Oil & Natural Gas Technology

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Quarterly Research Performance Progress Report

(Period ending: 9/30/2016)

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

July 1 – September 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 more than four terabytes of data collected during well drilling, completion and initial production. Production started on 15 December, 2015, but has been choked due to insufficient demand, which has limited compete production documentation. Plans are developed to complete production testing during the winter of 2016-17. The team held several meetings, presented numerous papers and participated in numerous sessions, including one at the Eastern Section of American Association of Petroleum Geologists dedicated to results of the MSEEL project. A large team meeting is planned for November 1, 2016 to discuss project progress, plans for publications, and for team breakout sessions to discuss technical work plans and sample (rock, water, etc.) workflows to ensure that all project partners had access to needed materials. Monitoring of the wells continued through this quarter during the initial production phase with the fiber-optic DTS system. The team also has worked to update the Project Management Plan to capture the plans developed for the coming budget period.

Quarterly Progress Report

July 1 – September 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 fourth quarter of the FY2016 (July 1 through September 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

<u>Subtopic 1.1. – Project Management</u>

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 continued to be very active, as the team has started in-depth analysis of the data collected during well development. The team held several meetings, including a large team meeting on February 12, 2016 to discuss project progress, and four team breakout sessions to discuss technical work plans and sample (rock, water, etc) workflows to ensure that all project partners had access to needed materials. A total of 80 people participated in the meeting. Monitoring of the wells continued through this quarter during the initial production phase. The team also has worked to update the Project Management Plan to capture the plans developed at the team meeting on 2/12.

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 1.1)

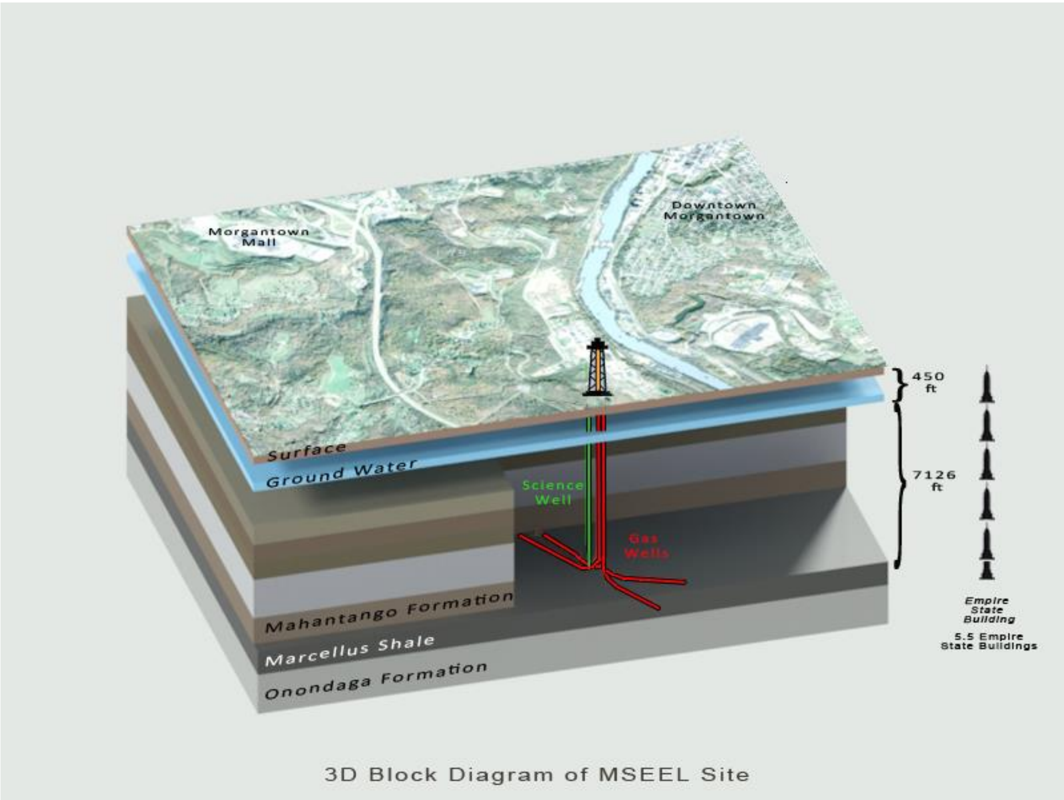

Figure 1.1. Static 3D image of the MSEEL sit showing the existing production wells and the two new production wells along with the science/observation well.

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, a new core plug sample from the science well has been obtained. The established protocols for sample analysis have been implemented to characterize the core plugs. The base set of experiments using Helium for measurement of porosity, permeability, and compressibility are under way.

The analysis of the production and stimulation data from the new horizontal wells (3H and 5H) at the MIP site is under way..

In addition, the analysis of the data generated during drilling wells MIP-3H and MIP-5H at NNE site is in progress. The determining formation characteristics from wireline and thermal logs is also in progress.

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 2.b.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

Products

Production Monitoring

Gas and fluid production at the surface has continued to be monitored using a supervisory control and data acquisition (SCADA) to remotely monitor production of gas and water (Figures 2.1 and 2.3). Production is limited to the City of Morgantown's consumption and has been limited since production began. However, production was severely limited in May 2016 due to warmer weather (Choked to 20%). The constrained production was reflected in the fiber optic distributed temperature system (DTS) with an instantaneous increase in temperature (reduced production) (Figure 2.2). We have attempted to normalize the increased temperature to examine production under constrained conditions (Figure 2.4). It appears that production from the engineered stages (14-19) is higher than the other stages as evidenced by decreased normalized temperatures.

