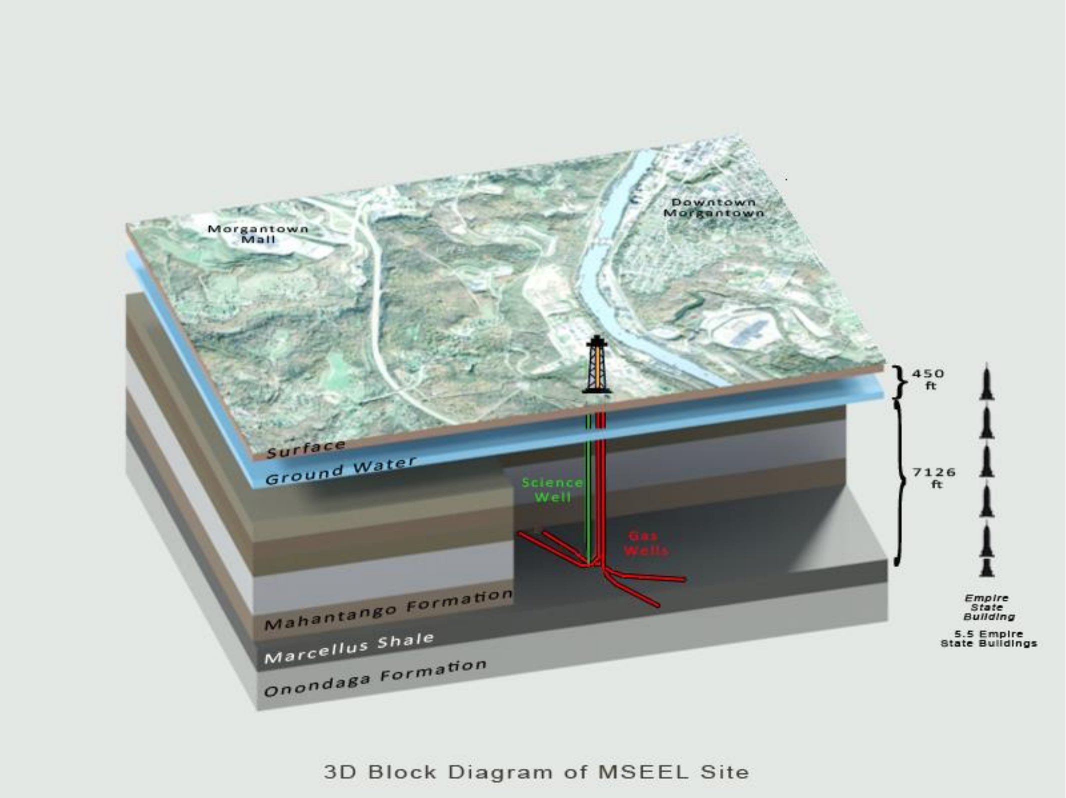


Figure 1.2. Static 3D image of the MSEEL sit showing the existing production wells and the two new production wells along with the science/observation well.

Plan for Next Quarter

Upload 3D static and dynamic images to online site and federate MSEEL portal with EDX.

Topic 2 – Geologic Engineering

Approach

The geologic engineering team will work to generate to improve the effectiveness of fracture stage design. Evaluating innovative stage spacing and cluster density practices to optimize recovery efficiency. The team will use a data driven approach to integrate geophysical, fluid flow and mechanical properties logs, microseismic and core data to better to characterize subsurface rock properties, faults and fracture systems to model and identify the best practices for field implementation, and assess potential methods that could enhance shale gas recovery through experimental and numerical studies integrated with the results of the production wells at the MSEEL site.

Results and Discussion

Task 2a – Rock Analysis

During the reporting period, the experimental investigations were focused on developing a complete permeability-stress profile. The core plug sample #103, obtained at the depth of 7547.03 feet from the science well, was utilized for these experiments. The permeability of the core plug was measured at 4 different average gas (pore) pressures ranging from 200 to 500 psig while maintaining the net stress on the sample constant. It should be noted that each permeability value measured is the average of nearly 100 measured permeability values during each experiment. The measured permeability values at different pore pressures were then utilized to determine the absolute permeability of the core plug by the application of the double-slippage method. The double-slippage correction as discussed in the previous report is the appropriate method for evaluating the absolute permeability due to transition flow regime. Subsequently, the net stress on the sample was increased by increasing the confining pressure. The permeability of the core plug was then measured at same 4 average gas pressures while maintaining the net stress on the sample at new level. The absolute permeability at new stress level was then determined. The net stress was increased in 7 steps from 1300 psig to 7000 psig. As a result, a total of 28 permeability measurements were performed. Table 2.a.1 below summarizes the experimental conditions and the results. Figure 2.a.1 illustrates the impact of the net stress on the absolute permeability. As can be clearly observed from Figure 2.a.1, the absolute permeability response to the stress is non-linear. This non-linear response is contributed to the presence of two pore system within the rock with different compressibilities, i.e. fracture and matrix. At low stress conditions, the fractures and matrix both contribute to the permeability. As stress increases, the fractures which are more compressible begin to close down resulting in a major reduction in the total permeability. At higher stress conditions, the fractures would be completely closed and the matrix would become the only contributor to total permeability. Walsh suggested that a linear relationship exists between $(k/k_o)^{1/3}$ and $ln(P/P_o)$ where k is the permeability measured at a specific stress (P), and k_o is the permeability measured at the lowest stress (P_o). When more than one porous systems are present in the rock, the Walsh plot yield more than one straight line with different slopes. Therefore, the Walsh plot can be used to detect the presence of different media. Figure 2.a.2 illustrate the Walsh plot for same data in Figure 2.a.1. It appears that two separate straight lines are present on Figure 2.a.2. The first straight line (blue) reflects the stress range where the permeability is dominated by the fractures. The second straight line (red) represents the stress range when the fractures are completely closed and the matrix is the only contributor to the permeability. Figure 2.a.2 suggests that fractures are completely closed when the stress is above 4,770 psi.

Table 2.a.1. Permeability Measurement Experimental Conditions and the Results

Upstream Pressure, psig	Downstream Pressure, psig	Average Pressure, psig	Confining Pressure, psig	Net stress Pressure, psi	Measured Permeability (nD)	Absolute Permeability (nD)
300	100	200	1500	1300	2450	**1031.8**
400	200	300	1600	1300	1720	
500	300	400	1700	1300	1380	
600	400	500	1800	1300	1237	
300	100	200	2600	2400	1807	**602.26**
400	200	300	2700	2400	1152	
500	300	400	2800	2400	853	
600	400	500	2900	2400	807	
300	100	200	3300	3100	1307	**437.25**
400	200	300	3400	3100	853	
500	300	400	3500	3100	640	
600	400	500	3600	3100	575	
300	100	200	4200	4000	960	**366.12**
400	200	300	4300	4000	680	
500	300	400	4400	4000	512	
600	400	500	4500	4000	440	
300	100	200	5200	5000	615	**243.03**
400	200	300	5300	5000	425	
500	300	400	5400	5000	350	
600	400	500	5500	5000	286	
300	100	200	6100	5900	440	**168.42**
400	200	300	6200	5900	308	
500	300	400	6300	5900	240	
600	400	500	6400	5900	192	
300	100	200	7200	7000	281	**87.02**
400	200	300	7300	7000	190	
500	300	400	7400	7000	137	
600	400	500	7500	7000	109	

The analysis of the production and stimulation data from the previously drilled horizontal wells (4H and 6H) at the MIP site have been completed. The production profiles for both wells have been closely matched with the numerical model predictions. The shale characteristics obtained from the history matching process are in close agreement with measured values. The shale characteristics and completion information available from the new horizontal wells (3H and 5H) have been utilized to predict the production and close agreements with the limited production profiles have been obtained.

The analysis of the data generated during drilling the new horizontal wells (3H and 5H) is in progress. The determining formation characteristics from wireline and thermal logs is also in progress.

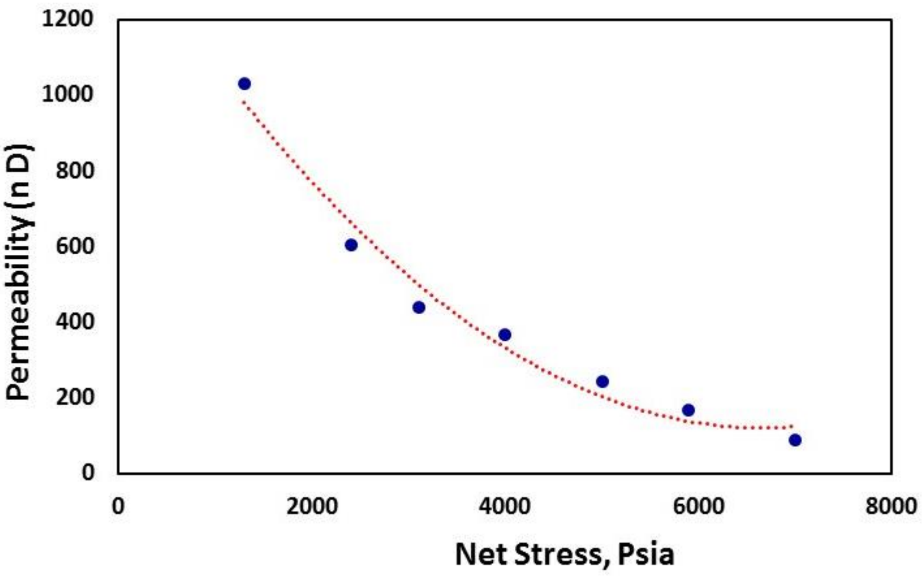


Figure 2.a.1. The Impact of Stress on the Absolute Permeability

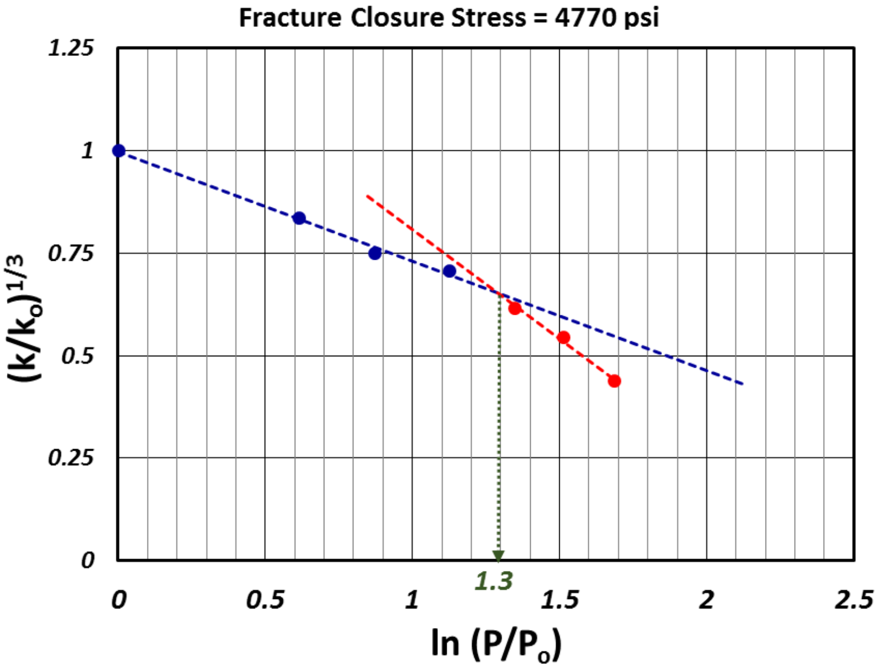


Figure 2.a.2. Walsh Plot for Fracture Closure Stress Estimation

Task 2b – Water Treatment

Our first research activity of produced water treatment focuses on developing an (bio)electrochemical method to remove scale-forming cations as a pre-treatment system for produced water treatment. A two-chamber bioelectrochemical system used in this study contained an anode and cathode chambers separated by a cation exchange membrane. Each chamber contained graphite woven felt electrodes. An electric current was used to create a pH unbalance between the anode and cathode. The high-pH cathlyte was then used to treat raw produced water to remove multi-valent cations as a softening process. Produced water sample was collected at the MSEEL site and used in the study. The treatment method was shown to be effective in removing scale-forming cations.

Results and Discussion

1. Produced water chemical characterization (Table 1)

Table 2.b.1. Chemical characterization of the raw produced water collected from the MSEEL site.

Parameter	Unit	Concentration	Parameter	Unit	Concentration
pH		4.55	Aluminum (Al)	mg/L	0.29
TSS	g/L	0.21	Magnesium (Mg)	g/L	2.30
COD	mg/L	958	Strontium (Sr)	g/L	3.85
Alkalinity	mg $CaCO_3$/L	107.84	Calcium (Ca)	g/L	38.64
Acidity	mg $CaCO_3$/L	280.87	Sodium (Na)	g/L	27.00
Conductivity	mS/cm	109.70	Iron (Fe)	mg/L	156.00
Sulfate (SO_4^{2-})	mg/L	5.00	Manganese (Mn)	mg/L	3.56
Chloride (Cl)	g/L	68.20	Barium (Ba)	g/L	11.01

2. Bioelectrochemical treatment for produced water softening
   Catholye pH reached as high as 11.5 depending on the current intensity applied. Mixing the catholyte with the raw produced water at different ratios resulted in excellent removal of scale-forming cations. Figure 1 shows removal calcium and magnesium for different volumetric mixing ratios (raw produced water:catholyte). Other results of the study include those from miscroscopic and chemical analyses of the precipitated materials and chemical composition evolution in the anode and cathode chambers.

Products

Plan for Next Quarter

The measurement on the core plug samples will continue to obtain a complete set of characteristics. In addition, experiments with Carbon Dioxide or Methane will be initiated to evaluate the adsorption characteristic of the core plugs.

Products

Plan for Next Quarter

Topic 3 – Deep Subsurface Rock, Fluids, and Gas

Approach

The “Deep Subsurface Rock, Fluids & Gas” team will be responsible for high resolution temporal and/or spatial characterization of the core, produced fluids, and produced gases. The team will use whole and sidewall core and geophysical logs from the science well to conduct various petrophysical analyses to analyze physical rock properties. Data generated by all team members will be integrated to answer following key research questions: 1) geological controls on microbial distribution, diversity and function and how it can effect gas productivity, potential for fracture and pore clogging, well infrastructure and souring 2) major controls on distribution/source/type of organic matter that has implications for oil vs gas production, fracability, restimulation and porosity/permeability effects 3) what are spatiotemporal variations in elemental, isotopic, mineralogical and petrological properties that control presence, geological migration, and modern flow of fluids, water, gases and microorganisms and also effect long-term production behavior of reservoir 4) what are possible water-rock-microbial interactions as a result of injection of fracturing fluids, and 5) does hydraulic fracturing create new pathways for fluid/gas migration

Plan is to develop specific methodology for testing during the next quarter, so that all scientific objectives can be achieved.

Results and Discussion

Accomplishments:

- Samples will continue to be collected and distributed to all investigators on monthly basis
- Data will be presented at Eastern AAPG 2016 conference, Annual GSA conference 2016 and Goldschmidt/AAPG/GSA conference in 2017.
- Results from these analyses will be presented at EAAPG and AGU conferences in Fall 2016
- Sharma and Mouser Lab expect to submit two peer-authored manuscripts during 2016-2017.
- Data will be presented at a conference in 2016 (EAAPG).
- Data from this sequencing effort will be curated and available for use by summer 2016.
- Data from contamination control samples will be included in the phospholipid fatty acid presentation and manuscript

Major goals – progress towards

Goal 1: Sample collection and Analysis

Sidewall and Vertical Core

The side wall cores are curated at OSU and WVU. Based on the geophysical logs eight samples were selected from different lithologies i.e. zones where we expect to see maximum biogeochemical variations. Samples were homogenized and distributed among different PI’s are currently being processed for biomarker, isotope analysis, elemental analysis, porosity/pore structure, and noble gas analysis and expected to complete by end of summer 2016. The remaining intact and cleaned sidewall cores are archived in Sharma’s Lab at WVU and Mouser lab at OSU for future analysis.

For whole core analysis a meeting was held at NETL's Morgantown office and everyone was briefed on how the cores taken from 1-foot interval through the 111 feet of whole were distributed among different research groups. A series of tests were conducted on test samples from another core in order to establish a sample processing procedure that would provide representative geochemical results of each sample processed through the MSEEL project. One experiment tested the consistency in analytical results among splits from the same sample. All six splits were analyzed using the XRD and the results showed a consistent overlap of all splits throughout the 5°-70° 2θ range. The second experiment was designed to test if varying grind times (2, 4, 6, and 10 minutes) produced any signs of thermal alteration within the data. Comparison of the XRD emission spectra showed distinct overlap, with no evidence of different peaks appearing in the powders with longer grind times. These tests helped to establish confidence in our processing procedure prior to grinding of the MSEEL samples. Thirty five samples from the MIP 3H well have been ground and split six times (XRD/XRF, ICP-MS, Metal Isotopes, C & O Isotopes, Pyrolysis, and Archive). Larger samples chips (approximately 5 g) were preserved for potential Sm-Nd isotopic dating. Of the 35 samples, 25 have been sent out for thin sectioning and all 35 samples have been analyzed through x-ray diffraction. The rest of the plugs from the MIP 3H well have been trimmed and 30 of them contain enough sample to process for geochemical analyses. The rest of the samples will be ground and splits will be sent out for various other geochemical analyses by the end summer.

Dr.'s Lopano and Crandall at NETL are working with SLAC to evaluate Ba speciation in MSEEL core samples (data being collected this week on Stanford synchrotron).The Darrah/Cole labs are conducting trace element 'mapping' of mineralized vein-filled fractures, fluid inclusions, and matrix from rock cores. They currently have preliminary core analysis underway for major and minor elements. A comprehensive suite of trace elements will be conducted by sequential cryogenic laser ablation with an excimer laser with cryogenic plate in-line with a high resolution Element II ICP-MS (OSU TERL Laboratory).

Produced Fluid and Gas

Produced water samples were collected in 5 gallon carboys every month. The samples were the tranported, filtered and processed in Sharma Laboratory at WVU. All water samples were collected in different containers using different methods/ preservatives etc. specified for different kinds of analysis. All PI's at OSU and NETL and provided their detailed sampling instructions. Dr. Warrier, Wilson from WVU and Daly from OSU were primarirly incharge of sample collection and distribution among different PI's at WVU, OSU and NETL. The collected fluids are curretly being processsed for biomass, reactive chemistry, organic acids, and noble gas and stable isotope analysis at different institutes. Mouser is curating a master database of geochemistry data, which will be posted to MSEEL by end of summer. Dr. Phan from Hakala's group at NETL has been working on measurements of major and trace elements, and Sr isotope fractionation, in colloidal versus dissolved fractions of the produced water samples from MSEEL, and is analyzing the results. Hakala's group is also working on developing the electrochemical method for detecting trace metals in produced waters.

The produced gas samples were collected from well heads of the two production wells and transported to Sharma Lab at WVU and analyzed for molecular composition and C/H isotope composition of methane, ethane and CO_2. A duplicate set of gas samples were then sent to Darrah's lab at OSU for He, Ne, Ar, Kr, and Xe concentration analysis by quadruple mass spectrometry; and helium, neon, and isotopes by noble gas mass spectrometry. Both flow back fluids and produced gas samples have shown low levels atmospheric gases, indicating the acquisition of high quality samples (a known challenge in sampling for noble gases).

Goal 2: Test methods biomarker extraction, identification and quantification

Out of the 44 sidewall cores collected from the well 3H 8 cores were selected for analysis. Method has been established in Sharma lab to extract biomarkers from Marcellus shale samples of two different maturities. The publication on initial results is currently under preparation. The same method has been used to extract biomarkers from few sidewall cores collected from well #3H. Sharma's PhD. Student Vikas is currently analyzing the data and it is expected to be completed by Dec 2016.

Using an extraction method that was optimized for lipids within the shale matrix, the Mouser and Sharma labs have extracted the phospholipid fatty acids (PLFA's) and diglyceride fatty acids (DGFA's) from 3 different shale cores, including the Mahantango, Marcellus top, and Upper Marcellus. The Mouser lab also extracted lipids from contamination controls to compare with pristine samples, including drilling muds and washes. Data reduction for these 3 cores is currently underway. Sharma PhD. Student Rawlings is working in collaboration with Mouser Lab to harmonize DGFA analysis with their phospholipid fatty acid (PLFA) analysis to better understand to determine viable and dead microbial biomass in MSEEL core samples.