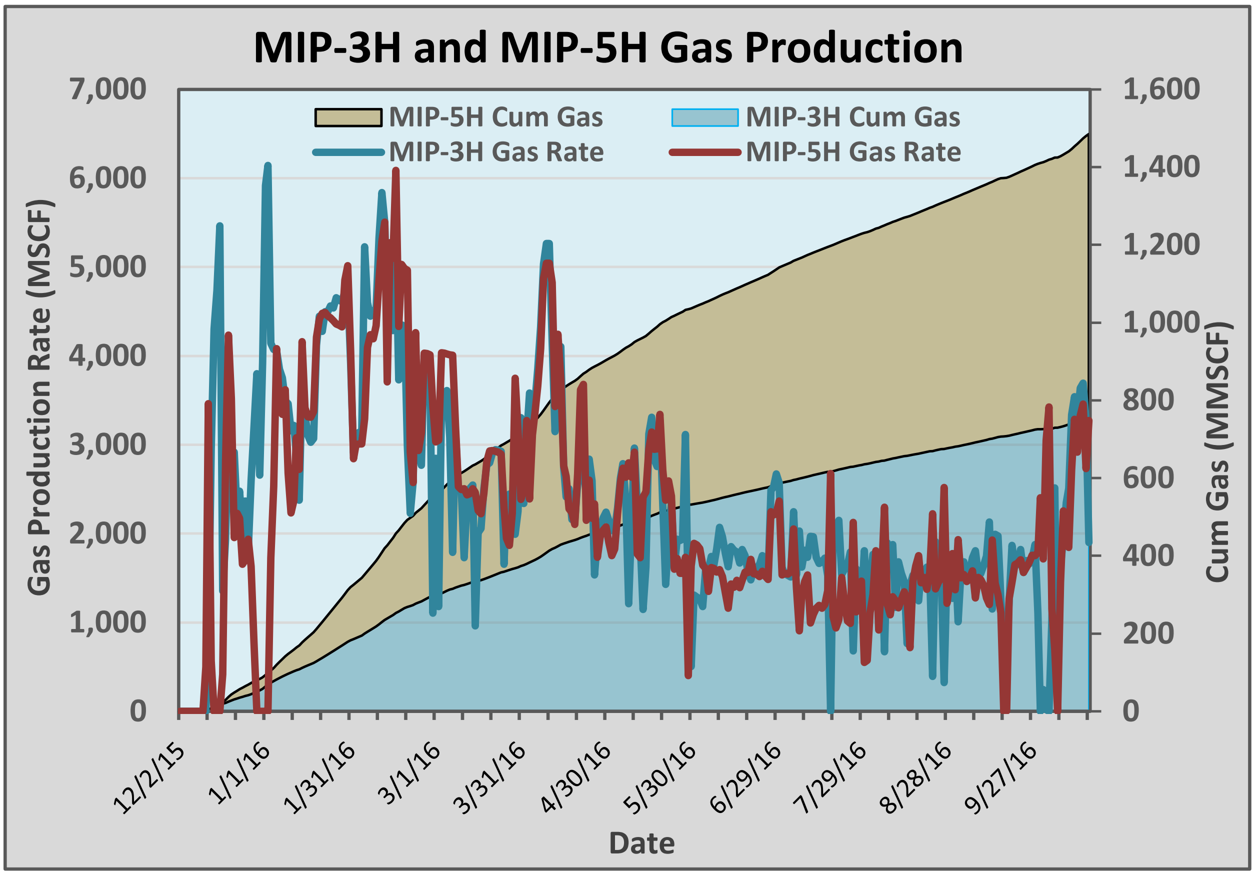

Figure 2.1 Daily and cumulative gas production from the MIP 3H and MIP 5H at the MSEEL site. Gas production was curtailed beginning in May 2016 due to weak demand. Production has begun to increase at the end of September 2016.

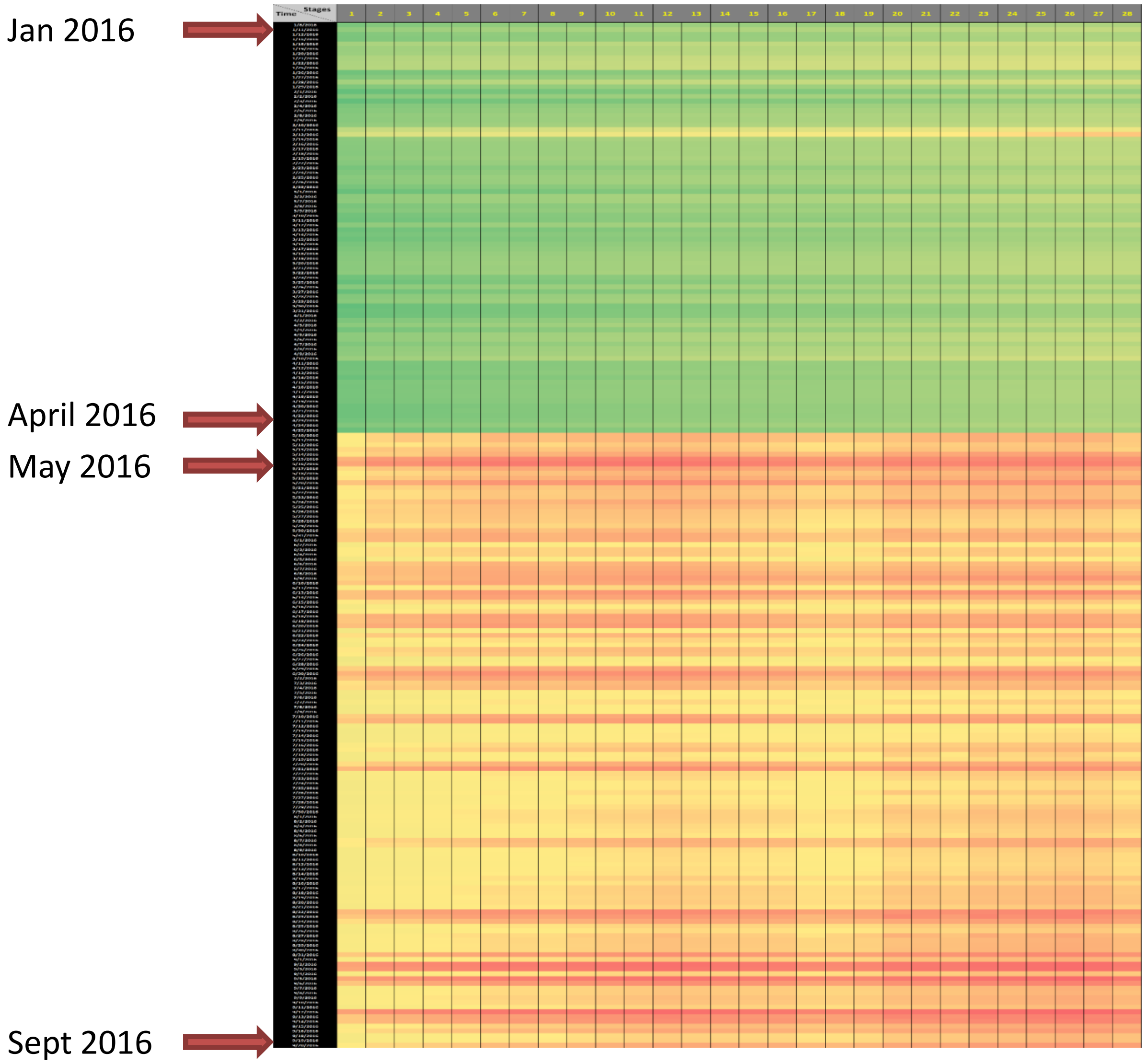

Figure 2.2 Distributed fiber-optic determined temperature by stage from the MIP 3H showing the increase in temperature due to curtailed production at the beginning of May 2016.