Goal 3: Microbial DNA analysis and microbial cultivation

The Wrighton lab has extracted microbial DNA from 8 side wall cores and sent all wash samples (375 total samples) to DOE's Joint Genome Institute (JGI) for 16S rRNA gene sequence analysis. Data from this sequencing effort will be curated and available for use by end of summer. Data from contamination control samples will be included in the phospholipid fatty acid presentation and manuscript. Using pristine cleaned core materials the Wilkins lab has set up enrichments in 8 different media types for native microbial communities. Enrichments include carbohydrate fermenters, iron reducing bacteria, sulfate reducing bacteria, acetoclastic methanogens, hydrogenotrophic methanogens, hydrocarbon fermenters, and both aerobic and anaerobic hydrocarbon oxidizers. In addition, three sets of enrichments were performed at both atmospheric pressure and under 8,000 psi using Wilkin's high-pressure culturing equipment.

1. Training/Professional Development

- None this quarter

2. Data Dissemination

Invited Talks

1. Sharma S., 2016. Unconventional Energy Resources: A view from the Appalachian Basin. US Embassy Berlin, Germany 25 May 2016.
2. Sharma S., 2016. Biogeochemistry of Marcellus Shale. German National Research Centre for Earth Sciences GFZ, Postdam, Germany. May 22, 2016
3. Sharma S. 2016,. Biogeochemistry of Marcellus Shale. SouthWestern Energy, Houston, Texas. May 5, 2016.
4. Sharma S. 2016. Marcellus Shale Energy and Environment Laboratory (MSEEL), West Virginia University Extension Conference, Clarksburg, WV. May 18, 2016.

5. Sharma S. 2016. Role of Geochemistry in Unconventional Resources Development. Appalachain Geological Society Meeting, Morgantown, April 5, 2016.
6. Sharma S. 2016. Marcellus Shale Energy and Environment Laboratory (MSEEL), Exxon WVU visit, Morgantown, June 23, 2016.

Plan for Next Quarter

- Sharma lab will be working on preparing and analyzing samples for C/N/S isotopes
- Sharma lab will work on extraction, analysis and interpretation of biomarkers from selected sidewall and vertical core plugs from MSEEL
- Sharma lab will work on refining the kerogen extraction method for higher recovery and get trained in new techniques like XPS, FTIR and Raman Spectroscopy for kerogen analysis
- Sharma lab and Mouser \will meet to finalize research publications on PLFA and DGFA analysis from preliminary set of samples
- Mouser group will continue processing fluid samples from MSEEL wells. Circulate preliminary chemistry data to identify samples for future metagenomics/lipid analysis.
- Mouser lab plans to conduct a more detailed phospholipid fatty acid analysis with remaining pristine cores to include LC separation of polar head groups in conjunction with fatty acid methyl ester analysis. We intend to split samples with the Sharma lab for concurrent fatty acid/diglyceride analysis.
- Wrighton lab is continuing to optimize DNA extraction protocols for shale core material. We anticipate extracting DNA from three or more pristine cores and sequencing for 16S rRNA gene analyses and metagenomics, pending DNA quality and quantity.
- Wrighton lab will extract DNA from injected and flowback fluids during the coming year and sequence 16S rRNA and metagenomes through an existing DOE Joint Genome Institute user grant. Bioinformatics analysis will be conducted in her lab, with information to be posted and available to other researchers through DOE JGI's IMG website.
- Wilkins lab is currently developing methods to remove cultured cells from shale particles in order to proceed with single cell genomics surveys of enriched communities through an existing user grant at the DOE's Joint Genome Institute. He anticipates submitting samples for single cell genome sequencing and analyzing this data in the coming year.
- Mouser/Wrighton/Wilkins labs are triaging enrichments to isolate key bacteria and archaea from flowback fluids. At current, we have several enrichments underway and expect to sequence the genomes of isolates cultured from these fluids. Genome data will enable comparisons with metagenomics data, while the availability of relevant isolates will allow more detailed laboratory physiology studies to understand how such species persist in deep shales.
- Cole lab will continue FIB/SEM analysis to provide 3-D rendering of the material to assess the distribution of minerals, organic matter, and pores. The SEMCAL SEM work will further inform this by adding mineral microanalysis (high resolution BSE, EDXS) to distinguish minerals and their associations with OM and pores.
- Darrah lab will work on analysis of argon, krypton, and xenon isotopes by high resolution, high precision noble gas mass spectrometry in the near future.
- Hakala's group at NETL will continue to work on Sr isotope characterization, major/minor/trace element analysis of produced water and core samples. They will

continue developing the electrochemical method for detecting trace metals in produced waters and organizing, quality-checking, and plotting the major and minor chemical data from the MSEEL produced water samples collected and analyzed.

Topic 4 – Geophysical and Geomechanical

Approach

Team will conduct microseismic analyses during the frac jobs of the production wells and tie that data back to the geophysical logs obtained from the science well, providing a clearer picture of proppant placement through the establishment of a detailed rock velocity model. Some inferences toward fracture quantity and patterns will also be vetted.

Plan is to identify specific methodology to obtain the data that will provide most understanding of subsurface rock model

Results and Discussion

Task 4a - Geophysics:

The effort this past quarter involved: 1) paper accepted for publication/presentation SEG 2016 Dallas; 2) Simulation tests continued; 3) model calibration effort initiated; 4) correlation dimension calculated stage-by-stage for the 3H well; 5) moment and density weighted stimulated rock volumes calculated stage-by-stage for the 3H well; 6) preliminary examination of fracture spacing data evaluated for power law behavior.

FY16 effort to date: 2.1 FTE months.

Hydraulic fracture stimulation tests

Work presented in Wilson et al. (2016, in press) revealed the need for an additional fracture set and horizontal gradient in S_{hmin} to produce the asymmetry observed in the distribution of microseismic events. In their model, upward and downward growth were forced to remain less than 50 feet below the base of the Marcellus and not more than 350 feet above the base of the Marcellus. This allowed limited downward growth into the underlying Onondaga and Oriskany and confined upward growth below the Tully.

Without arbitrary confinement, downward growth was extensive and upward growth limited (Figure 4.a.1). This was expected since the minimum stress gradient (TXSG_TIV log response) was much lower than that observed in the Marcellus and overlying shale intervals (Figure 4.a.2).

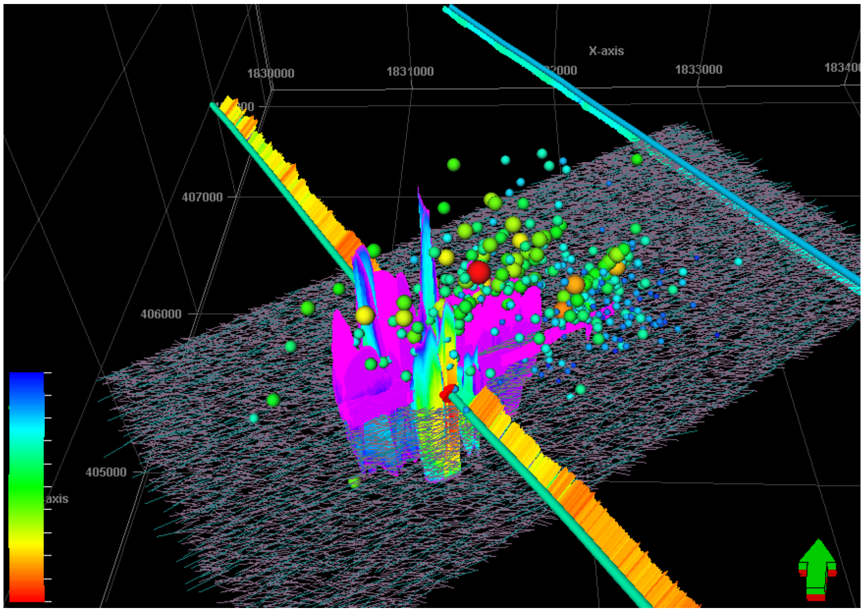


Figure 4.a.1: Upward and downward fracture growth is unconstrained and reveals extensive downward growth with more limited upward growth.

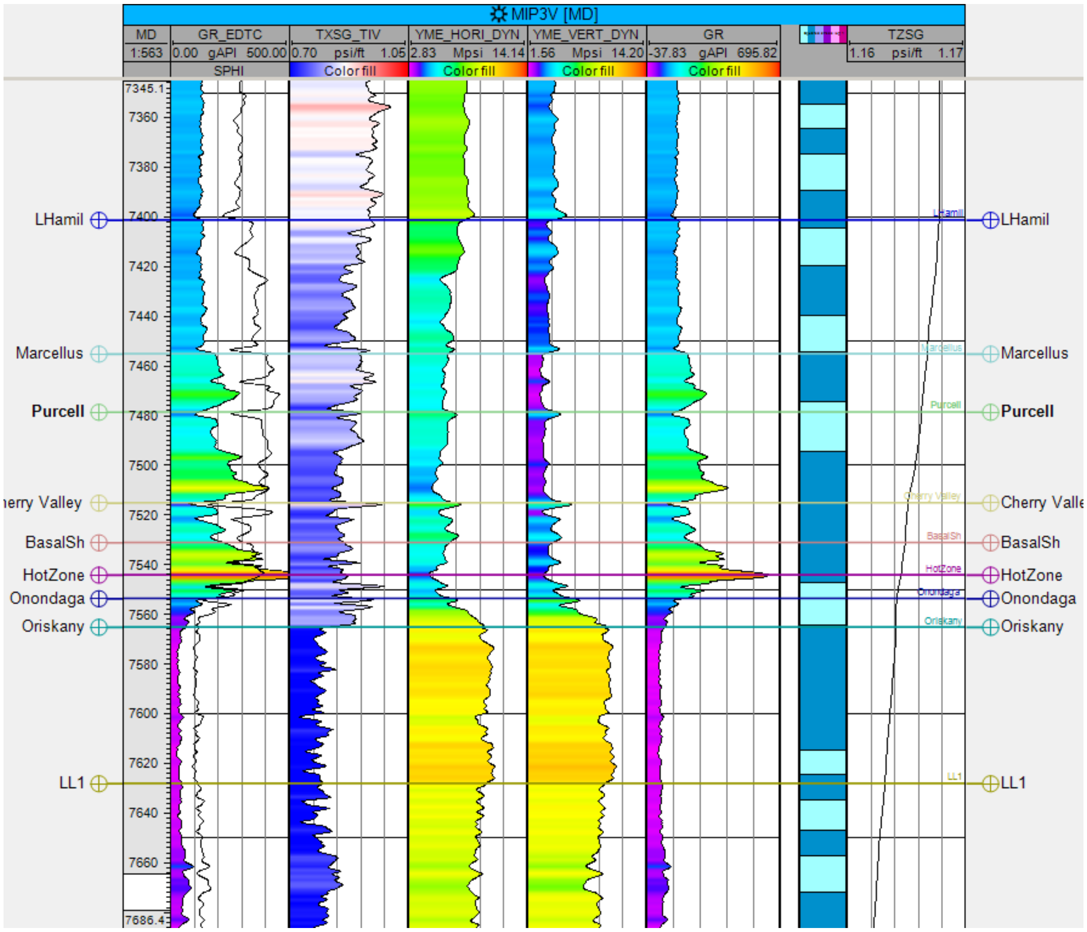


Figure 4.a.2: Log display for the vertical pilot well. TXSG_TIV in track 2 reveals a significant drop in stress gradient across the base of the Onondaga Ls. into the Oriskany Ss.

The lack of microseismic activity below the Marcellus Shale suggests S_{hmin} in the Oriskany and underlying intervals is much greater than that inferred from the stress log. The minimum horizontal stresses in the model zones associated with the Onondaga and deeper intervals were varied to test their influence on subsequent stimulation tests.

The effort was also preceded by adjustment of the completion parameters in the model to match the details of the actual completion report. While additional work needs to be done on this, some of the preliminary calibration is illustrated in Figure 4.a.3. This is still in preliminary form and additional refinements are required.

Downward growth was limited with an increase in the model minimum horizontal stress of 1000 psi for the Onondaga Ls and deeper intervals. Some downward and upward growth remains (Figure 4) but it is consistent with the microseismic behavior.

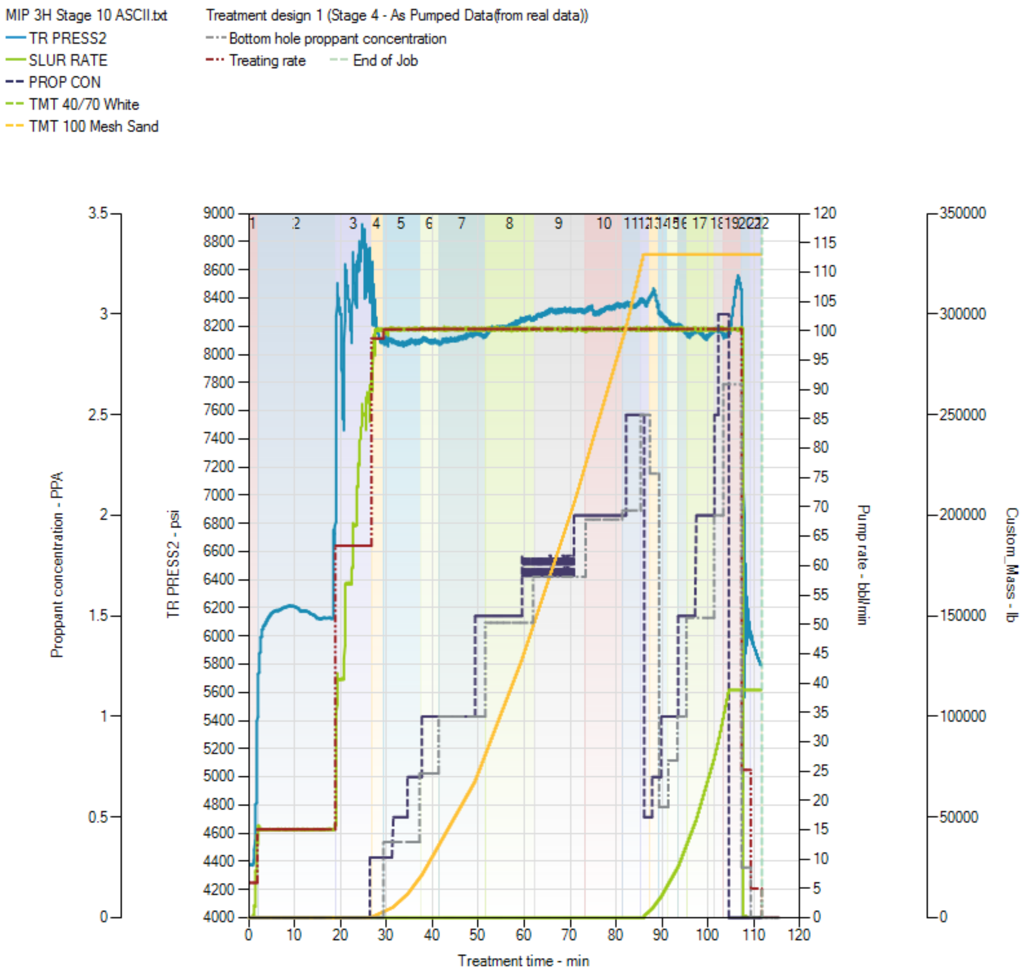


Figure 4.a.3: Steps in the pump schedule were assigned to match variations in the bottom-hole proppant concentrations inferred from the completion report.

Layers in the earth model (Figure 4.a.4A) are colored by S_{hmin}. The red colors in the zones beneath the Marcellus represent high stress intervals that are harder to fracture. Stresses in all other zones honored the values logged in the pilot well.

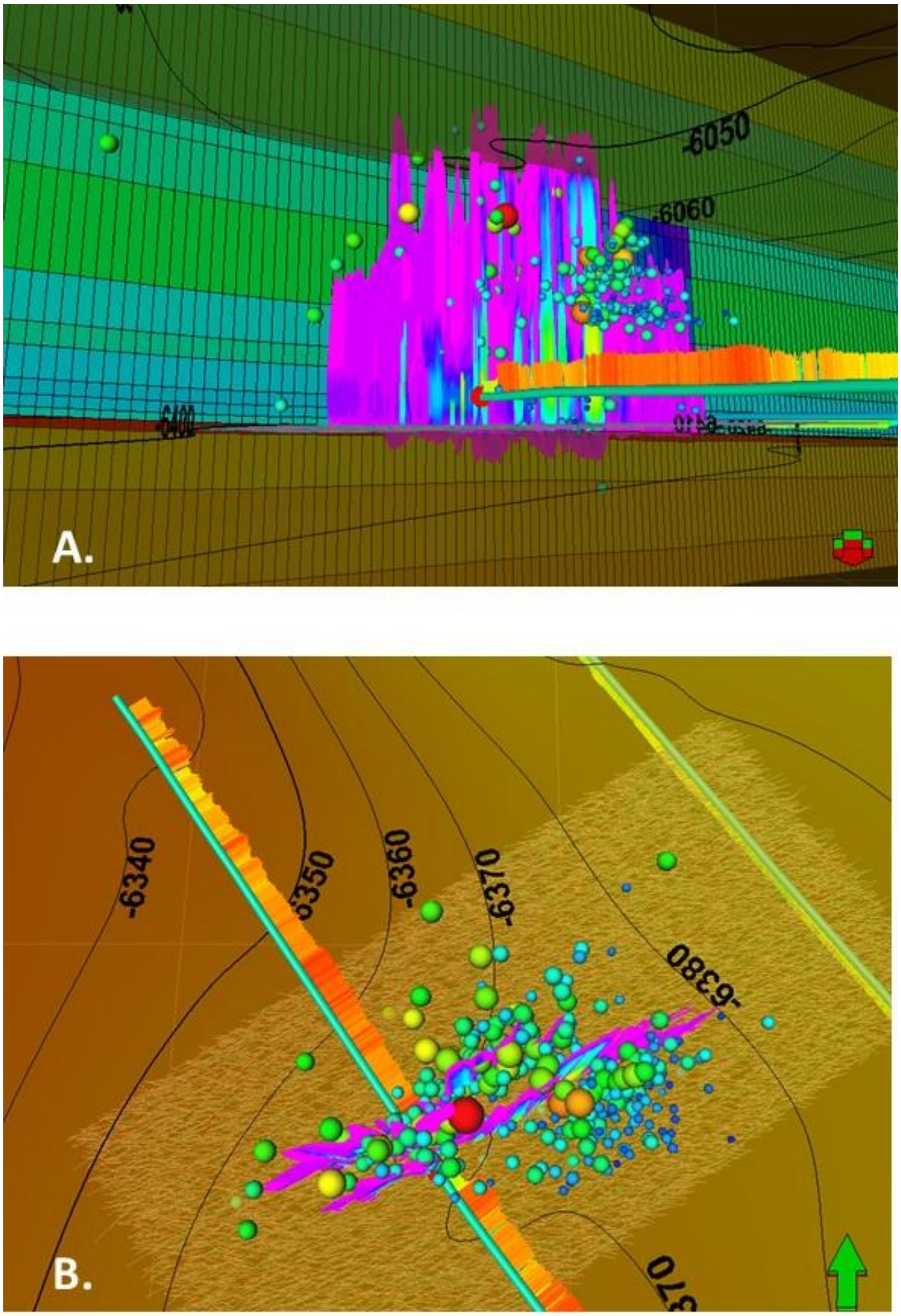


Figure 4.a.4: Stimulated natural fracture network obtained using actual completion design with modified earth model. A) Horizontal view between the Tully and Onondaga with zone set reference display and B) downward vertical view onto the Onondaga Ls. surface shows stimulation of natural fractures and distribution of microseismic events.

The results (figures 4.a.4 and 4.a.5) reveal the asymmetry to the northeast observed in the microseismic event distributions along with some bifurcation in the stimulated regions of the natural fracture network. Also note the presence of some deviation in local structural trend across this area (Figure 4.a.4B).