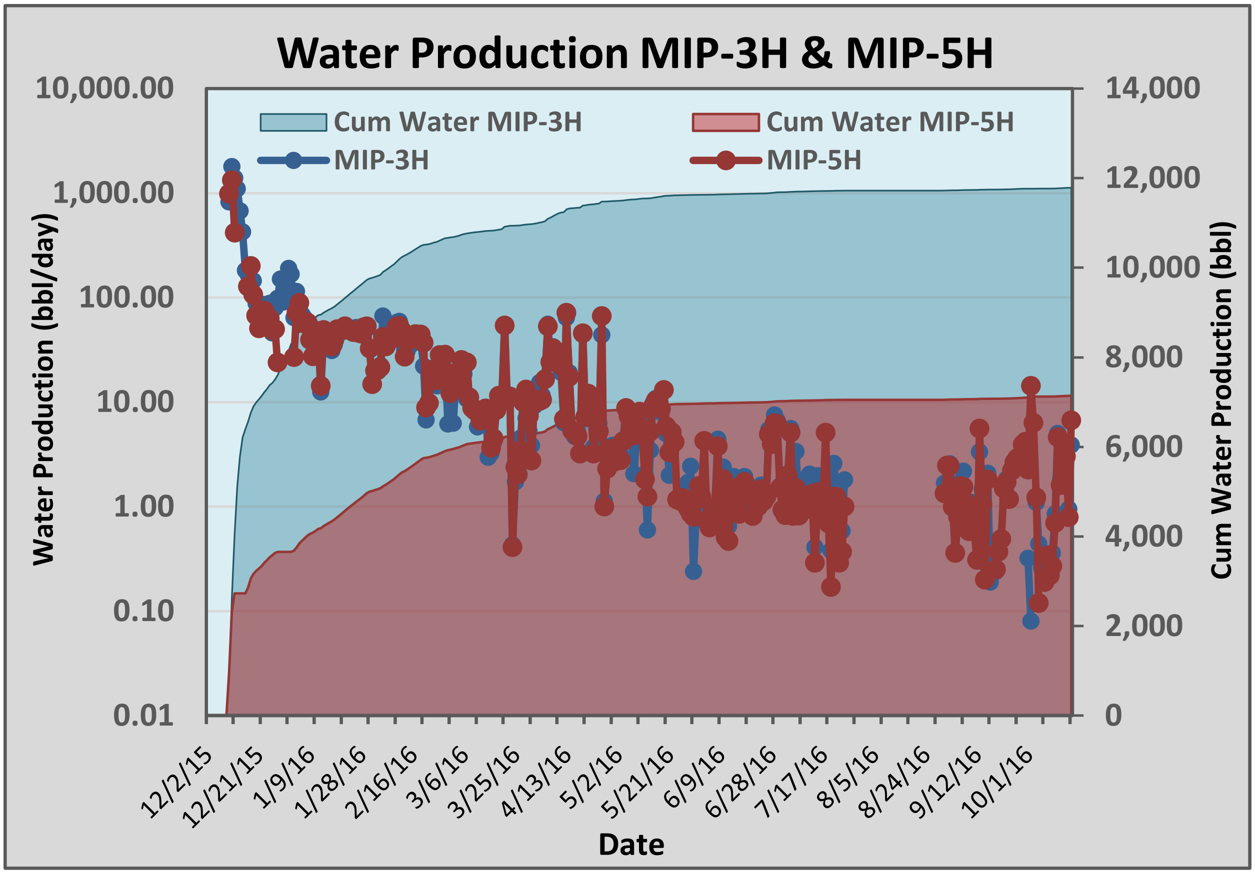

Figure 2.3 Water production from both the MIP 3H and MIP 5H. Daily water production decreased quickly from 1,000 barrels per day to one to ten barrels per day. A small increase is evident due to small increase in production in late September and October.

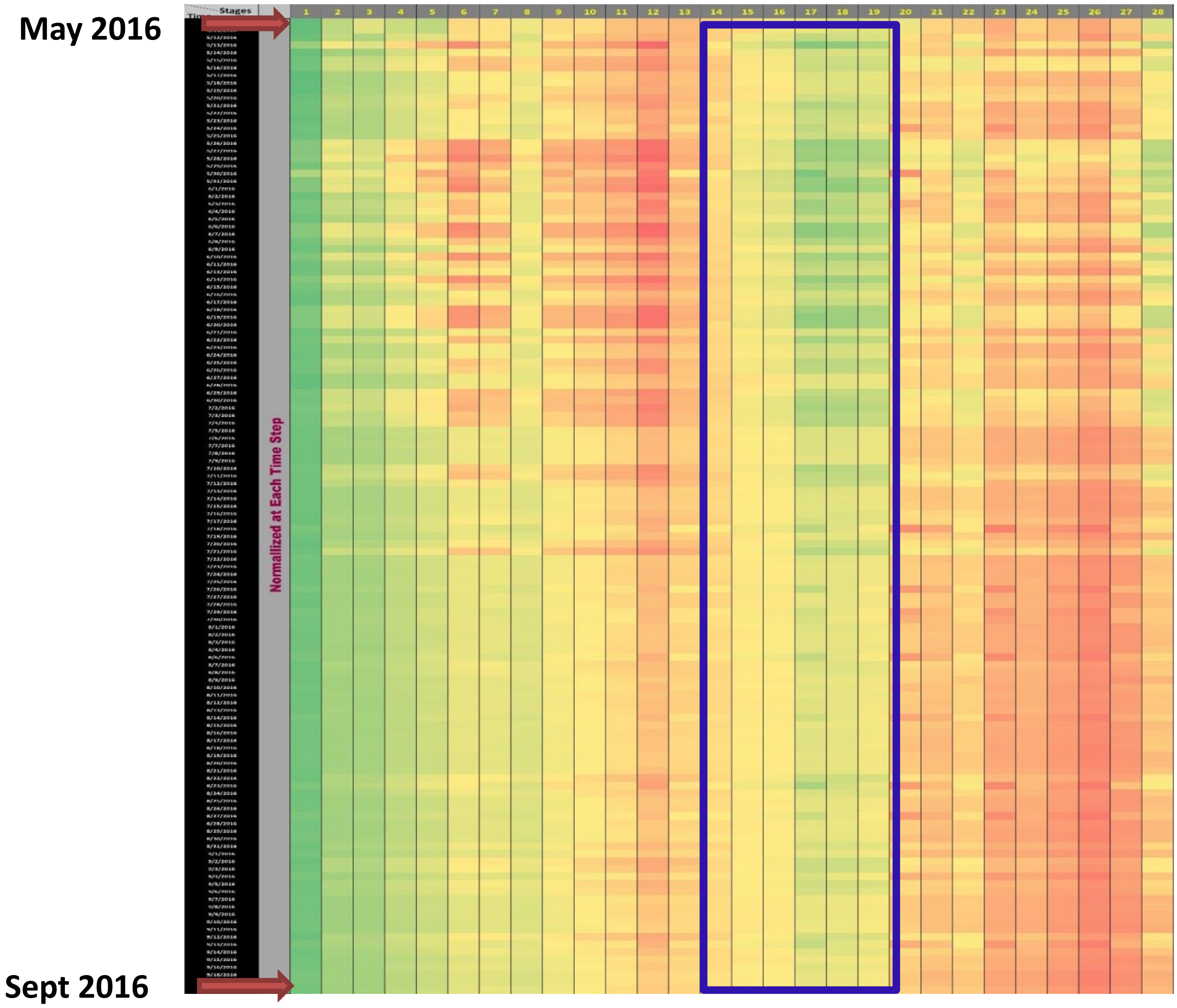

Figure 2.4 Normalized distributed fiber-optic determined temperature by stage from the MIP 3H showing the decrease temperature departing from the general trend indicating that the engineered stages 14 to 19 may be producing more gas than the earlier geometric stages.

Plans 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.

Plans have been developed to run production logs in the MIP 3H while shutting in the MIP 5H. This is planned to occur during the winter when gas consumption due to heating in Morgantown will be significant higher. It is also planned to closely monitor the fiber-optic system for temperature and sonic. This should enable us to directly assign production to individual clusters within individual stages and evaluate the effectiveness of engineered completion design.

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, frackability, 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

Results and Discussion

Accomplishments:

The main focus of the subsurface team led by Sharma this quarter was to analyze core, fluid and gas samples collected from the MSEEL site. Members of Sharma’s lab group (Dr. Warrier and Mr. Wilson) and Dr. Hanson from Mouser’s lab group continue to coordinate and supervise all sample collection. Samples were also distributed to research team at OSU and NETL for analysis under different sub-tasks. Several talks and presentations were given at local and regional conferences /universities.

1. Major goals – progress towards

Goal 1: Sample collection and Analysis

Sidewall Core, Vertical Core & Cuttings

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. For whole core analysis cores were taken from 1foot interval through the 111 feet of whole vertical core. Samples were ground homogenized and distributed to different groups at WVU, OSU and NETL for different analysis.

Lopano and Hakala’s research group at NETL finished initial analysis of drill cuttings. Samples were analyzed for elemental composition by inductively coupled plasma-mass spectroscopy (ICP-MS) mineral phases by X-ray diffraction (XRD), and trace metal associations were mapped by micro X-ray florescence (m-XRF) at Stanford Synchrotron Light Source (SSRL). Preliminary results show that cutting samples containing trace metals such as: As, U, Zn, and Cu, tend to be samples that contain high organic carbon (up to 10.3 wt%) and pyrite content. Micro-XRF mapping shows 50-100µm size U, As and Cu hotspots, mainly co-localized with small Fe grains (50-200 µm), or distributed on larger Fe grains (0.5-2 mm). Barium content is elevated throughout all samples (~ 5 wt%) and can in part be attributed to residual drill mud. Micro-XRF mapping reveals Ba coatings on mineral grains; which supports Ba being primarily from residual drilling muds in these samples. Leaching tests further identify various leaching conditions influencing trace metal mobility, such as different leachate composition (simulating rainfall or landfill conditions), pH and liquid: solid ratio. Tests are designed to mimic short-term and long-term leaching tests under different conditions in order to evaluate key elements to monitor in Marcellus shale drill cutting disposal scenarios. Preliminary XRD analysis of 35 samples was performed by Weislogel's student Hupp to assess bulk mineralogy using the reference intensity ratio (RIR) method. Results show the samples are mainly dominated by muscovite/illite (approximately 40-60%), quartz (~20-40%), and pyrite (~10-15%). These findings are consistent with previous XRD analyses performed on another well in Monongalia Co. by the Eastern Gas Shales Project in the 1970's. Other minor minerals found in the samples include calcite, dolomite, albite, and barite. Thin-section petrography is needed to evaluate diagenetic versus detrital origin of these phases. Additional analyses to be completed include bulk-sample major-element XRF and Sm-Nd radioisotopic dating. The objective is to further constrain provenance evolution of fine-grained Middle Devonian sediments in the central Appalachian Basin. All Results were presented at the annual Geological Society of America Meeting.

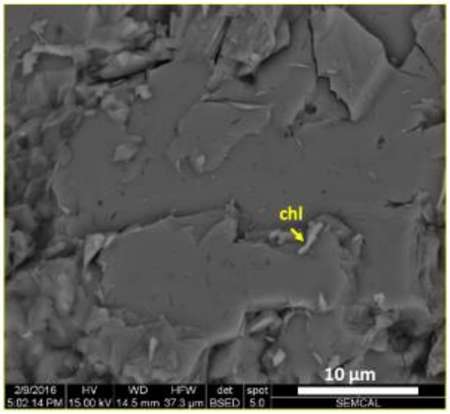

Figure 3.1 Calcite-rich matrix with dispersed, sub-micron platelets of chlorite in Marcellus, depth 7467'

Julie Sheets from Cole's research group presented results of XRD, SEM and MICP analysis of core samples at the Eastern Section AAPG meeting in Lexington, Kentucky. XRD analysis to determine bulk mineralogy of core samples from well MIP 3H shows that Marcellus core is composed mainly of siliciclastic mudstones with interbedded carbonates. Of the four sidewall cores targeted within the Marcellus, three (Marcellus Top (depth 7451'), Middle (7509') and Lower (7543') are mainly comprised of phyllosilicates (illite and chlorite), quartz, pyrite, and alkali feldspar. One (Upper Marcellus, depth 7467') is a carbonate mudstone composed mostly of calcite, quartz, and dolomite, but with minor illite and chlorite detected. SEM images of unpolished fragments of this sample show sub-micron scale chlorite platelets (Figure 3.1) disseminated throughout a dominantly calcite matrix, with some relatively small organic matter (OM) patches disseminated throughout the carbonate. SEM analysis of unpolished cleavage fragments of Marcellus Top (7451') show 100-200 micron diameter pods of organic material (OM), interpreted as preserved algal cysts (Tasmanites?) containing large (several 10s of microns in dimension), euhedral dendritic chlorite crystals, as well as euhedral forms of calcite, quartz, and pyrite. Figure 3.3 shows an example of such an OM-rich feature that was targeted for dual beam FIB/SEM. In addition, gallium-ion beam slices and subsequent images of a large (40 x 40 µm) region of interest including one the pods, obtained from the Molecular Foundry (LBNL), reveal small, porous patches of OM dispersed within the fine grained illitic clay matrix, as well as pores formed at mineral phase boundaries and between OM and minerals. These data suggest that more than one

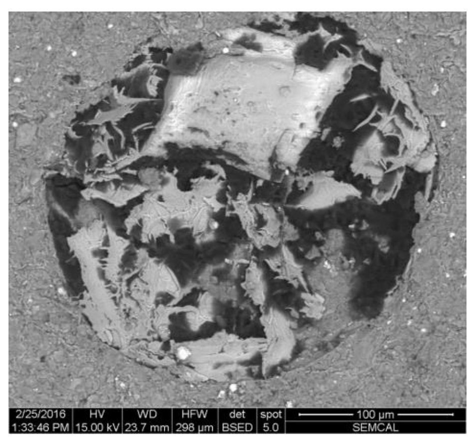

Figure 3.2 Algal material (Tasmanites?) replaced by OM, euhedral chlorite, and other secondary minerals in Marcellus Top, depth 7451'

type of OM exist within a single core sample, and that OM/mineral/pore microstructure also varies with depth in the formation.