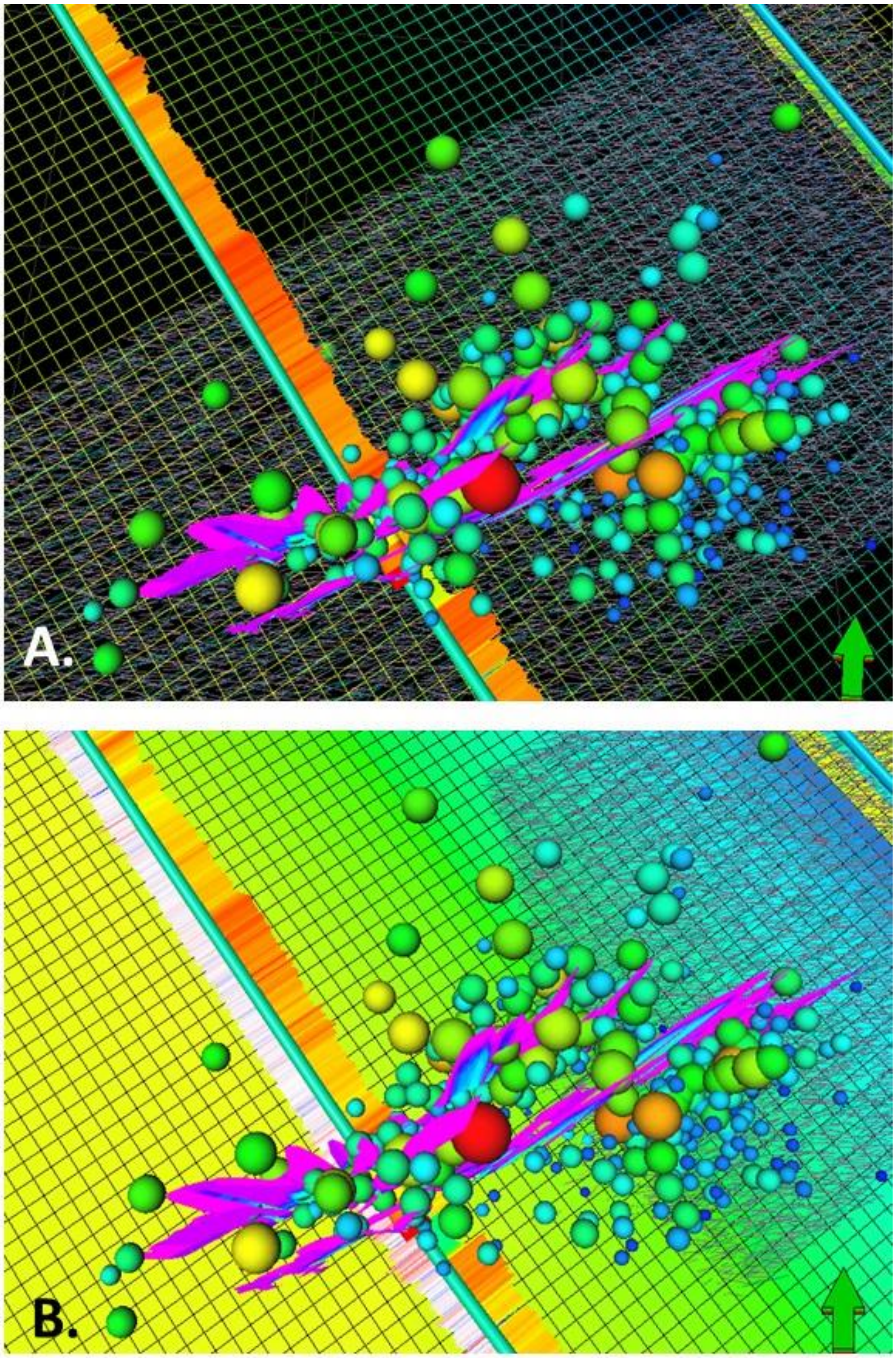


Figure 4.a.5: Fractures in the DFN stimulated in response to model completion. A) Downward wireframe view; B) downward view with colored grid cells revealing the horizontal stress gradient. These perspectives provide additional views of microseismic event distribution and stimulated fractures in the model local natural fracture network.

Spatial distribution of microseismic events

Asymmetry in the distribution of radiated energy is commonly observed along the 3H lateral. With radiated energy concentrated northeast of the lateral (Figure 4.a.6).

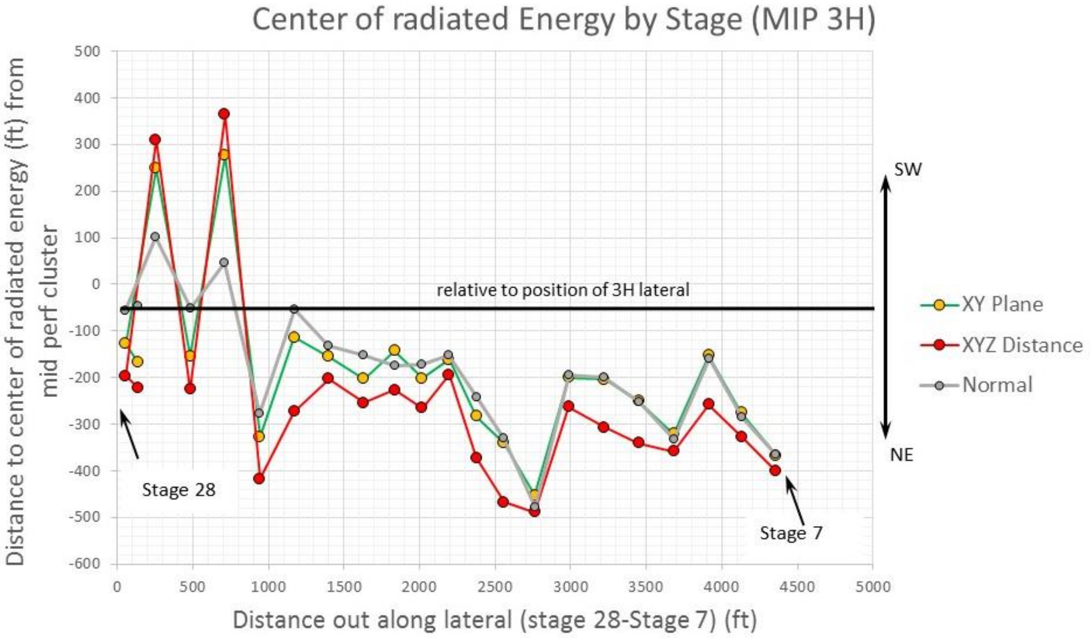


Figure 4.a.6: Centers of radiated energy observed along the MIP 3H lateral are generally displaced NE of the lateral. The distances are measured relative to the center perforation cluster in each stage. Actual distance to the center from the center perforation, *r* (*XYZ*), are shown along with the projection of the vector onto the XY plane (r_{xy}) and the measured distance in the XY plane *normal* to the lateral.

We see that the center of radiated energy generally lies between 200ft to 500ft northeast of the lateral and converges onto the lateral toward the last 5 to 6 stages near the toe to the southeast. The *xy* location of the lateral is used as a zero reference line in this display. The displacement of the radiated energy to the northeast suggests the strata in this direction are weaker and more easily stimulated. Similarly along the MIP 5H lateral, all energy is concentrated to the northeast of the lateral (Figure 4.a.7). The referential stimulation to the northeast is persistent in the area of these two laterals.

The centers of radiated energy are also located about 190ft above the 3H lateral and about 300ft above the 5H lateral (Figure 4.a.8). The frac-barriers, the Tully and Onondaga limestones are separated by about 360 feet in the area, so that along the 3H lateral microseismic energy release is localized roughly midway between the Tully and Onondaga. Along the 5H, radiated energy is focused on average near the base of the Tully. The 3D perspective view (Figure 4.a.9) illustrates these differences.

There is no clear correlation between the centers of radiated energy and local structure (Figure 4.a.10). However, there is clearly some discontinuity in structure between the 3H and 5H laterals and the increased structural relief on the fold to the northeast may progressively weaken strata across the area to the northeast, produce asymmetry in the energy distribution about perforation clusters and lead to less confined stimulation.

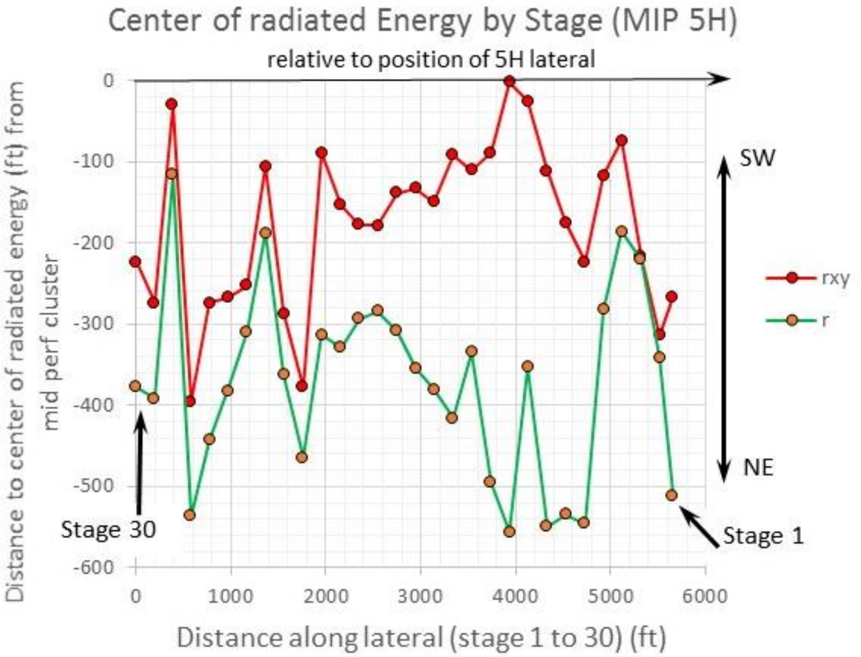


Figure 4.a.7: Centers of radiated energy observed along the MIP 5H lateral are generally displaced NE of the lateral. The distances are measured relative to the center perforation cluster in each stage. Actual distances (XYZ) are shown along with the projection of the vector onto the XY plane

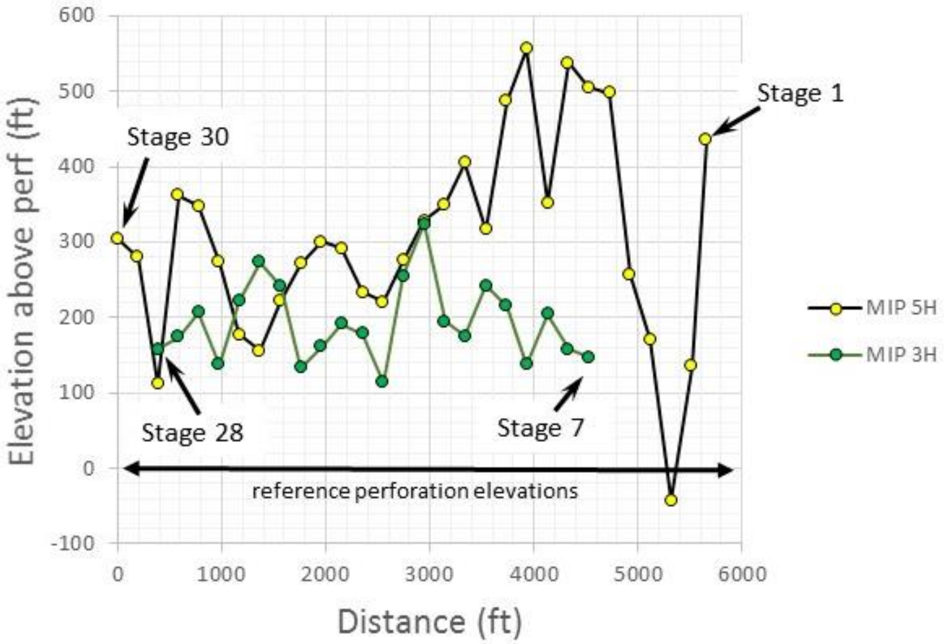


Figure 4.a.8: The vertical distance of radiated energy centers above the perforation clusters observed along the MIP 3H and 5H laterals.

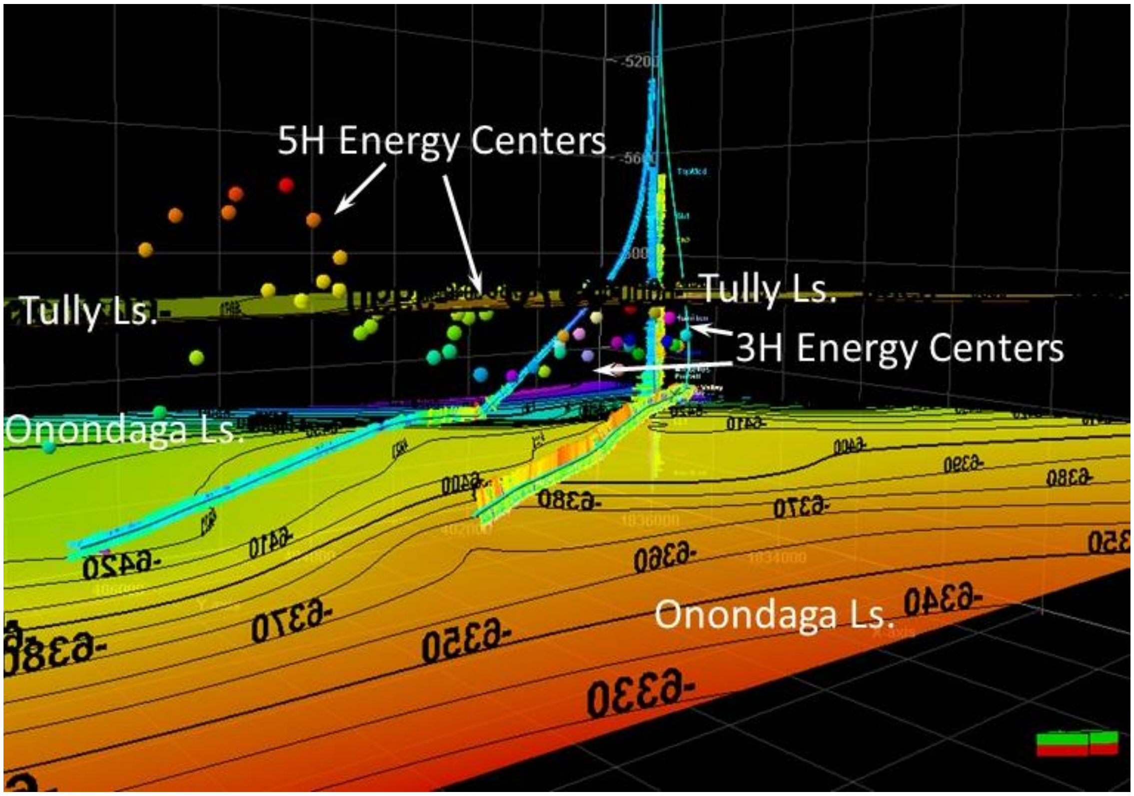


Figure 4.a.9: centers of radiated energy release observed along the 3H and 5H laterals.

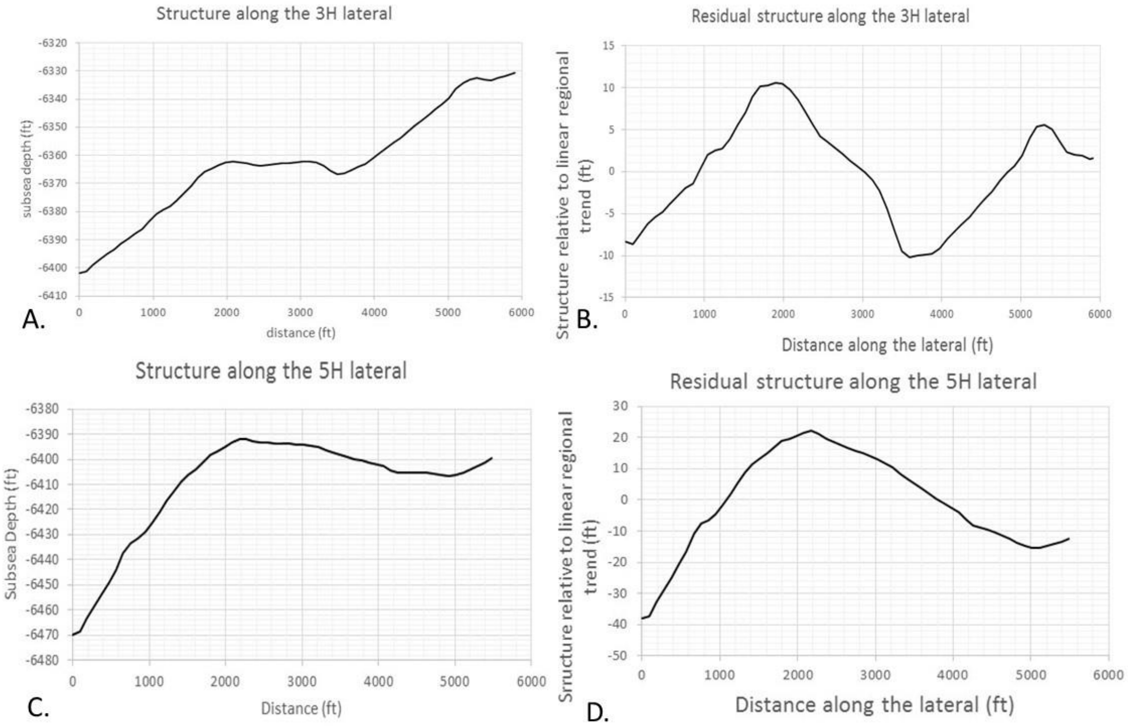


Figure 4.a.10: Local and residual structure along the 3H (A and B) and 5H (C and D) laterals.

Microseismic characterization

Microseismic behavior was assessed stage-by-stage by calculating and comparing different microseismic response parameters. These included 1) event density based estimates of the stimulated rock volume (SRV), 2) seismic moment weighted estimates of SRV, 3) number of events per stage, 4) the correlation dimension; 5) moment weighted correlation dimension, and 6) power law characteristics of the natural fracture spacing per stage.

Moment & Density weighted estimates of SRV

Seismic moment is linearly related to fracture rupture area as $M_o = \mu\bar{\delta}S$ where μ is the shear rigidity, $\bar{\delta}$ the average displacement and *S*, the rupture area. The comparison suggests only minor differences between moment-weighted and simple density-weighted estimates of SRV (Figure 4.a.11).

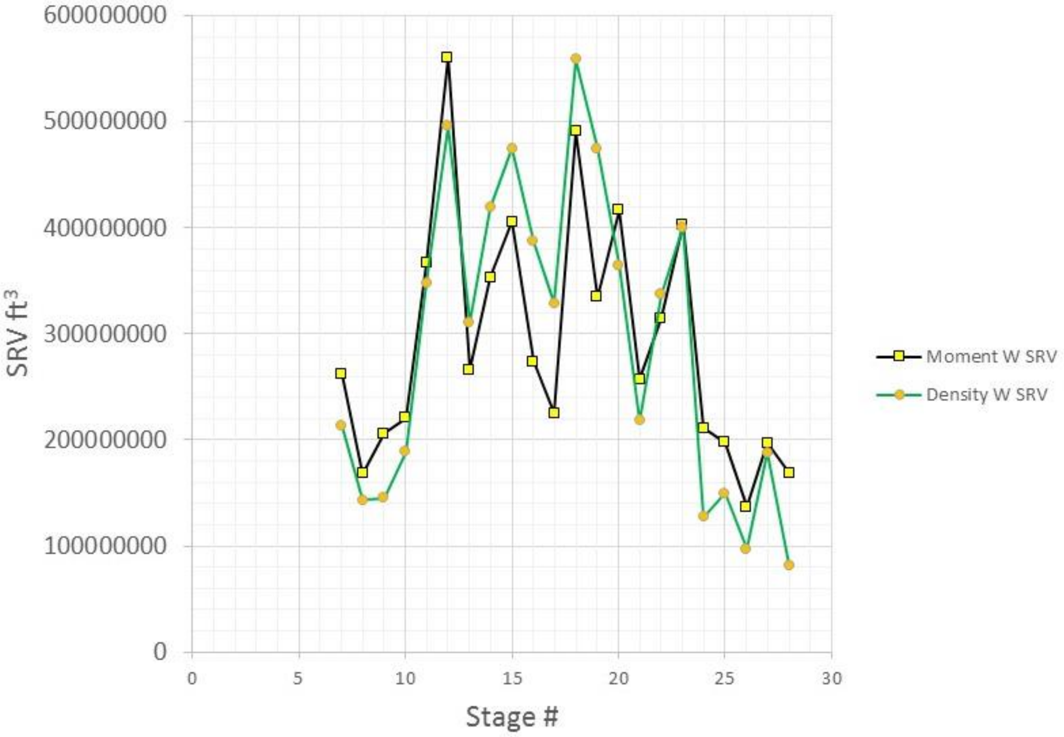


Figure 4.a.11: Density-weighted (green) and moment-weighted (black) estimates of SRV by stage.