Produced Fluid and Gas

Produced water samples were collected in 5 gallon carboys every 4-6 weeks. 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. Geochemistry data from MIP 3H and 5H wells run at Cole’s lab show that Chloride concentrations range from approximately 55,000 to 84,000 mg/L, however, the Cl^- concentrations did not increase systematically over time, nor did these two wells exhibit similar changes. Dissolved sulfate was not detected in the flowback samples collected from April through September. Fluoride concentrations were approximately an order of magnitude lower during this time, as compared to the first month of flowback samples. Ammonia and phosphate were measured on the Skalar nutrient analyzer. Dissolved NH_3 followed a similar trend as Cl^-, with concentrations ranging from approximately 80 to 100 mg/L N. Data reduction from trace metal analysis on the ICP-OES and ICP-MS continues.

Goal 2: Test methods biomarker extraction, identification and quantification

The complex shale matrix, including high concentrations of organic constituents and salts as well as exceedingly low porosities constitute serious challenges in extracting microbial lipids from shales. Mature Shale like the Marcellus pose further challenge because high temperatures and pressures during burial destroy or modify microbial existence. Sharma’s PhD. student Akondi in collaboration with Texler from Mouser’s group at OSU has finalized a manuscript that summarizes a novel modified lipid extraction method in which a combination of solvents, buffers, and spikes were tested for their ability to improve recovery and reproducibility of extracted microbial lipid biomarkers from deep subsurface shale sediments. In this paper the authors summarize results from three different methods; viz. modified Bligh and Dyer (mBD), Folch (FOL), a Lipid biomarker analyses (inc. phospholipid fatty acids (PLFAs), diglyceride fatty acids (DGFAs)d microwave assisted extraction (MAE). The modified Bligh and Dyer method using a phosphate buffer and phospholipid spike (mBD+Phos+POPC) consistently provided

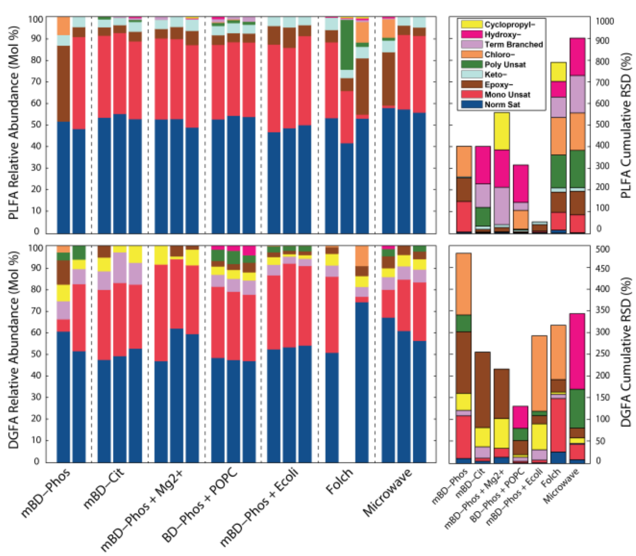

Figure 3.3. Relative abundances of PLFA (n=20) and DGFA-FAME (n=19) profiles based on the classes of each sample across all extraction treatments (n=7), and RSD measurements for PLFA and DGFA FAME classes for each treatment. *(From: Akondi et. al., in prep for Frontiers-Extreme Microbiology)*

reproducible results and higher recovery of biomarkers for both PLFA and DGFA over other methods (Figure 3.3), suggesting that the addition of the POPC spike helped with the extraction of a pool of lipid material that was not accessible with the other methods. This method demonstrates that the extraction solvent mixtures are polar enough to release PLFA from microbial cell membranes, and non-polar enough to release DGFA from neutral lipids. The results from these experiment will be used for effective extraction of microbial lipid biomarkers from all MSEEL samples.

Goal 3: Microbial DNA analysis and microbial cultivation

This quarter Mouser group has begun to characterize optimal salinities and carbon donor profiles for microbial isolates cultured from MSEEL wells. Samples were also submitted DNA to DOE JGI to sequence the genomes for these isolates. Samples were prepared and shipped to Germany for intact lipid analyses. Andrea Hanson, a post-doc partially funded on the MSEEL project is currently in Germany to extract and analyze lipids using high resolution MS.

Using pristine cleaned core materials, the Wilkins lab has been mainly focusing on the potential sulfide generation by Halanaerobium over the last few months. Initial results demonstrate that Halanaerobium can generate sulfide in the presence of thiosulfate (but not sulfate) (Figure 3.4).

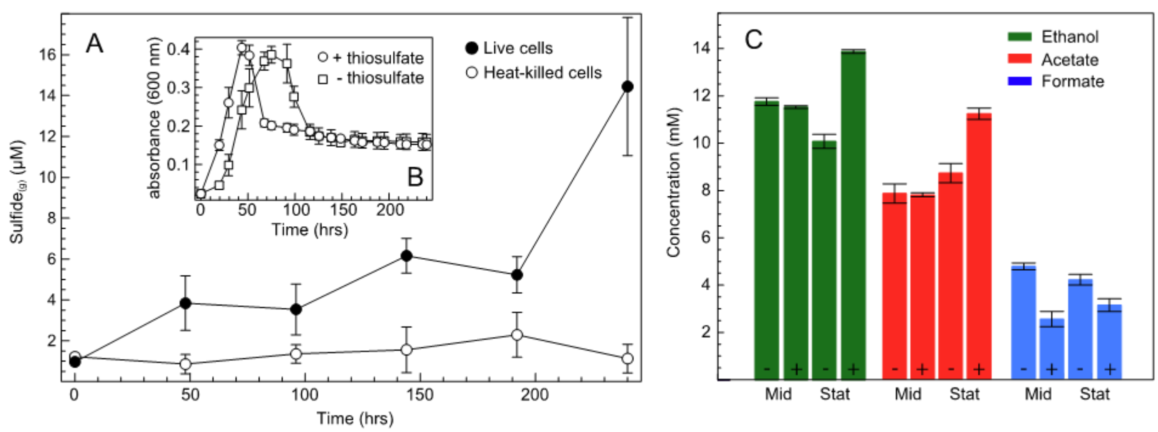

Figure 3.4. (A) Sulfide production via thiosulfate transformations in live-cell incubations. (B) Growth curves for *Halanaerobium* WG8 in both the presence and absence of thiosulfate. (C) Changes in major *Halanaerobium* fermentation products when cultured in the presence and absence of thiosulfate (+/-), at both mid-log (Mid) and stationary (Stat) growth phases *(From: Booker et. al., in prep for Environmental Science & Technology)*