However, iso-level parameters used to estimate the SRV using these two approaches can increase or decrease the SRV. The energy-weighting approach used by Wilson et al. (2016) is recommended so that the computations are standardized. In their approach, each event is replaced by a number of events corresponding to a multiple of the lowest energy event observed in a stage. In this approach, the same algorithm and parameters are used to estimate the SRV.

Correlation Dimension

The correlation dimension d_G (Grassberger and Procacaccia, 1983) provides a means to compare the spatial distribution of points in a cluster (or clusters). d_G is easily computed from the correlation function: $C(\mathrm{R}) = \lim_{N\to\infty}\left[\frac{1}{N^2}\sum_{i,j=1}^{N} H\left(\mathrm{R}-\left|r_i - r_j\right|\right)\right]$ (e.g. Baker and Gollub, 1990). This formula basically provides a scaled count of the number of points (or microseismic events, in this case) that fall inside a sphere of radius R centered about all the events in the set. *R* is varied from the minimum to maximum event separations in the set. *H* is the Heaviside function. *H* takes on values of 1 or 0. If an event falls within the sphere it is counted (assigned a 1), if not, it is not counted (assigned a value of 0). The slope of the straight line portion of the graph of *logC* vs. *logR* represents the correlation dimension d_G. When not normalized by $1/N^2$ this becomes a $logN_r$ vs. *logR* plot.

The correlation dimension is a particularly useful method of evaluating distributions of earthquake hypocenters (e.g. Oncel and Wilson, 2002, 2004 and 2006). The following illustrations (Figure 4.a.12) highlight use of the correlation dimension to help characterize stress anisotropy inferred from various microseismic event cloud shapes. The differences are exaggerated but represent from top to bottom cases where the stress difference (S_{Hmax}-S_{hmin}) is nearly 0 (Cluster1); (S_{Hmax}-S_{hmin}) is significantly greater than 0 (Cluster 2) and a case where (S_{Hmax}-S_{hmin}) is very large (Cluster3).

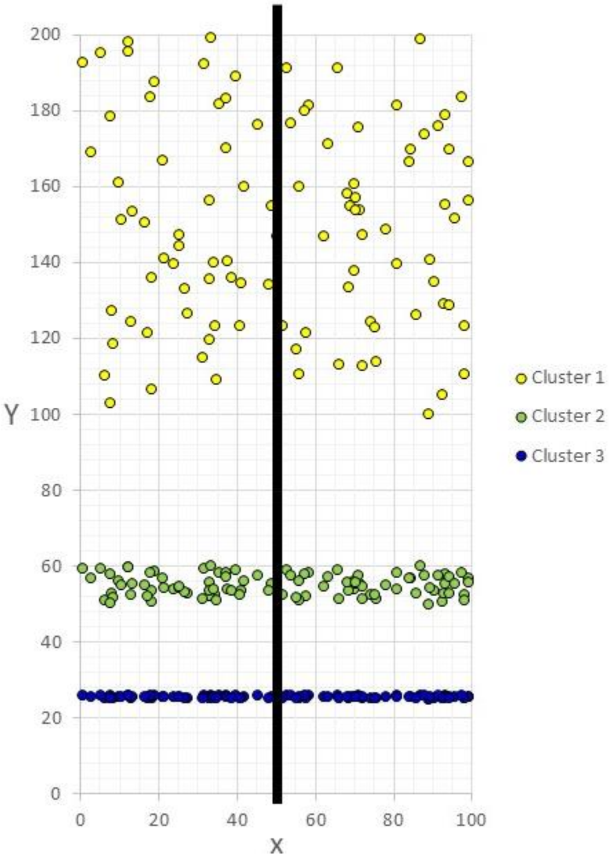


Figure 4.a.12: Model clusters representing varying degrees of stress anisotropy.

In the results (Figure 4.a.13) note that Cluster 1, which is the most dispersed (Figure 4.a.12), tends to be space filling and has dimension close to 2 (that of a plane). The distribution of events in Cluster 3 nearly fall along a straight line, and have dimension close to 1 (that of a line).

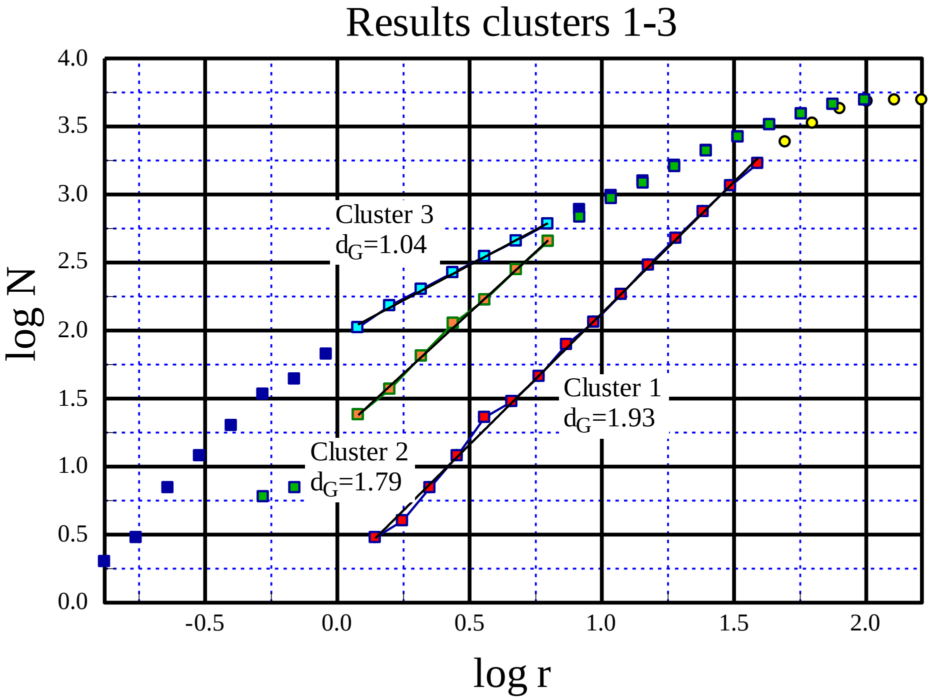


Figure 4.a.13: LogN-logr plot for the models depicted in Figure 4.a.12.

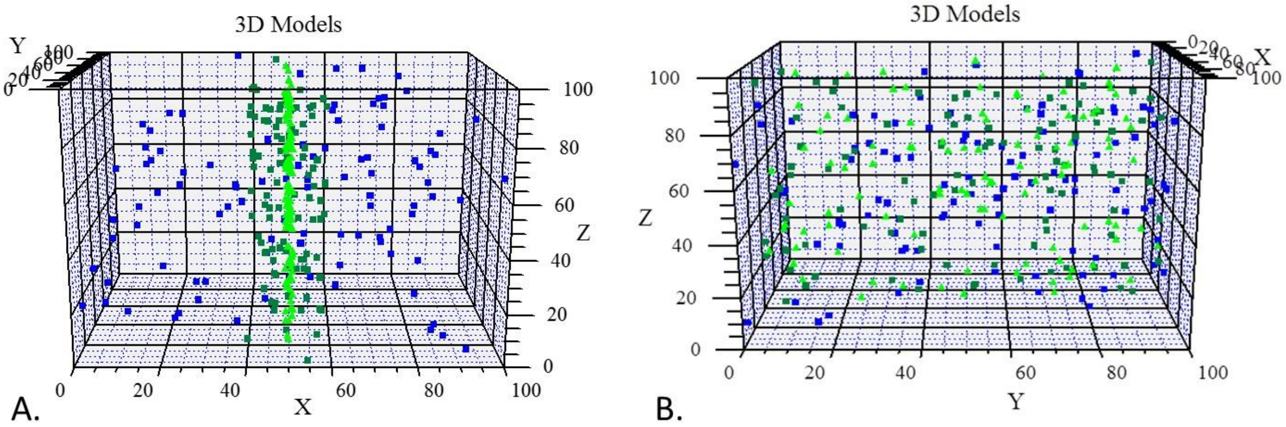


Figure 4.a.14: 3D models. A) A look along the y-axis reveals a widely dispersed field of events (blue, cluster 4), a loosely clustered field (dark green, cluster 5) and highly clustered field (light green, cluster 6); B) viewing down the X axis, all events are loosely clustered in the *yz* projection.

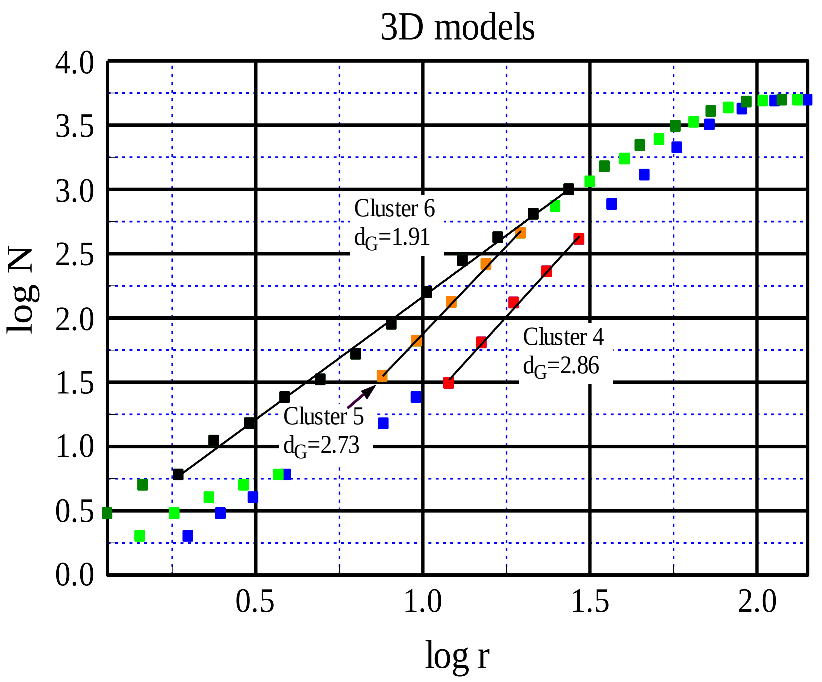


Figure 4.a.15: logN vs. logr plots for the 3D models.

For microseismic data, models are extended into 3D (Figure 4.a.14). The events are equally dispersed in the *yz* plane, but become increasingly clustered in the *xz* plane. The models extend from almost space filling to planar in extent. The correlation dimensions (Figure 4.a.15) vary from ~1.9 (planar) to 2.86 (highly dispersed and nearly volume distributed).

Two additional models illustrate the influence of more complex differences (Figure 4.a.16).

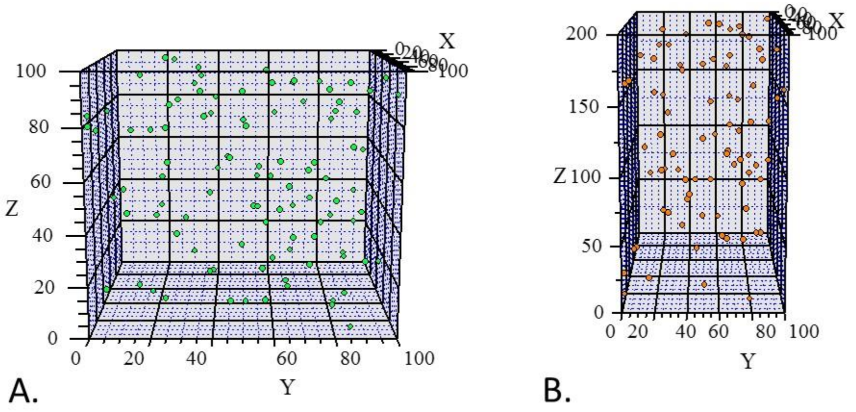


Figure 4.a.16: In both these models events are distributed randomly. A) Events are distributed randomly in a cube; B) events are distributed in a rectangular prism twice as high as wide. The number of events contained in volume B) is only 80% that contained in volume A).

The results are intuitive in the simplified models shown in Figure 4.a.s 12 and 14. The models shown in Figure 4.a.16 yield results that are not easily interpreted. The elongated region filled with a smaller number of events has the higher d_G (Figure 4.a.17). Thus the variations in d_G (Figure 4.a.18) observed along the 3H lateral reveal differences in the spatial distribution of microseismic events that may not be easy to interpret.

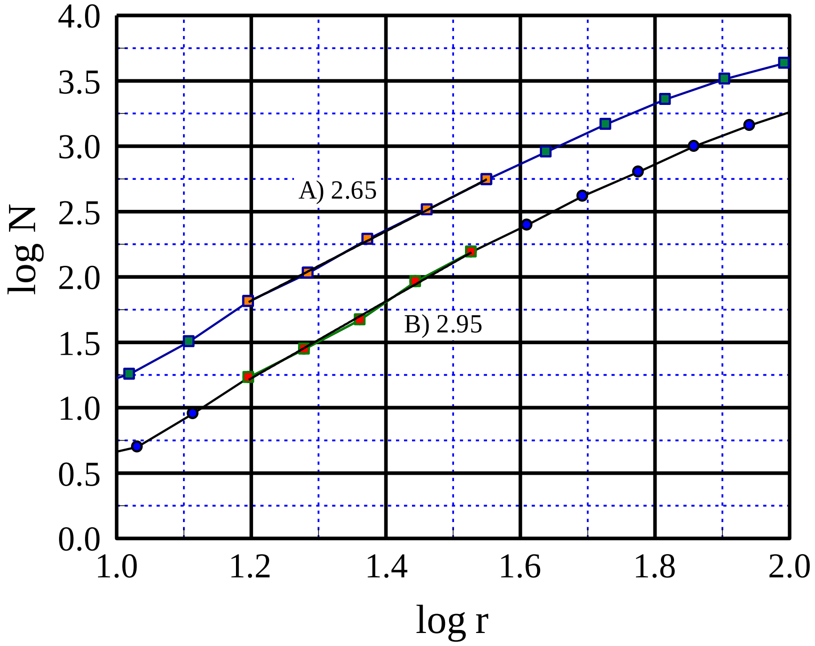


Figure 4.a.17: Results for models A and B of Figure 4.a.12.

Using the correlation dimension as a measure of clustering, we see some interesting variations along the length of the MIP 3H well (Figure 4.a.19).

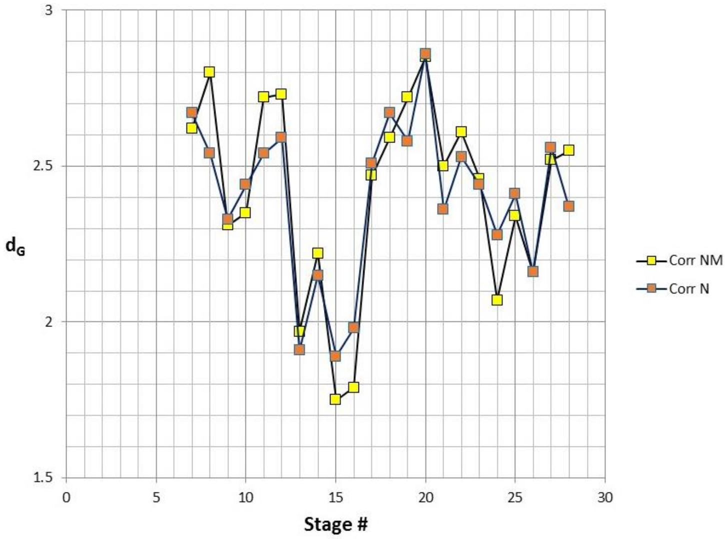


Figure 4.a.18: Stage-to-stage variations in d_G along the MIP3H lateral.

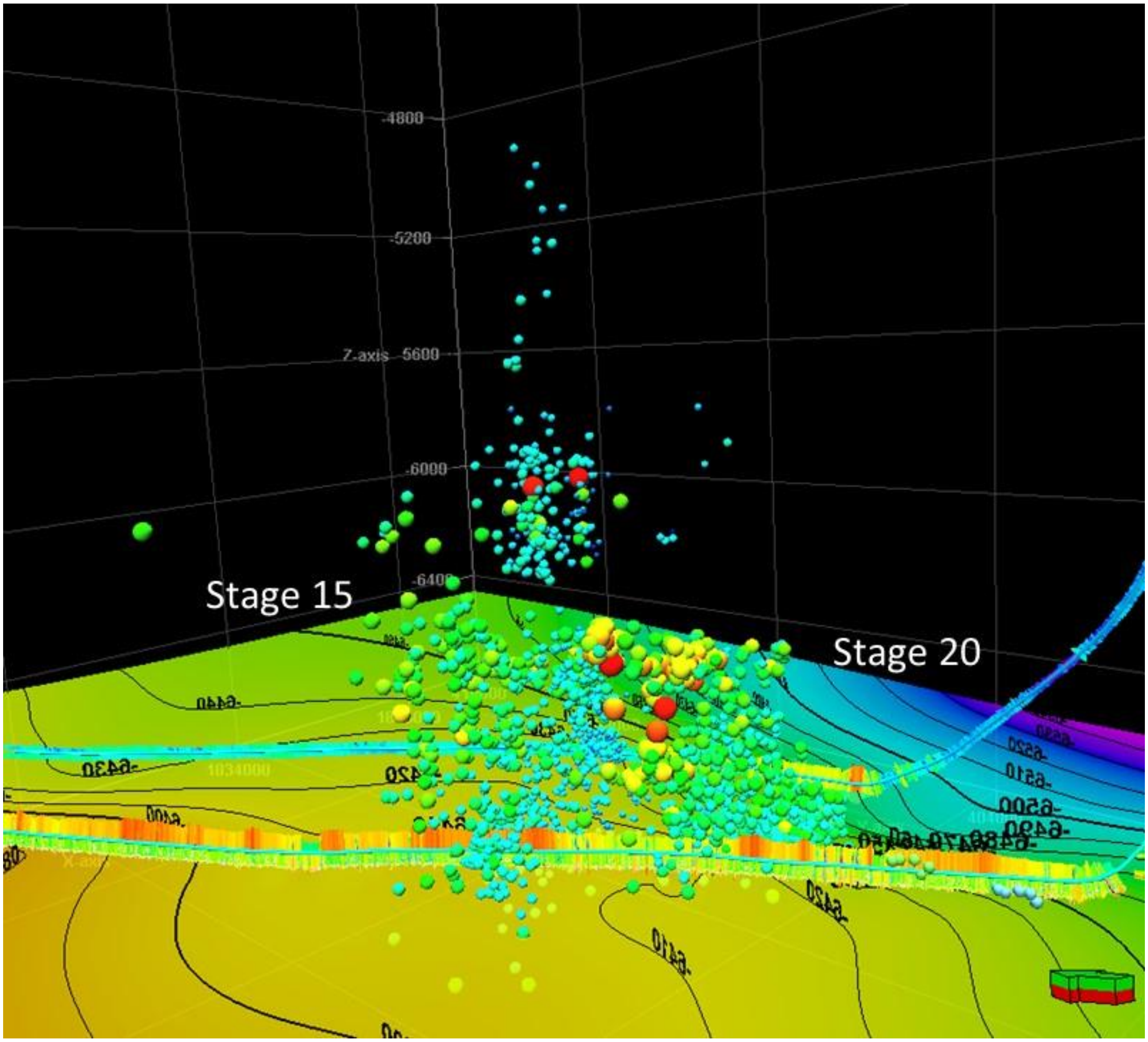


Figure 4.a.19: Microseismic events from stages 15 and 20 illustrate complexity not yet included in models.

Stages 15 and 20 illustrate the maximum range of variation encountered in the d_G (Figure 4.a.19) and highlight the difficulty of making clear distinctions between clustering based on d_G alone. In cluster 20, a larger number of events is localized in a smaller volume. However, the clustering is complex. The events from stage 20 are distributed in 2 to 3 clusters, while the events from stage 15 are distributed into 4 to 5 much more diffuse clusters. Models illustrating this level of complexity have not been developed, but in general, d_G for these two stages reveals that the larger number of events and smaller number of sub-clusters packed into the smaller volume yields increased d_G.

Discussion

Efforts this quarter have resolved some modeling issues and highlight the need for calibrating the earth model either through trial and error or assisted by lab core testing. The lower S_{hmin} in the Oriskany Ss. inferred from the logs is inconsistent with experience in the region that the Onondaga Ls. and Oriskany Ss. strata serve as significant barriers to downward hydraulic fracture growth. An increase in S_{hmin} by 1000 psi is required to prevent downward growth in the models.

The distribution of the center of radiated microseismic energy reveals that stress gradients are non-uniform through the area and that asymmetry in the distributions of microseismic events can vary significantly from one stage to the next and well-to-well. Some visual relationship of energy offset and local structure may be present that leads to the tendency for microseismic events to preferentially fracture areas to the northeast of the laterals.

Numerous microseismic parameters were calculated and compared. Some issues with moment and density weighted SRVs were identified. Depending on the parameters used to compute SRVs, a variety of answers are possible. The suggested solution for this is one employed by Wilson et al (2016) and Wilson and Sullivan (2016) wherein the number of events observed in a stage is scaled by radiated energy to represent an equivalent number of identical energy events.

The correlation dimension (d_G) is often used to characterize earthquake seismicity (see Oncel and Wilson, 2002, 2004 and 2006). Models developed this quarter illustrate the relationship between the correlation dimension and spatial distributions of points. Actual distributions of microseismic events tend to be more complex and involve sub-clusters. The models do not replicate the variety of features observed in actual microseism event distributions. However, in general, variations in d_G generally indicate distributions of events that vary from linear to space filling.

Task 4b - Geomechanical:

During this quarterly period, numerical modeling simulations were conducted to simulate stage 1 of well MIP 3H by using measured injection data. The geologic column used in the analysis is shown in Figure 4.b.1. The wellbore profile used in the modeling study is shown in Figure 4.b.2. Stimulation input parameters were selected from available measured data. Figure 4.b.3 and Figure 4.b.4 show a comparison of the slurry volumes and the slurry rates used in the model and the available measured data. Figure 4.b.5 shows the proppant concentrations used in the model and those which were measured. An idealized step-wise schedule for the proppant injection was used in the model, as shown in this figure. Figure 4.b.6 shows the idealized proppant injection rate, while Figure 4.b.7 shows the proppant mass used in the model in comparison with the measured injection data. Figure 4.b.8 shows a comparison of computed and measured surface pressures. These computed values compare well with the measured surface pressure data. Figure 4.b.9 shows the computed fracture geometry from the model. For stage 1, the fracture length was found to be 624.4 feet, the height was found to be 100.3 feet, and the maximum computed fracture width at the wellbore was approximately 1.27 inches at the end of the injection period.

The analysis of microseismic data at well MIP 3H was initiated. No microseismic data was available for stage 1 of MIP 3H.