Halanaerobium central metabolic flux is altered in the presence of thiosulfate, resulting in greater concentrations of organic acid fermentation products which have implications for corrosive potential. They also interpret that these reactions proceed through a series of genes (rhodanase and sulfide reductases) that are nearly always detected in produced fluid samples

2. Data Dissemination

- Agrawal V, Sharma S, and Warrier A. 2016. Understanding kerogen composition and structure in pristine shale cores collected from Marcellus Shale Energy and Environment Laboratory. Eastern Section American Association of Petroleum Geologists' Meeting, Lexington, Kentucky, September 2016

- Akondi R, Trexler RV, Pfiffner SM, Mouser PJ, Sharma S. 2016. Comparing Different Extraction Methods for Analyses of Ester-linked Diglyceride Fatty Acids in Marcellus Shale. Eastern Section American Association of Petroleum Geologists' Meeting, Lexington, Kentucky, September 2016
- Booker AE, Borton MA, Daly R, Welch S, Nicora CD, Sharma S, et. al., 2016. Sulfide Generation by Dominant Colonizing Halanaerobium Microorganisms in Hydraulically Fractured Shales. Eastern Section American Association of Petroleum Geologists' Meeting, Lexington, Kentucky, September 2016
- Crandall D, Moore J, Paronish T, Hakala A, Sharma S, and Lopano C 2016. Preliminary analyses of core from the Marcellus Shale Energy and Environment Laboratory. Eastern Section American Association of Petroleum Geologists' Meeting, Lexington, Kentucky, September 2016.
- Daly RA, Borton MA, Wilson T, Welch S., Cole D. R., Sharma S., et. al., 2016. Microbes in the Marcellus Shale: Distinguishing Between Injected and Indigenous Microorganisms, Eastern Section American Association of Petroleum Geologists' Meeting, Lexington, Kentucky, September 2016
- Evert M, Panescu J, Daly R, Welch S, Hespen J, Sharma S, Cole D, Darrah TH, Wilkins M, Wrighton K, Mouser PJ 2016. Temporal Changes in Fluid Biogeochemistry and Microbial Cell Abundance after Hydraulic Fracturing in Marcellus Shale. Eastern Section American Association of Petroleum Geologists' Meeting, Lexington, Kentucky, September 2016
- Hanson AJ, Trexler RV, Mouser PJ (2016). Analysis of Microbial Lipid Biomarkers as Evidence of Deep Shale Microbial Life. Eastern Section American Association of Petroleum Geology (AAPG), Lexington, KY, Sept 25-27, 2016.
- Lopano, C.L., Stuckman, M.Y., and J.A. Hakala (2016) Geochemical characteristics of drill cuttings from Marcellus Shale energy development. Annual Geological Society of America Meeting, Denver, CO, September 2016.
- Pansecu J, Evert M, Hespen J, Daly RA, Wrighton KC, Mouser PJ (2016). Arcobacter isolated from the produced fluids of a Marcellus shale well may play a currently unappreciated role in sulfur cycling. Eastern Section American Association of Petroleum Geology (AAPG), Lexington, KY, Sept 25-27, 2016.
- Sharma S, Carr T, Vagnetti R, Carney BJ, Hewitt J. 2016. Role of Marcellus Shale Energy and Environment Laboratory in Environmentally Prudent Development of Shale Gas. Annual Geological Society of America Meeting, Denver, CO, September 2016.
- Sharma S, Agrawal V, Akondi R, and Warrier A. 2016. Understanding biogeochemical controls on spatiotemporal variations in total organic carbon in cores from Marcellus Shale Energy and Environment Laboratory. Eastern Section American Association of Petroleum Geologists' Meeting, Lexington, Kentucky, September 2016
- Trexler RV, Akondi R, Pfiffner S, Daly RA, Wilkins MJ, Sharma S, Wrighton KC, and Mouser, PJ (2016). Phospholipid Fatty Acid Evidence of Recent Microbial Life in Pristine Marcellus Shale Cores. Eastern Section American Association of Petroleum Geology (AAPG), Lexington, KY, Sept 25-27, 2016.
- Wilson T and Sharma S 2016. Assessing biogeochemical interactions in the reservoir at Marcellus Shale Energy and Environment Laboratory Annual Geological Society of America Meeting, Denver, CO, September 2016.

3. <u>Data Dissemination</u>

- Sharma S. 2016, Environmentally Prudent Development of Unconventional Shale Gas: Role of Integrated Field Laboratories. Invited talk at International Shale Gas and Oil Workshop , India, 28-29 January, 2016
- Sharma S. 2016, Role of Geochemistry in Unconventional Resource Development. Invited talk at Appalachian Geological Society Meeting, Morgantown, April 5 2016.
- Hakala, J.A., Stuckman, M., Gardiner, J.G., Phan, T.T., Kutchko, B., Lopano, C. 2016 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.

Plan for Next Quarter

- Sharma lab will complete C, N isotope and TOC analysis of all sidewall and vertical core samples
- Sharma lab will continue working on extraction and analysis of biomarkers from selected sidewall and plugs from vertical core
- Sharma lab will continue working on refining the kerogen extraction method for higher recovery and get trained in new techniques like XPS and FTIR
- Mouser group will continue processing fluid samples from MSEEL wells. Circulate preliminary chemistry data to identify samples for future metagenomics/lipid analysis.
- Mouser/Wrighton/Wilkins labs will continue triaging enrichments to isolate key bacteria and archaea from flowback fluids.
- Cole lab will continue data reduction of trace metal analyses from fluid samples. Acquire large field SEM BSE imagery and QEMSCAN analyses, and neutron scattering data from thick sections of eight intact core samples.
- Darrah lab will continue working on analysis of argon, krypton, and xenon isotopes by high resolution, high precision noble gas mass spectrometry in the near future.

Plan for Next Quarter

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 concentrated on: 1) preparation of presentations for the SEG Dallas meeting (16-21 October); 2) preparation of a paper for submission to the Journal Interpretation by November 1.

Summary

Paper and presentations have been prepared and circulated for comment by co-authors.

The accelerated effort this past fiscal year has brought most of my work on the first four years of the MSEEL project to completion.

This quarter I will present a paper at the SEG annual international meeting in Dallas and submit another paper, just completed, to the Journal Interpretation for their special section on Appalachian unconventionals (see next two pages for information on the special section).