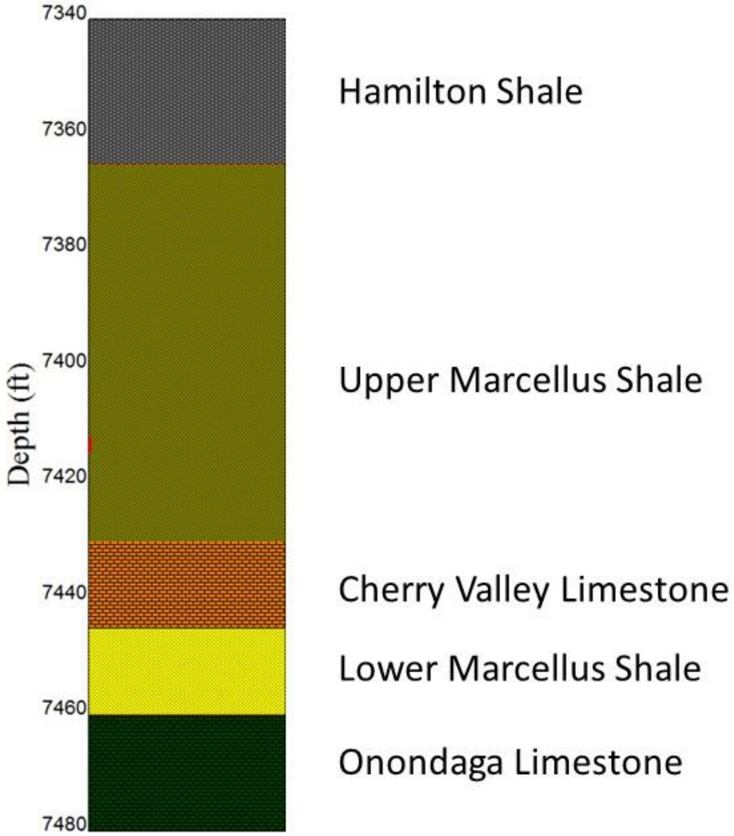


Figure 4.b.1: Geologic Column used in the Modeling Study

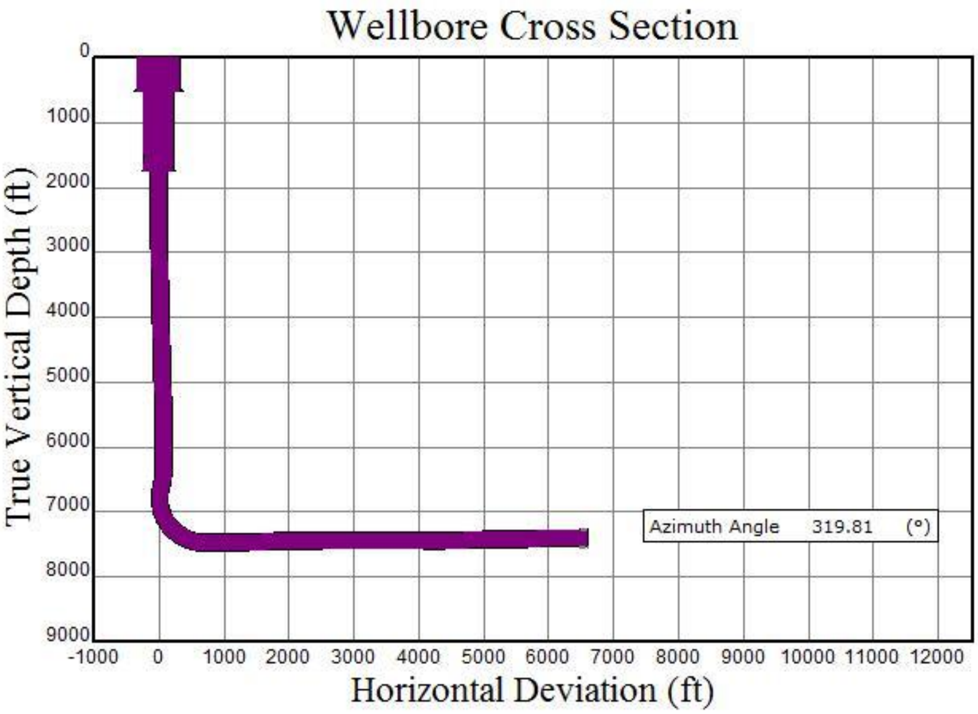


Figure 4.b.2: Model Wellbore Configuration for MIP 3H

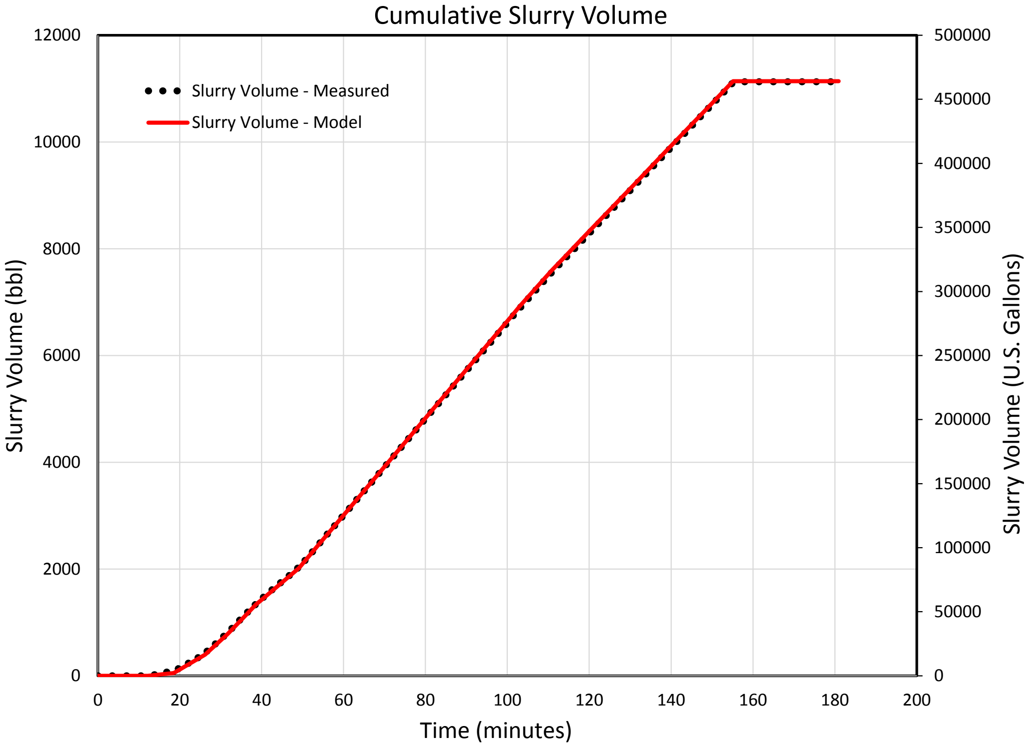


Figure 4.b.3: Slurry Volume vs Time - Stage 1 - MIP 3H

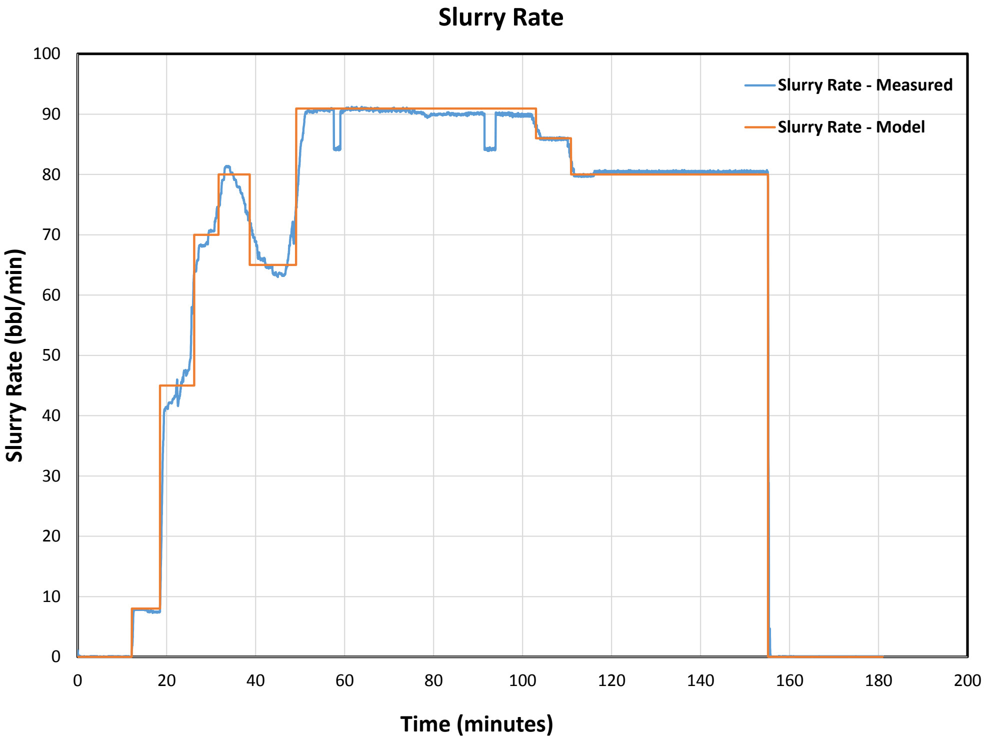


Figure 4.b.4: Slurry Rate vs Time for Stage 1 - MIP 3H

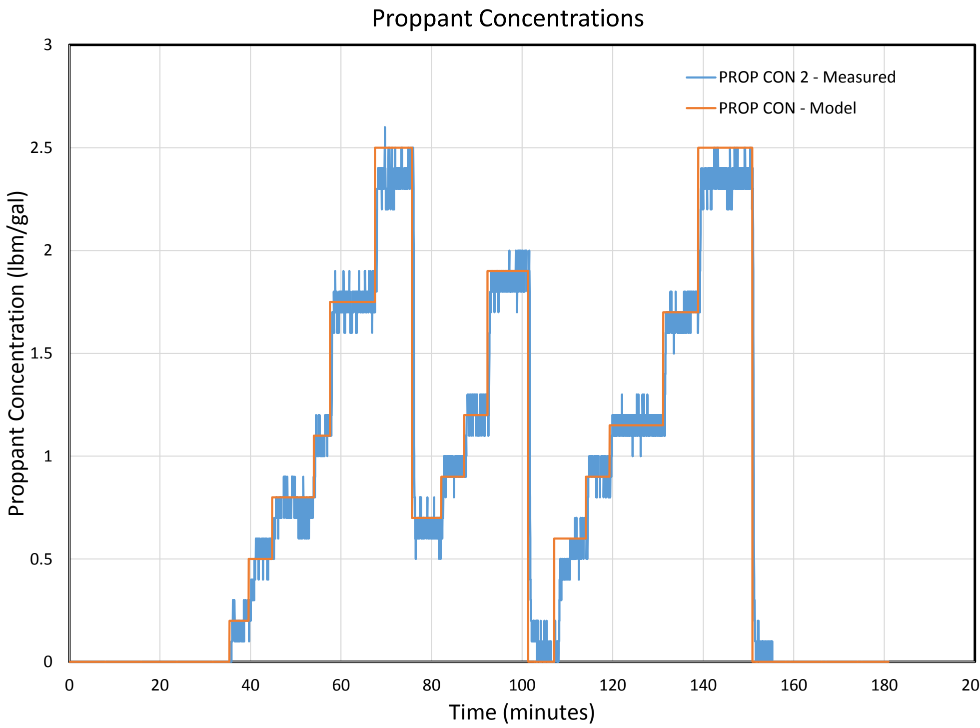


Figure 4.b.5: Proppant Concentration vs Time for Stage 1 - MIP 3H

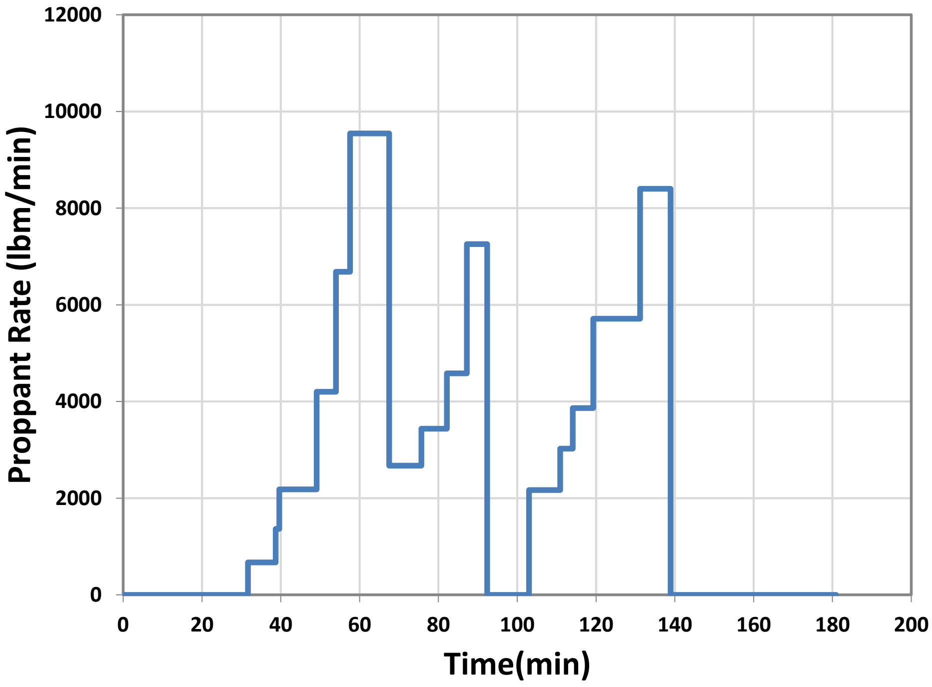


Figure 4.b.6: Idealized Proppant Rate vs Time for Stage 1 - MIP 3H

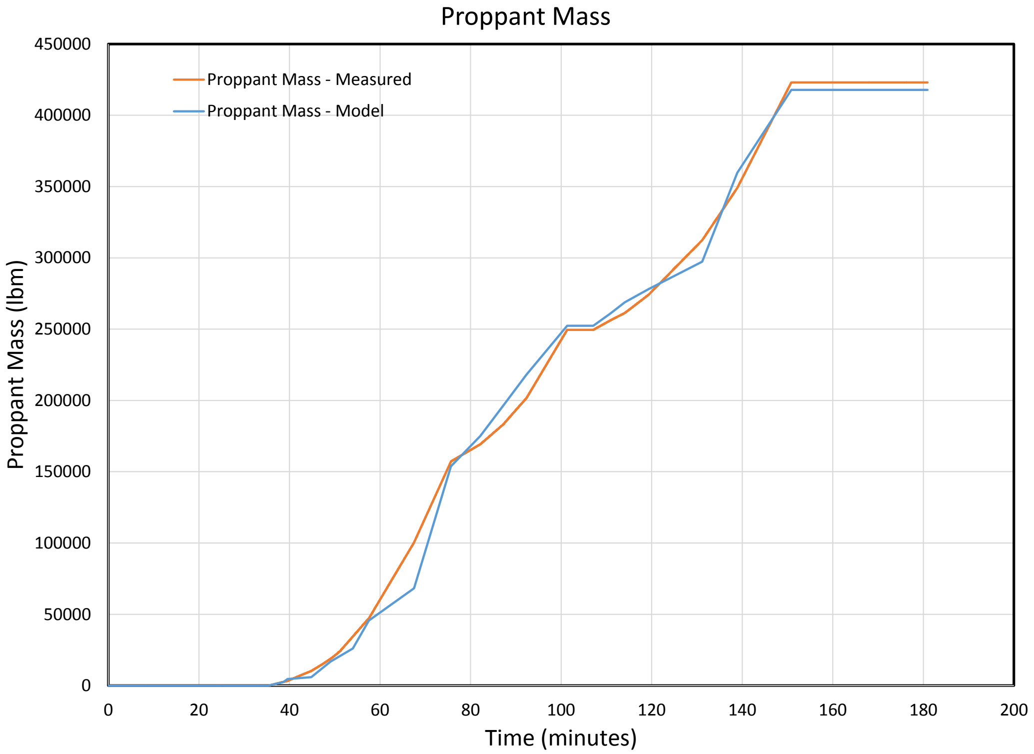


Figure 4.b.7: Proppant Mass vs Time for Stage 1 – MIP 3H

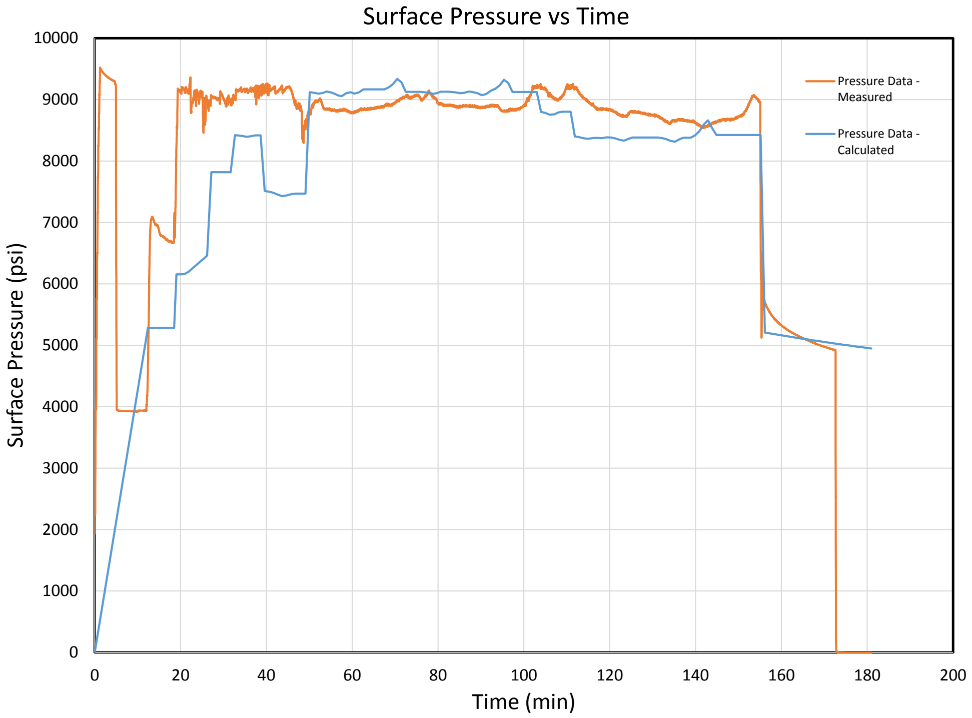


Figure 4.b.8: Surface Pressure vs Time for Stage 1 - MIP 3H

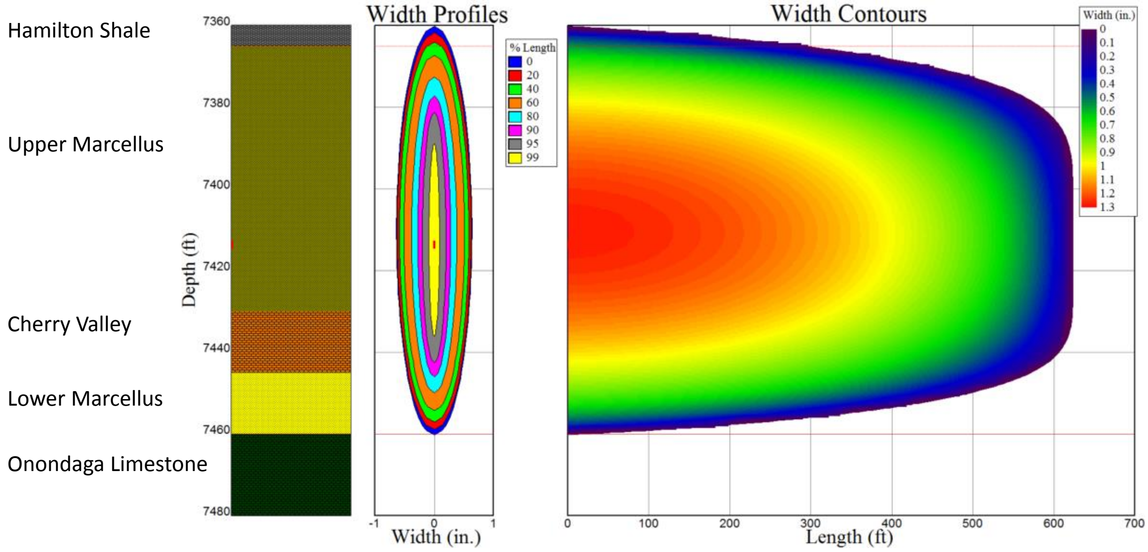


Figure 4.b.9: Fracture Geometry for Stage 1 - MIP 3H

Products

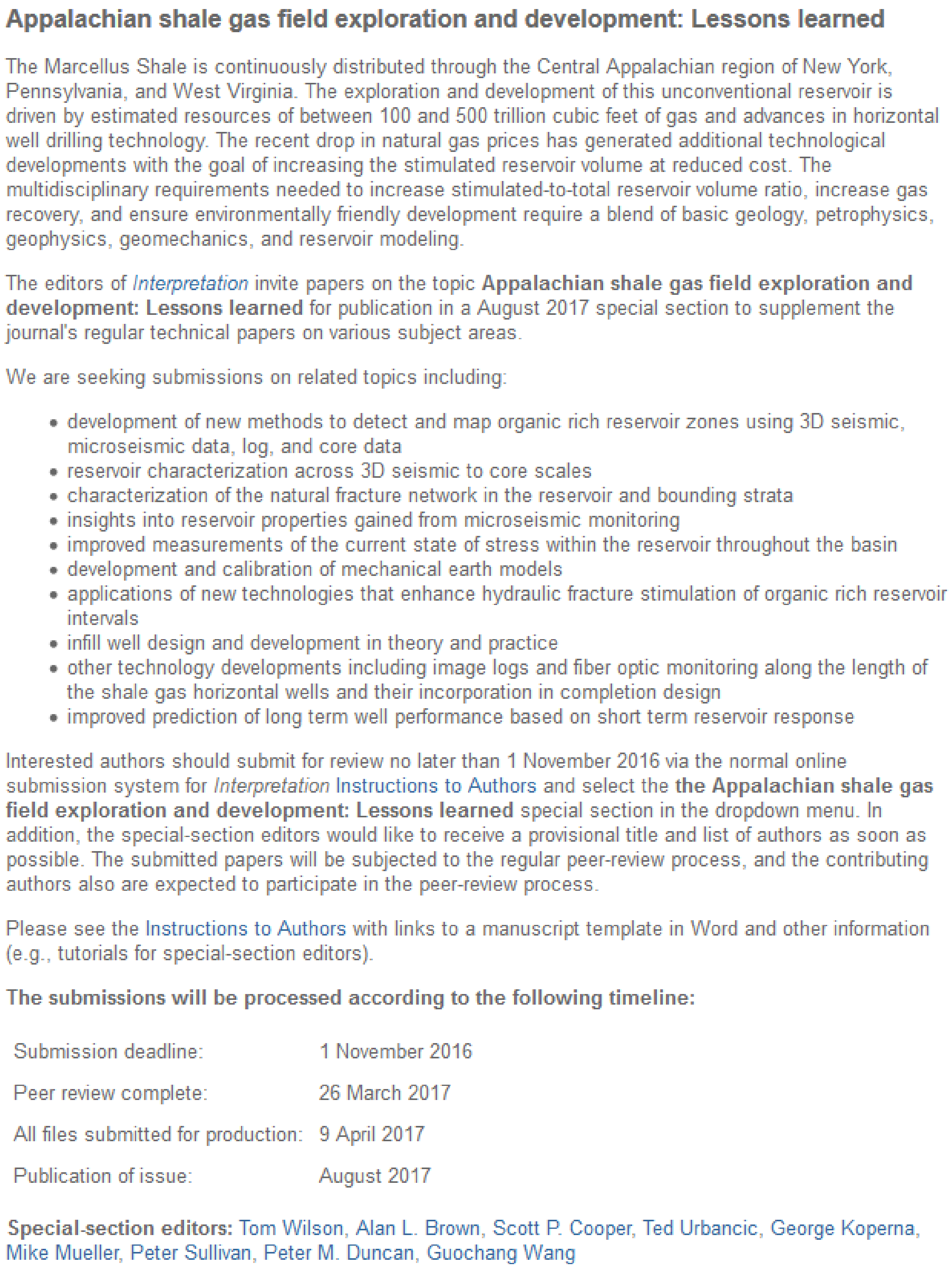
Plan for Next Quarter

Task 4a-Geophysics

Efforts will focus on developing presentations for the 2016 SEG meeting in Dallas. The paper noted below will be presented.

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,** 5p.

Also note that Wilson will serve as editor of a special section in the Journal Interpretation, The ad follows. Considerable effort will be expended on this activity in the coming year.



Appalachian shale gas field exploration and development: Lessons learned

The Marcellus Shale is continuously distributed through the Central Appalachian region of New York, Pennsylvania, and West Virginia. The exploration and development of this unconventional reservoir is driven by estimated resources of between 100 and 500 trillion cubic feet of gas and advances in horizontal well drilling technology. The recent drop in natural gas prices has generated additional technological developments with the goal of increasing the stimulated reservoir volume at reduced cost. The multidisciplinary requirements needed to increase stimulated-to-total reservoir volume ratio, increase gas recovery, and ensure environmentally friendly development require a blend of basic geology, petrophysics, geophysics, geomechanics, and reservoir modeling.

The editors of *Interpretation* invite papers on the topic **Appalachian shale gas field exploration and development: Lessons learned** for publication in a August 2017 special section to supplement the journal's regular technical papers on various subject areas.

We are seeking submissions on related topics including:

- development of new methods to detect and map organic rich reservoir zones using 3D seismic, microseismic data, log, and core data
- reservoir characterization across 3D seismic to core scales
- characterization of the natural fracture network in the reservoir and bounding strata
- insights into reservoir properties gained from microseismic monitoring
- improved measurements of the current state of stress within the reservoir throughout the basin
- development and calibration of mechanical earth models
- applications of new technologies that enhance hydraulic fracture stimulation of organic rich reservoir intervals
- infill well design and development in theory and practice
- other technology developments including image logs and fiber optic monitoring along the length of the shale gas horizontal wells and their incorporation in completion design
- improved prediction of long term well performance based on short term reservoir response

Interested authors should submit for review no later than 1 November 2016 via the normal online submission system for *Interpretation* Instructions to Authors and select the **the Appalachian shale gas field exploration and development: Lessons learned** special section in the dropdown menu. In addition, the special-section editors would like to receive a provisional title and list of authors as soon as possible. The submitted papers will be subjected to the regular peer-review process, and the contributing authors also are expected to participate in the peer-review process.

Please see the Instructions to Authors with links to a manuscript template in Word and other information (e.g., tutorials for special-section editors).

The submissions will be processed according to the following timeline:

Submission deadline:	1 November 2016
Peer review complete:	26 March 2017
All files submitted for production:	9 April 2017
Publication of issue:	August 2017

Special-section editors: Tom Wilson, Alan L. Brown, Scott P. Cooper, Ted Urbancic, George Koperna, Mike Mueller, Peter Sullivan, Peter M. Duncan, Guochang Wang

Task 4b - Geomechanical:

The modeling study will be continued to investigate other stimulation stages at well MIP 3H by using available information on the hydraulic fracturing field parameters (fluid volumes, pumping rate, proppant schedule, and geophysical data). The analysis of microseismic data will be continued and a comparison of fracture geometries will be made with available microseismic data.

Topic 5 – Surface Environmental

Task 5a – Surface Environmental – Water

Approach

The Monongahela River surface water network has been sampled twelve times since June 2015. Two sets of baseline samples were collected one month prior to gas well development activity at the MSEEL site. Surface water samples have been collected during and after each phase of gas well development at the three points selected along the Monongahela River. Figure 5.1 shows the locations of sampling points MR-1, MR-2, and MR-3 in red with the Northeast Energy site indicated in purple.

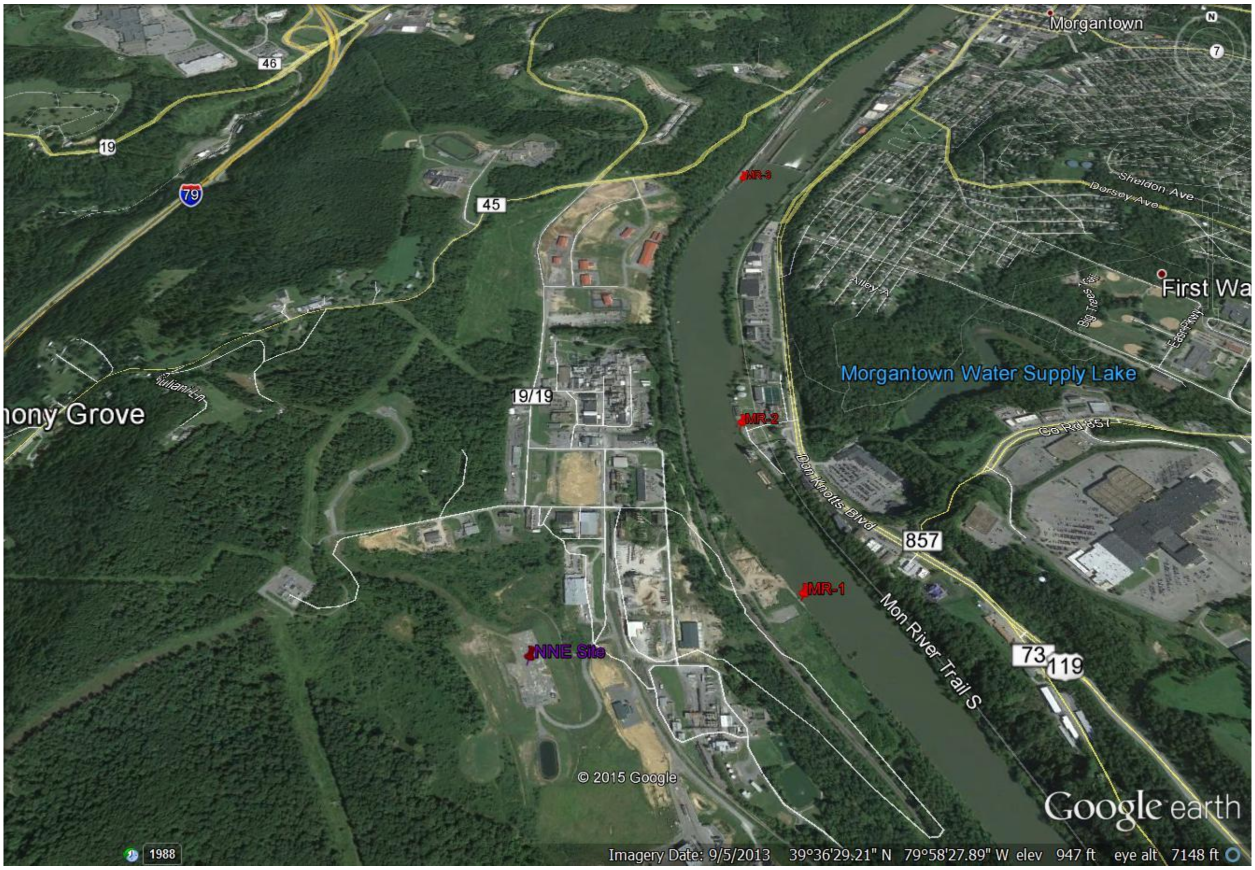
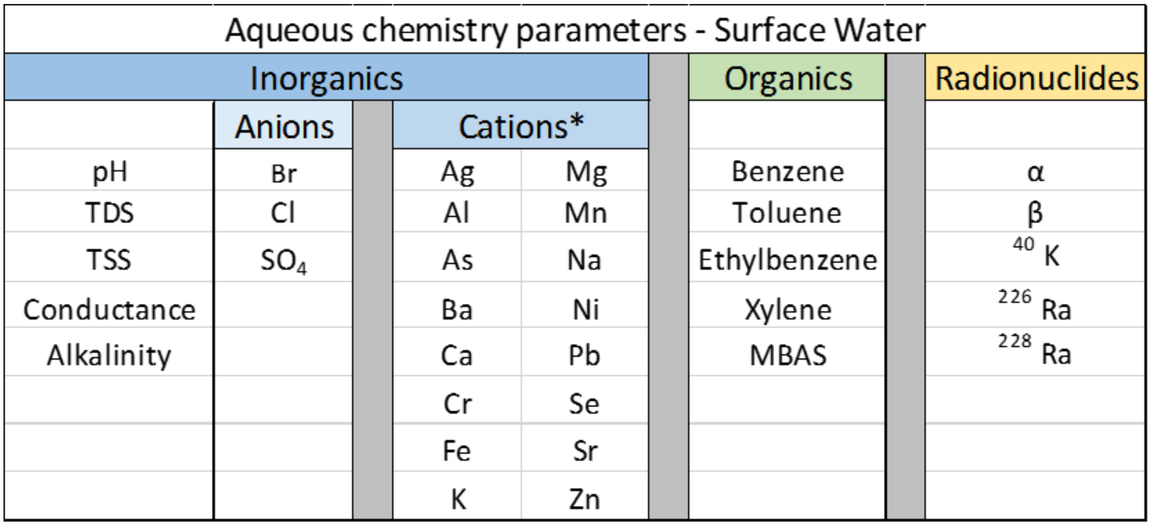


Figure 5.a.1: MSEEL surface water sampling locations

Results and Discussion

Parameters analyzed for each surface water sample are listed in Table 5.a.1. In addition to these parameters, field readings for temperature, electric conductivity, total dissolved solids, dissolved oxygen and pH are field-measured at each sampling point during each sampling event. Figures 5.a.2 and 5.a.3, revised from the previous quarter, graphically represent two common parameters of interest along the Monongalia River at each of the three surface water sampling points upstream and downstream of the MIP well pad site over the course of monitoring activities.

Table 5.a.1: Analytical parameters



Aqueous chemistry parameters - Surface Water					
Inorganics				Organics	Radionuclides
	Anions	Cations*			
pH	Br	Ag	Mg	Benzene	α
TDS	Cl	Al	Mn	Toluene	β
TSS	SO_4	As	Na	Ethylbenzene	^{40}K
Conductance		Ba	Ni	Xylene	^{226}Ra
Alkalinity		Ca	Pb	MBAS	^{228}Ra
		Cr	Se		
		Fe	Sr		
		K	Zn		

*total and dissolved

Figure 5.a.2 Bromide levels

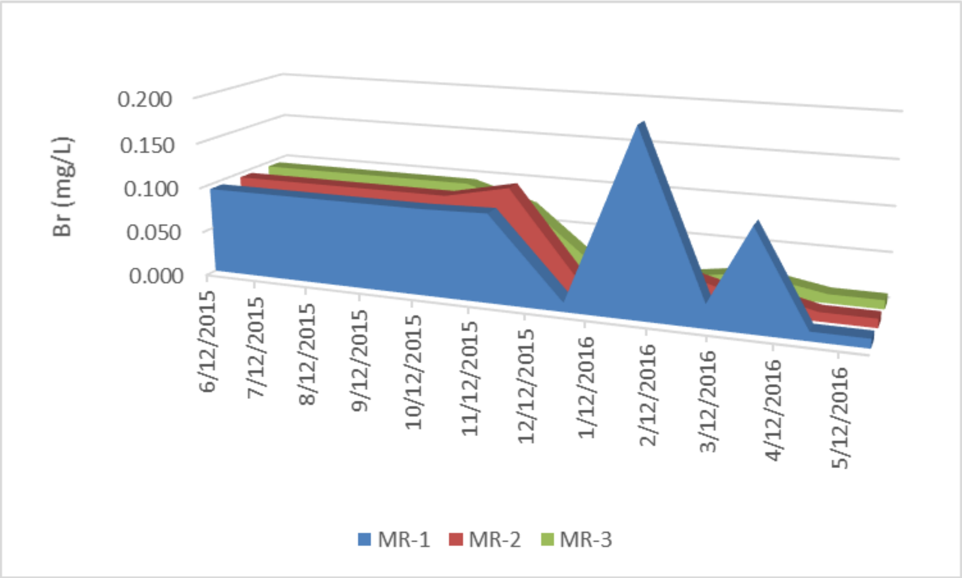
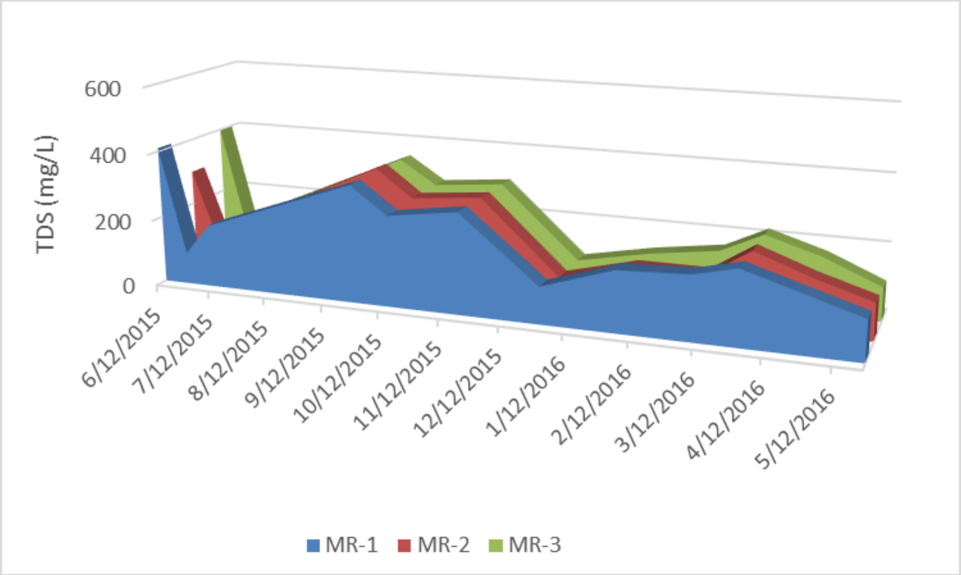
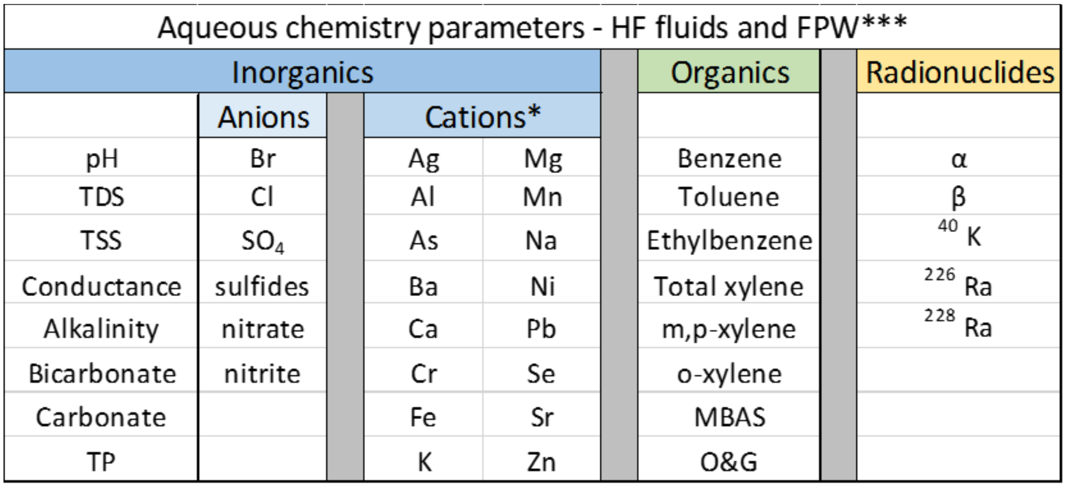


Figure 5.a.3 Total Dissolved Solids (TDS)



Parameters analyzed for FPW are listed in Table 5.a.2. Makeup water was pumped from the Monongahela River and mixed with the hydraulic fracturing fluids. Samples of HF were collected after the mixing had occurred. FPW samples were taken at the upstream end of each well's separator.