The paper is currently in review by co-authors and is titled:

Marcellus Shale model stimulation tests and microseismic response yield insights into mechanical properties and the reservoir DFN

Thomas H. Wilson[1], Malcolm Yates[3], Keith MacPhail[3], Ian Costello[2], Tim Carr[1], B. J. Carney[2], Jay Hewitt[2], Emily Jordon[2], Natalie Uschner[3], Mandy Thomas[3], Si Akin[3], Oluwaseun, Magbagbeola[3], Adrian Morales[3], Asbjoern Johansen[3], Leah Hogarth[3], Olatunbosun Anifowoshe[3], Kashif Naseem[3]

[1]West Virginia University, [2]Northeast Natural Energy, LLC, [3]Schlumberger

I will also serve as editor of this special section. Related information follows on the next two pages. Note that several associate editors will share review solicitation responsibilities. The paper I have prepared will be submitted to one of the associate editors for independent review. Considerable effort will be expended on this activity in FY2017.

See http://library.seg.org/journal/inteio (& next page couple pages) for additional information

http://library.seg.org/journal/inteio

Interpretation

Image Gather

Current Issue: August 2016

The August 2016 issue of *Interpretation* features special sections on near-surface imaging and interpretation, ambient noise, seismic facies classification and modeling, building complex and realistic geological models from sparse data, detection of hydrocarbons, and the South China Sea deep-water.

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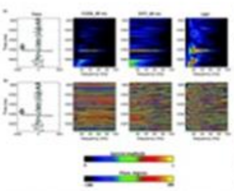
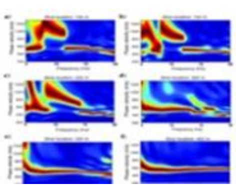
Featured Articles



Phase decomposition

John Castagna, Arnold Oyem, Oleg Portniaguine, and Understanding Aikulola

Any seismic trace can be decomposed into a 2D function of amplitude versus time and phase. We call this process phase decomposition, and the amplitude variation with time for a specific seismic phase is referred to as a phase component. For seismically thin layers, phase components are particularly useful in simplifying seismic interpretation. Subtle lateral impedance variations occurring within thin layers can be greatly amplified in their seismic expression when specific phase components are isolated. For example, the phase component corresponding to the phase of the seismic wavelet could indicate isolated interfaces or any other time symmetrical variation of reflection coefficients. Assuming a zero-phase wavelet, flat spots and unresolved water contacts may show directly on the zero-phase component. Similarly, thin beds and impedance ramps will show up on components that are 90° out of phase with the wavelet. (Continue reading)



Skeletonized inversion of surface wave: Active source versus controlled noise comparison

Jing Li and Sherif Hanafyn

We have developed a skeletonized inversion method that inverts the S-wave velocity distribution from surface-wave dispersion curves. Instead of attempting to fit every wiggle in the surface waves with predicted data, it only inverts

Time Slices

Interpretation

Preview the May 2016 issue with Kurt Marfurt, editor

Upcoming Special Section Deadlines

Geocellular models
Submission deadline: 1 November 2016
Publication of issue: August 2017
Special section editors: Sharma Dronamraju, Michael Pyrcz, Michael King, Kurt J. Marfurt

Characterization of hydrocarbon and geothermal resource potential and carbon sequestration opportunities of the Pannonian Basin
Submission deadline: 1 November 2016
Publication of issue: August 2017
Special section editors: Balazs Nemeth, Gábor Bada, Michal Kovac, Csaba Krezsek, Dejan Radivojevic, Bruno Tomljenović, Gábor Tari

Skeletonized/sparse/multiscale geophysical inversion for the interpreter
Submission deadline: 1 November 2016
Publication of issue: August 2017
Special section editors: Gaurav Dutta, Amr Ibrahim, Tristan van Leeuwen, Alexander Klokov, Yunsong Huang

Gas hydrates in South China Sea
Submission deadline: 1 November 2016
Publication of issue: August 2017
Special section editors: Guangfa Zhong, Hongliu Zeng, Shengxiong Yang, Jinqiang Liang, Xuewei Liu, Xin Su, Xiujuan Wang, Changling Liu, Ming Su

Least-squares migration
Submission deadline: 1 November 2016
Publication of issue: August 2017
Special section editors: Aimee Mao, Gerard Schuster, Kurt Marfurt, Yonghe Sun, Chong Zeng, Bin Wang, Bertrand Duquet,Paul Singer, Wei Dai, Gaurav Dutta, Jerry Young, Yu Zhang, Michael Kiehn

Appalachian shale gas field exploration and development: Lessons learned
Submission deadline: 1 November 2016
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, Jinming Zhu

Fault damage zones
Submission deadline: 5 December 2016

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:

During this quarterly period, numerical modeling simulations were conducted to simulate stage 1, stage 2, and stage 3 of well MIP 3H by using measured injection data. Stimulation input parameters were selected from available measured data for stage 3. Figure 4.b.1 and Figure 4.b.2 show a comparison of the slurry volumes and the slurry rates used in the model and the available measured data. Figure 4.b.3 shows the proppant concentrations used in the model and those which were measured. In the model, the termination time for proppant injection needed to be adjusted in order to match the measured slurry volume and proppant mass. An idealized step-wise schedule for the proppant injection was used in the model, as shown in this figure. Figure 4.b.4 shows the idealized proppant injection rate, while Figure 4.b.5 shows the proppant mass used in the model in comparison with the measured injection data. Figure 4.b.6 shows a comparison of computed and measured surface pressures. These computed values compare well with the measured surface pressure data. Figure 4.b.7 shows the computed fracture geometry from the model. Table 4.b.1 shows a comparison of computed fracture dimensions for stages 1, 2, and 3. No microseismic data was available for stages 1-3 of MIP 3H.