Table 5.a.2 Aqueous chemistry parameters – HF fluids and FPW



Aqueous chemistry parameters - HF fluids and FPW***						
Inorganics					Organics	Radionuclides
	Anions	Cations*				
pH	Br	Ag	Mg		Benzene	α
TDS	Cl	Al	Mn		Toluene	β
TSS	SO_4	As	Na		Ethylbenzene	^{40}K
Conductance	sulfides	Ba	Ni		Total xylene	^{226}Ra
Alkalinity	nitrate	Ca	Pb		m,p-xylene	^{228}Ra
Bicarbonate	nitrite	Cr	Se		o-xylene	
Carbonate		Fe	Sr		MBAS	
TP		K	Zn		O&G	

*total and dissolved
***flowback/produced water

FPW is strongly saline, typical values will run from 10,000 to 250,000 mg TDS/liter. Inorganics consist mainly of sodium, magnesium, calcium, strontium, barium, chloride, and bromide. Benzene, toluene, ethylene, and xylene (BTEX) is the organic of concern in FPW along with naturally occurring radioactive material levels for gross alpha, gross beta, and radium-228 and -228. Because the quality of the FPW samples are not typical aqueous samples, non-radiochemical parameters are subject to detection limit dilution. For this reason, we follow the USEPA standard convention of reporting below detection limits as one-half the actual detection limit. During flowback into production, FPW discharges drop off rapidly within the first few weeks with ion concentrations increase during this time. FPW volumes are shown in Figures 5.a.4 and 5.a.5, daily production and cumulative, respectively.

Figure 5.a.4 FPW daily production

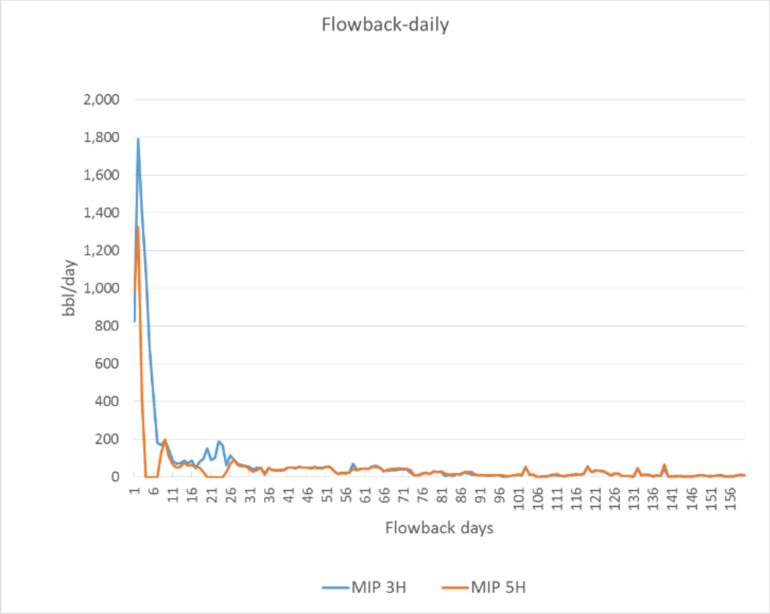
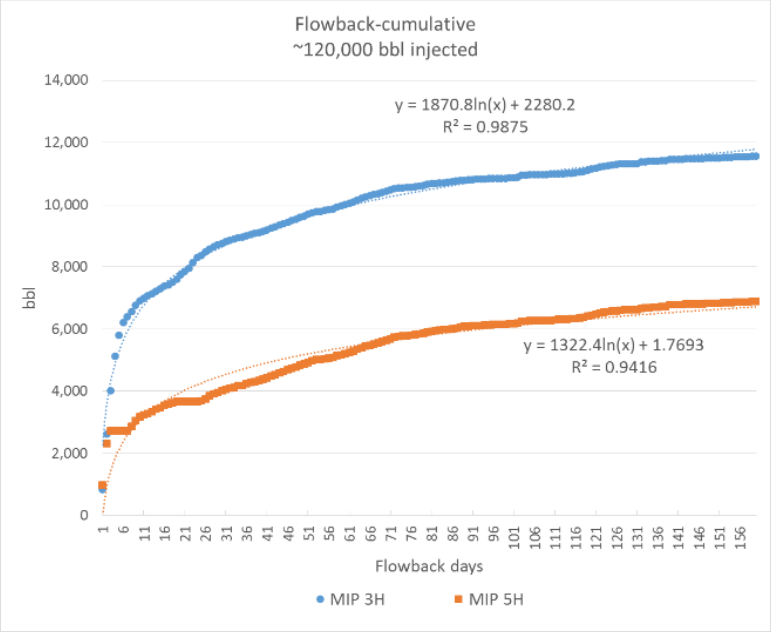


Figure 5.a.5 FPW cumulative production



The sampling schedule for surface water and gas well development water/waste streams during this quarter is detailed in Table 5.a.3. Water quality results received to date may be provided separately as a PDF and upon request.

Table 5.a.3 Third Quarter Sampling Schedule

	Freshwater		Aqueous/Solids: drilling, completion, production								
	Mon River	Ground Water	HF fluid makeup	HF fluids	Flowback/ Produced	Drilling fluids	Drilling cuttings/ muds	Total aqueous	Total solids	Sampling Dates	Sampling Notes
Sampling Stations	3	0	2	2	2	2	2				
Flowback @ 19 weeks - 3H					1			1		4/20/2016	one sample 3H
Flowback @ 19 weeks - 5H					1			1		4/20/2016	one sample 5H
Surface water sampling	3							3		4/27/2016	surface water sampling after 19 weeks
Flowback @ 23 weeks - 3H					1			1		5/18/2016	one sample 3H
Flowback @ 23 weeks - 5H					1			1		5/18/2016	one sample 5H
Surface water sampling	3							3		5/25/2016	surface water sampling after 23 weeks
Flowback @ 29 weeks - 3H					1			1		7/1/2016	Attempted to get 3H sample on 6/29. Returned on 7/1.
Flowback @ 29 weeks - 5H					1			1		6/29/2016	one sample 5H

Products

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 Workshop-Appalachian Basin Technology in Canonsburg, PA.

Plan for Next Quarter

Activities moving forward will include sampling of flowback and produced water from 3H and 5H only. Starting next quarter, project support will reduce to

1. On site sample collection
2. Sample preparation
3. Transmission to analytical lab
4. Archive lab reports

Task 5b – Surface Environmental – Air and Vehicular

The approach to the CAFEE portion of Topic 5 has been focused on methane and other emissions associated with unconventional well development. As data analyses are completed, our approach has transitioned to quantification of methane emissions from typical site operation. These audits will be completed with the use of WVU's Full Flow Sampling System (FFS), see Figure 5.b.1. We had hoped to complete these audits during this quarter but the systems mass airflow sensor failed and a new sensor had to be purchased.

Figure 5.b.1: Left- schematic of FFS, Right- image of FFS in use.

The new mass airflow sensor has been obtained and calibrated. Additional calibrations have been performed on the methane analyzer portion of the FFS. This analyzer is an Ultraportable Greenhouse Gas Analyzer (UGGA, from Los Gatos Research, Inc.). The mass airflow sensor was calibrated on June 30, 2016 using a NIST traceable Laminar Flow Element. The curve could be fit to a 4th degree polynomial. Figure 5.b.2 shows the calibration fit for the new mass airflow sensor.

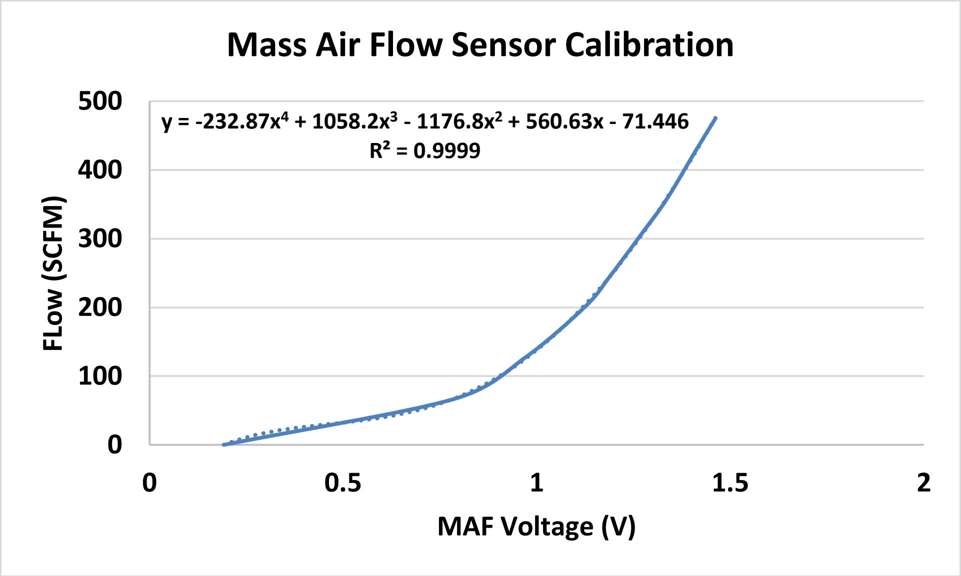


Figure 5.b.2: Mass airflow sensor calibration against a laminar flow element.

The FFS currently employ both a high-range and low-range UGGA. These have also been calibrated for next quarter's leak and loss audits. The high-range UGGA was internally calibrated on June 29, 2016 using 2.5% methane and balance nitrogen. A 10-point external verification was performed from zero to 2.5% methane and is shown in Figure 5.b.3.

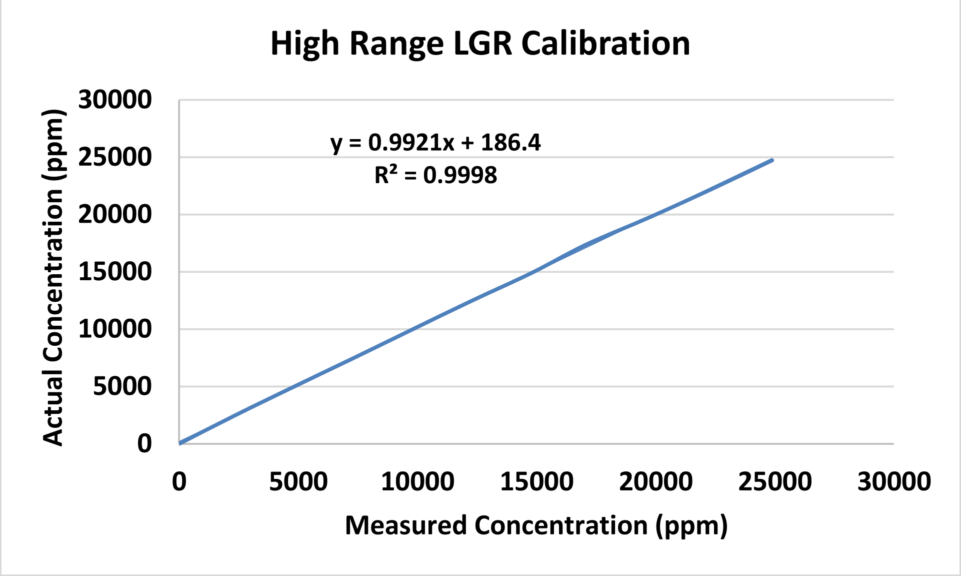


Figure 5.b.3: High-range UGGA verification.

The low-range UGGA was internally calibrated on June 28, 2016 using 25-ppm methane and balance nitrogen. A 10-point external verification was performed from zero to 25-ppm methane and is shown in Figure 5.b.4.

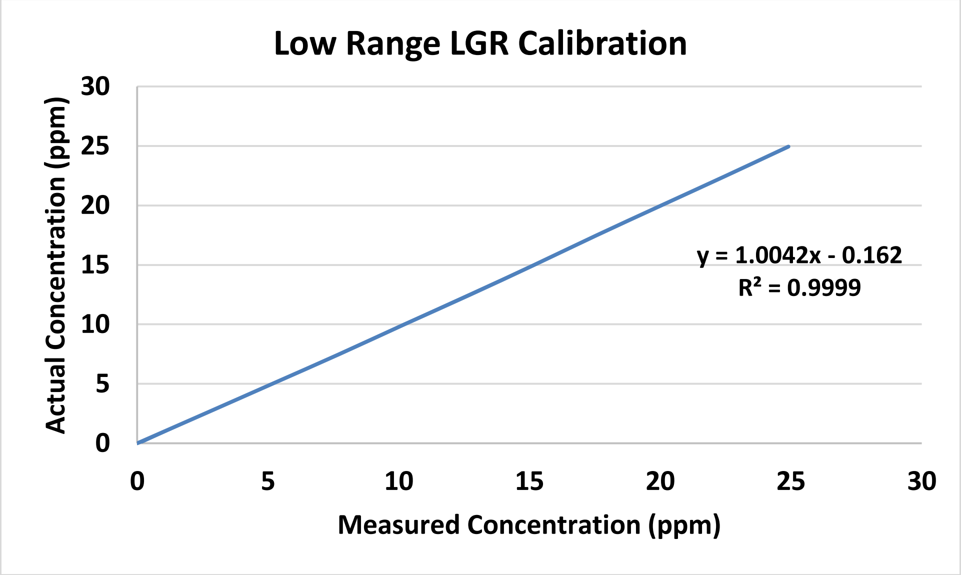


Figure 5.b.3: Low-range UGGA verification.

Results and Discussion

We have also worked with Northeast Natural Energy and other industry to develop and submit three full proposals to NETL under DE-FOA-0001538 – Methane Emissions Mitigation and Quantification from Natural Gas Infrastructures. These proposals highlighted the successful collaboration between WVU, CAFEE, NNE, and NETL.

No additional results are provided during this quarter. Within the coming quarters, draft publications will be submitted which cover the integrated data collected under combined programs. Also, future quarterly reports will also contain methane leak and loss audit data.

Products

The emissions and fuel consumption data have been integrated with data under DE-FE0013689. We are currently developing three publications that will be submitted to the Journal of Air and Waste Management, Environmental Science and Technology, and Proceedings of the National Academy of Sciences or others. The first publication will focus on the creation of activity cycles using MSEEL data and data collected across the US. This paper has been successfully submitted to JAWMA and is currently under review by two independent reviewers. The second publication had been an integrated case study on the effects of implementing dual fuel technologies in unconventional well development. The final publication had been developed to highlight collected from both programs to estimate a national inventory of emissions associated with unconventional well development. However, based on the interesting findings of our work on the MSEEL site and DE-FE0013689 we have received additional funding and time extensions to complete work under DE-FE0013689. Under these additions, we have already collected emissions and fuel consumption data for a dedicated natural gas rig. We will complete an additional measurement campaign for a dedicated natural gas engine and a Tier 4 demonstration engine. We may likely publish a single or multiple papers examining the emissions trends from both programs, which will include diesel only, dual fuel, dedicated natural gas, and Tier 4 diesel engines from four different shale plays.

Plan for Next Quarter

- Continue QC/QA of PM Data
- Publication the Journal of Air and Waste Management Paper – Cycles paper developed from data under the MSEEL program and DE-FE0013689.
- Emissions journal article has been withdrawn. See products above.
- Perform MSEEL Leak and Loss Audits.
- Continue to highlight MSEEL with new collaborators.

Task 5c. – Surface Environmental - Air

Results and Discussion

Direct-reading aerosol sampling at one minute intervals was done at five locations around an Unconventional Natural Gas Development (UNGD) site located in a river valley in Morgantown, WV as part of the Marcellus Shale Engineering and Environmental Laboratory (MSEEL) project. Sampling was done throughout all stages of well development other than pad preparation. Sampling locations included: on the drill pad itself, as well as 1 and 2 km distant. Background samples were also taken as reference. The first was 5 km upwind of the site and out of the valley. The second was located within the valley 7 km downwind but beyond the bend of a natural bowl in the valley, presumably diminishing the effect of air emissions from the UNGD site.

EPA-regulated $PM_{2.5}$ (particles less than 2.5 micrometers in diameter, capable of reaching the lung airspaces in a human) emissions were not detectable as differences in mass concentration from background (figure 5.c.1) at 1 km downwind during highest emissions periods (hydraulic fracturing) on the well pad. However, truck routes used for supplying the well were situated away from all the sampling sites and thus not monitored. Modeling data using sampling of similar truck routes in the area showed that levels expected to accompany well development could be above the background levels that were not from traffic sources and could therefore produce measurable health effects. Also, terrain and meteorological conditions are expected to influence the results at other locations and during other times.

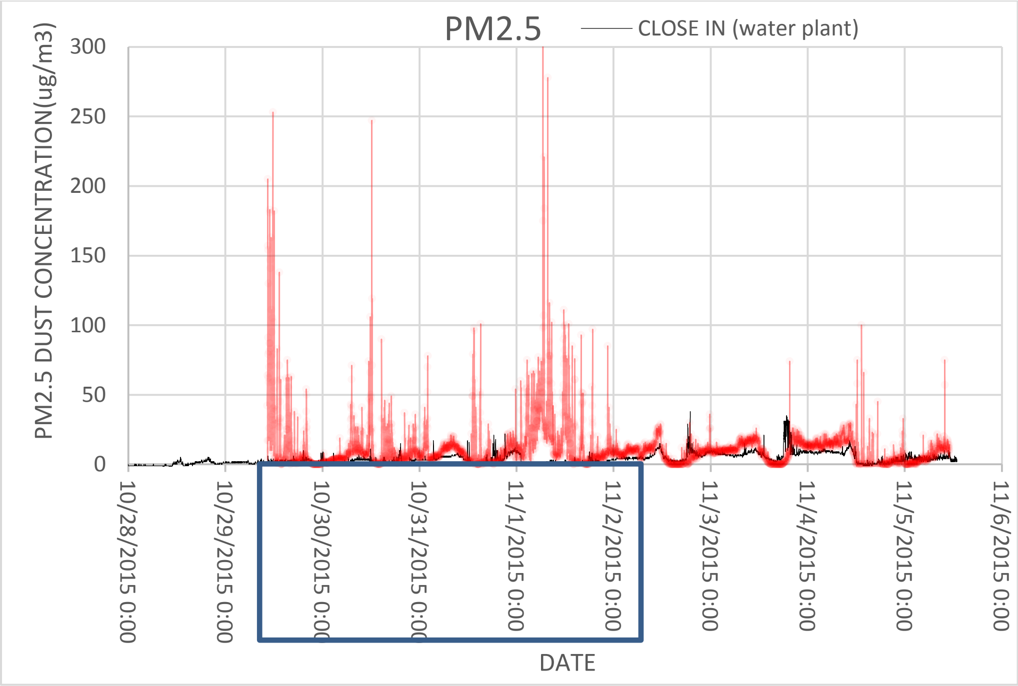


Figure 5.c.1a. PM2.5 dust levels from direct-reading Dust Track monitor showing concentration at the well-pad (red) as well as 1 km distant (black)

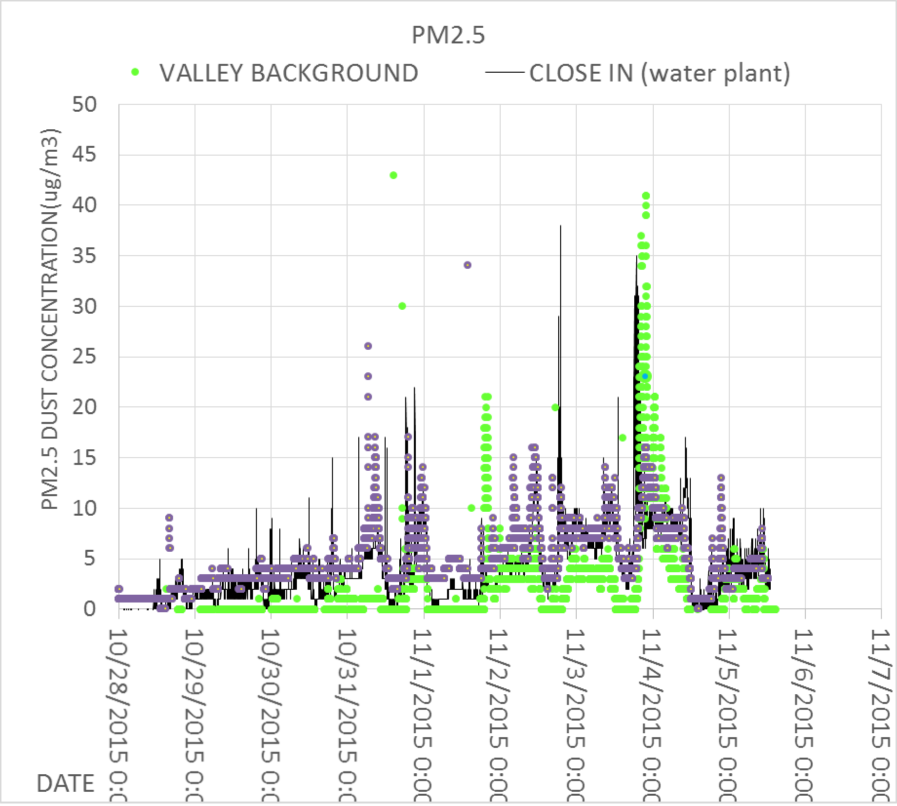


Figure 5.c.1b. PM2.5 Dust mass concentrations at approximately 1km (black), 2km (gold) and 7km (green) from the well pad. No discernable difference could be detected among the samples on the basis of mass.

Trace element analysis has now been partly completed is available for the same period as the results in Figure 5.c.1. These are shown in Table 5.c.I for the same sampling sites as in Figure 5.c.1b. A number of the detectable trace elements were found to fit a power function, expected for dispersion of materials from a ground-level source such as drilling or hydraulic fracturing activities on a well pad (Figure 5.c.2). Additionally, ratios of trace elements were analyzed to determine if the composition of the dust being analyzed maintained a constant proportion or if it was influenced by background sources extraneous to the source at the well pad. A majority of the elements were found to have constant proportions to one another out to the 7km sampling site (Figure 5.c.3). This would indicate that the relationship was steady and the equations descriptive of the relative change in concentration with distance, in spite of the difficulty in interpreting the levels in Figure 5.c.1.

Table 5.c.I. Flow Corrected Concentrations (ng/m3) by Distance from Well Pad

Analysis Date	6/6/2016	6/6/2016	6/6/2016	6/6/2016
Sample Date/ Location	10/30/15 pump2 zone 0	10/30/15 zone 1 water co	10/30/15 zone 1 sanford	10/30/15 zone 3 suncrest
Distance (km)	**0.00**	**0.92**	**2.30**	**7.16**
Al	193.49636	72.13129	15.40235	29.09538
Ba	9.92484	2.82419	2.31462	2.77552
Ca	722.98885	140.14941	42.51177	70.24757
Co	0.05086	0.01474	0.00752	0.01116
Cs	0.01754	0.00465	0.00284	0.00434
Fe	139.41810	39.52329	25.00408	35.17560
K	81.55782	36.63078	38.23487	41.23806
La	0.12473	0.03246	0.01928	0.02655
Li	0.14381	0.03672	0.01779	0.04794
Mg	57.65966	13.75400	6.24415	6.82441
Mn	3.28503	1.11800	0.88694	1.10440
Mo	0.21513	0.07743	0.11039	0.08241
Ni	0.27106	0.06121	0.05869	0.08605
P	8.17283	3.54676	5.62877	3.57348
Rb	0.32691	0.11518	0.06629	0.09190
Sr	1.47367	0.35801	0.20120	0.30553
Ti	12.82281	2.35979	1.26221	2.10502
U	0.02130	0.00457	0.00226	0.00285
V	0.30564	0.08216	0.05229	0.07558
Zn	8.39324	3.79258	4.34893	4.99476

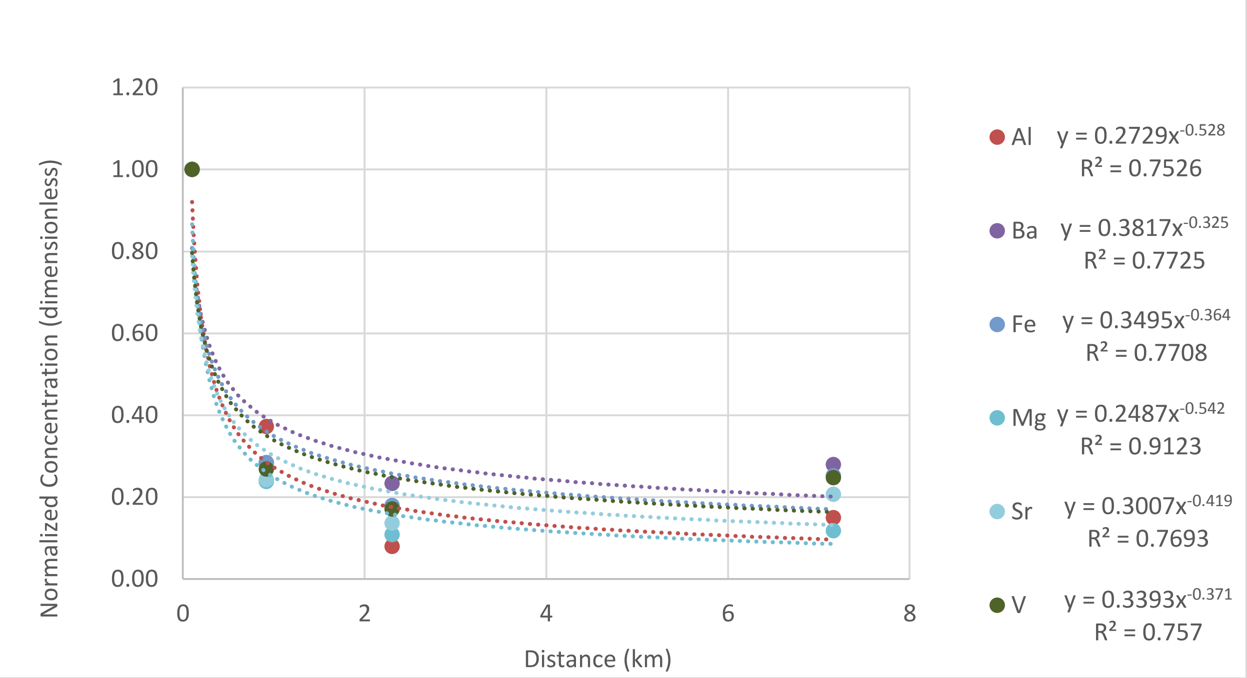


Figure 5.c.2. Concentration of Select Elements (WVU Gas Well - During Fracking 10/30/15) by distance from well pad showing a power equation relationship to distance chosen using correlation coefficients (R^2) > 0.7.

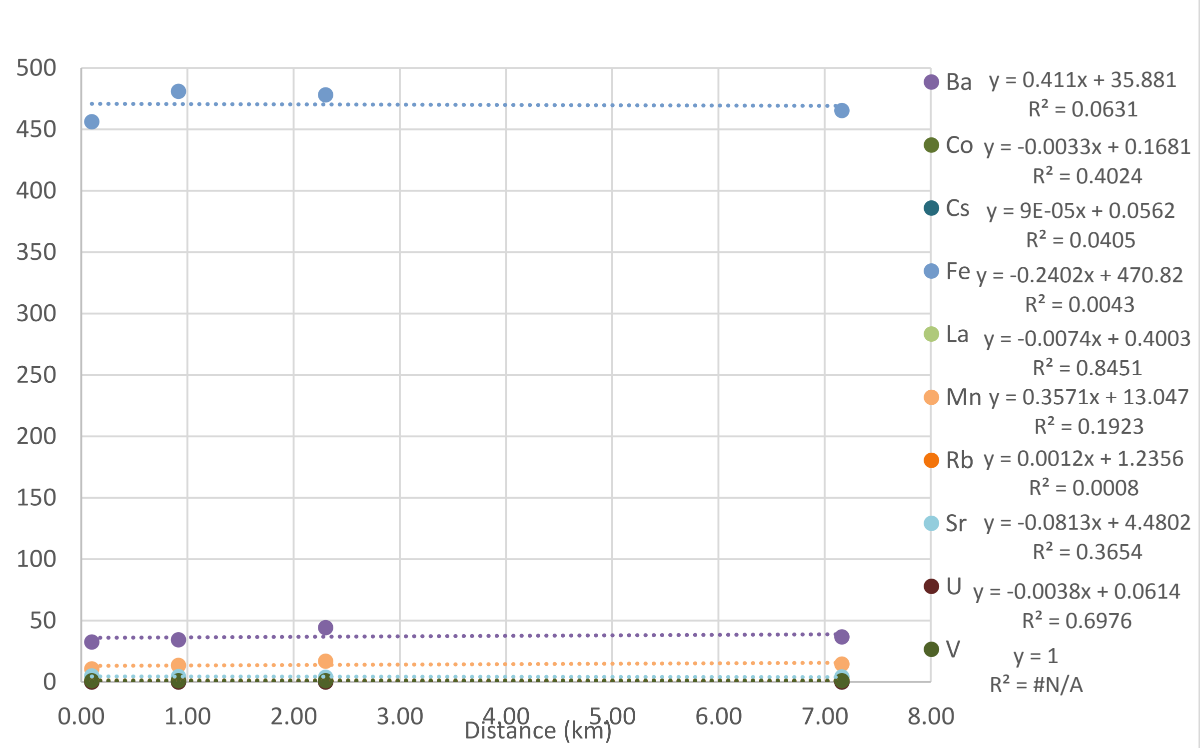


Figure 5.c.3. Ratio of Select Elements to Vanadium (WVU Gas Well - During Fracking 10/30/15) showing a constant proportion out to 7km.

Products

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.

Plan for Next Quarter

More trace element analyses are expected for other times during the well cycle, as well as some organics.

Topic 6 – Economic and Societal

Approach

The lead on the political and societal project will work to identify and evaluate the factors shaping the policymaking response of local political actors. Included in this assessment will be an accounting, past and present, of the actions of public and private individuals and groups acting in favor of or opposed to shale gas drilling at the MSEEL site.

First year activity includes developing, distributing, collecting and compiling the responses from a worker survey and a vendor survey. The worker survey will address job characteristics and offsite expenditures. The vendor survey will help to identify per-well cost structures.

Results and Discussion

STATE OF THE REGION REPORT

This report, outlined in the proposal, will provide a general overview of the economic conditions in the immediate area of the experimental science well, and in WV generally. Although we do not expect to be able to attribute changes to the health and welfare of the local or state economy to the activities related to a single well site, the report will provide a contextual description of conditions at the inception of the science well activity.

WORKER EXPENDITURES SURVEY

The worker expenditure survey instrument was designed to provide greater detail on types and levels of expenditures by well-site workers. The survey included questions designed to identify consumption behavior of typical onsite transient workers during their performance periods. Expenditures types include lodging and accommodations, food, entertainment, and incidentals. The survey instrument also collected information on income ranges and places of residence. These data should prove useful, e.g., in characterizing the geography of income and earnings impacts No other survey-based estimates based on actual well-sites have been collected and analyzed to our knowledge.

We collected a total of 70 responses. This is estimated to be a response rate of roughly 50 %, although not all surveys were filled out in their entirety, and a number of responses to specific questions will not be usable (e.g., respondents might have rephrased questions and or provided responses that cannot be coded). It isn't clear yet what to what extent the responses will be representative or whether biases might have been introduced by non-responses from one more than another category.

The expenditures summaries should improve the accuracy of drilling impacts assessments generally, and will be used as part of the basis for an economic impacts assessment for the science well, itself.

DRILLING EXPENDITURES DATA

Northeast Natural Energy has provided us with a spreadsheet detailing the operating expenditures for the well. This information will be directly useful in compiling a generalized cost basis for the estimation of production function representation for Marcellus drilling operations. We expect the resulting production cost function to be a valuable contribution to the impacts assessment community, for use in estimating economic benefits of drilling operations. To the extent possible, the cost function will be scalable and sensitive to a number of variables such as well pad size and accessibility, number of wells, and depth of wells.

Plan for Next Quarter

Drafts of all of these reports are expected to complete in the next reporting quarter. Target draft completion date is August 30, 2016.

Year 1

Start: 10/01/2014 End: 09/30/2015

Baseline Reporting Quarter

	Q1 (12/31/14)	Q2 (3/30/15)	Q3 (6/30/15)	Q4 (9/30/15)
<u>Baseline Cost Plan</u>	(From 424A, Sec. D)			
<u>(from SF-424A)</u>				
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				
<u>Actual Incurred Costs</u>				
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
<u>Uncosted</u>				
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

Cost Status

Start: 10/01/2014 End: 09/30/2015

Baseline Reporting Quarter	Q5 (12/31/15)	Q6 (3/30/16)	Q7 (6/30/16)	
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	
Non-Federal Share	$0.00	$2,189,863.30	$2,154,120.23	
Total Incurred Costs - Quarterly (Federal and Non-Federal)	$577,065.91	$6,670,802.72	$3,000,087.46	
Cumulative Incurred Costs	$1,130,203.32	$7,801,006.04	$10,637,732.23	
Uncosted				
Federal Share	$5,117,163.68	$636,224.26	$1,004,177.30	
Non-Federal Share	$2,814,930.00	$625,066.70	($1,503.53)	
Total Uncosted - Quarterly (Federal and Non-Federal)	$2,418,796.68	$1,261,290.96	$1,002,673.77	

Appendix A: Abstracts Accepted for the 45th Annual Meeting, Eastern Section, American Association of Petroleum Geologists

Eastern Section AAPG and Geological Society of America

Abstracts-MSEEL

1) V. Agrawal, S. Sharma, and A. Warrier, Understanding kerogen composition and structure in pristine shale cores collected from Marcellus Shale Energy and Environment Laboratory, **Poster**
2) R. Akondi, R. V. Trexler, S. M. Pfiffner, P. J. Mouser, S. Sharma, Comparing Different Extraction Methods for Analyses of Ester-linked Diglyceride Fatty Acids in Marcellus Shale, **Poster**
3) Rebecca A. Daly, Mikayla A. Borton, Travis A. Wilson, Susan A. Welch, David R. Cole, Shikha Sharma, Michael J. Wilkins, Paula J. Mouser, Kelly C. Wrighton, Microbes in the Marcellus Shale: Distinguishing Between Injected and Indigenous Microorganisms, **Poster**
4) Mary Evert, Jenny Panescu, Rebecca Daly, Susan Welch, Jessica Hespen, Shikha Sharma, David Cole, Thomas H. Darrah, Michael Wilkins, Kelly C. Wrighton, Paula J. Mouser, Temporal Changes in Fluid Biogeochemistry and Microbial Cell Abundance after Hydraulic Fracturing in Marcellus Shale, **Poster**
5) Andrea J. Hanson, Ryan Trexler, and Paula J. Mouser, Analysis of Microbial Lipid Biomarkers as Evidence of Deep Shale Microbial Life, **Poster**
6) Carr, Timothy R., Shikha Sharma, Thomas Wilson, Paul Ziemkiewicz, B.J. Carney, Jay Hewitt, Ian Costello, Emily Jordon, Zachary Arnold, Ryan Warner, Andy Travis, Dustin Crandall, Raymond Boswell, Robert Vagnetti, The Marcellus Shale Energy and Environment Laboratory (MSEEL), **Oral**
7) Jenny Panescu, Mary Evert, Jessica Hespen, Rebecca Daly, Kelly Wrighton and Paula J. Mouser, *Arcobacter* isolated from the produced fluids of a Marcellus shale well may play a currently unappreciated role in sulfur cycling, **Poster**
8) S. Sharma, V. Agrawal, R. Akondi, and A. Warrier, Understanding biogeochemical controls on spatiotemporal variations in total organic carbon in cores from Marcellus Shale Energy and Environment Laboratory, **Oral**
9) J. Sheets, A. Swift, T. Kneafsey, S. Welch, and D. Cole, Mineral/organic matter associations and pore microtextures in the Marcellus Formation, West Virginia, **Poster**
10) Ryan V. Trexler, Rawlings Akondi, Susan M. Pfiffner, Rebecca A. Daly, Michael J. Wilkins, Shikha Sharma, Kelly C. Wrighton, and Paula J. Mouser, Phospholipid Fatty Acid Evidence of Recent Microbial Life in Pristine Marcellus Shale Cores, **Oral** Presentation by Mouser
11) Casey Saup, Rebecca A. Daly, Danielle Goudeau, Rex Malstrom, Paula J. Mouser, Kelly C. Wrighton, and Michael J. Wilkins, Indigenous life in extreme environments: Characterizing pristine shale rock hosted biomass, **Poster**
12) Anne E. Booker, Mikayla A. Borton, Rebecca Daly, Sue Welch, Carrie D. Nicora, Shikha Sharma, Paula J. Mouser, David Cole, Mary S. Lipton, Kelly C. Wrighton, and Michael J. Wilkins, Sulfide Generation by Dominant Colonizing *Halanaerobium* Microorganisms in Hydraulically Fractured Shales, **Poster**
13) Dustin Crandall, Johnathan Moore, Tom Paronish, Ale Hakala, Shikha Sharma, and Christina Lopano, Preliminary analyses of core from the Marcellus Shale Energy and Environment Laboratory, **Oral**
14) Mikayla A. Borton, Rebecca A. Daly, David M. Morgan, Anne E. Booker, David W. Hoyt, Paula J. Mouser, Shikha Sharma, Michael J. Wilkins, Kelly C. Wrighton, *Methanohalophilus* is the dominant source of biogenic methane in hydraulically fractured shales, **Poster**
15) Paul Ziemkiewicz, West Virginia Water Research Institute, West Virginia University, Marcellus Shale Energy and Environment Laboratory Approach to Water and Waste Studies, **Oral**

16) Michael McCawley, Travis Knuckles, Maya Nye, Alexandria Dzomba, Addressing Health Issues Associated with Air Emissions around UNGD Sites, **Poster**
17) Sharma, Shikha, Carr, Timothy, Vagnetti, Robert, Carney, BJ and Hewitt, Jay, Role of Marcellus Shale Energy and Environment Laboratory in Environmentally Prudent Development of Shale Gas, Pardee Keynote Session, When Oil and Water Mix: Understanding the Environmental Impacts of Shale Development, Geological Society of America Annual Meeting, Denver, CO. **Oral**
18) Travis Wilson and Shikha Sharma, Assessing biogeochemical interactions in the reservoir at Marcellus Shale Energy and Environment Laboratory, Understanding the Environmental Impacts of Shale Development, Geological Society of America Annual Meeting, Denver, CO. **Poster**
19) Hupp, Brittany N., Weislogel, Amy L. and Donovan, Joseph J., Interactions Between Provenance, Paleoclimate, and Productivity in the Devonian Millboro Shale, Northcentral West Virginia, , Geological Society of America Annual Meeting, Denver, CO. **Poster**

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