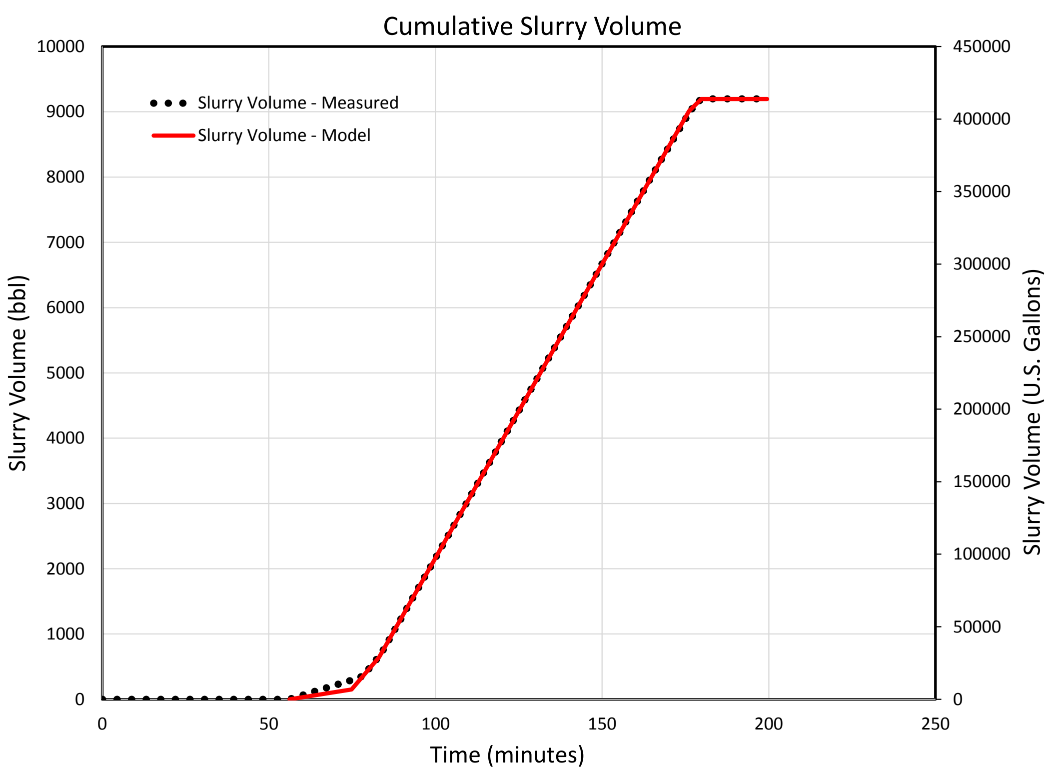


Figure 4.b.1: Slurry Volume vs Time - Stage 3 - MIP 3H

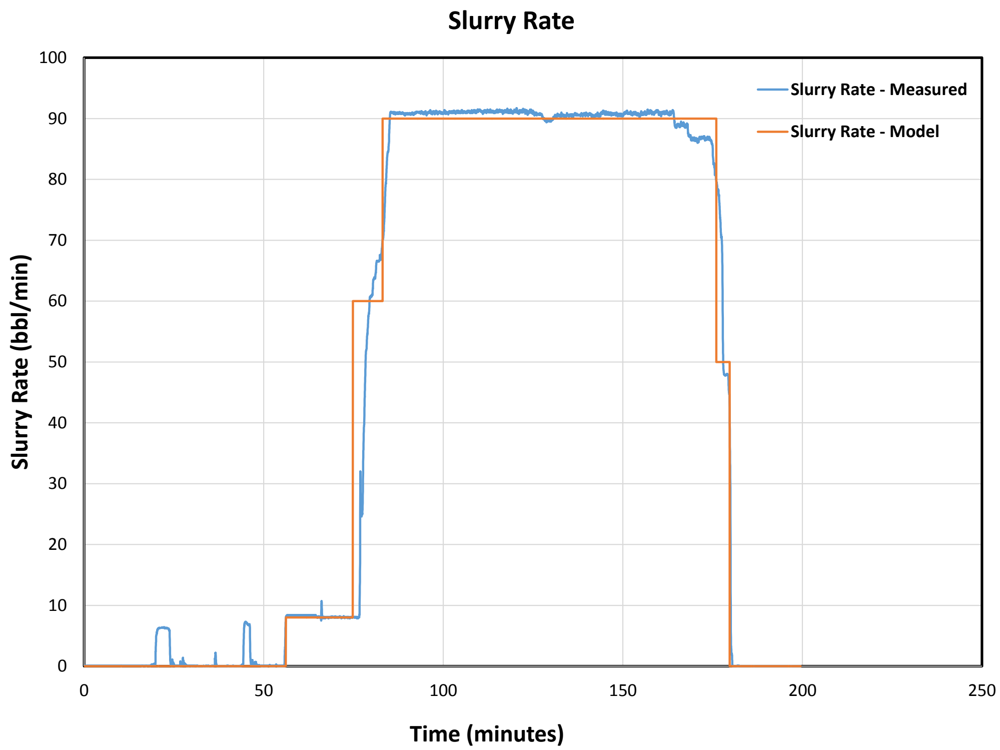


Figure 4.b.2: Slurry Rate vs Time for Stage 3 - MIP 3H

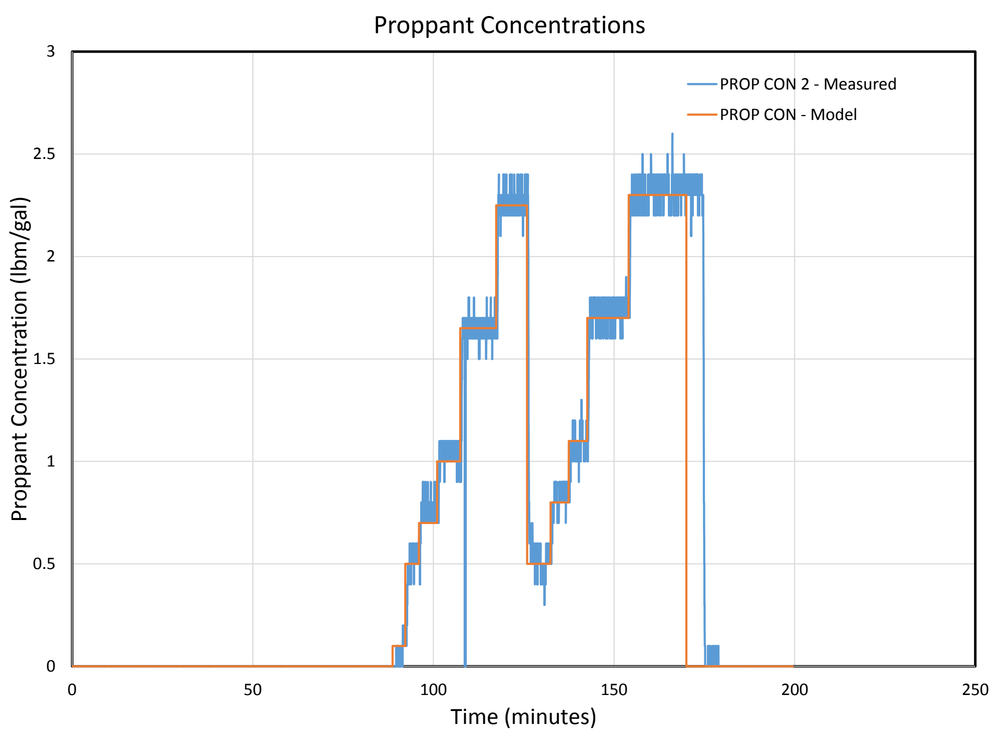


Figure 4.b.3: Proppant Concentration vs Time for Stage 3 - MIP 3H

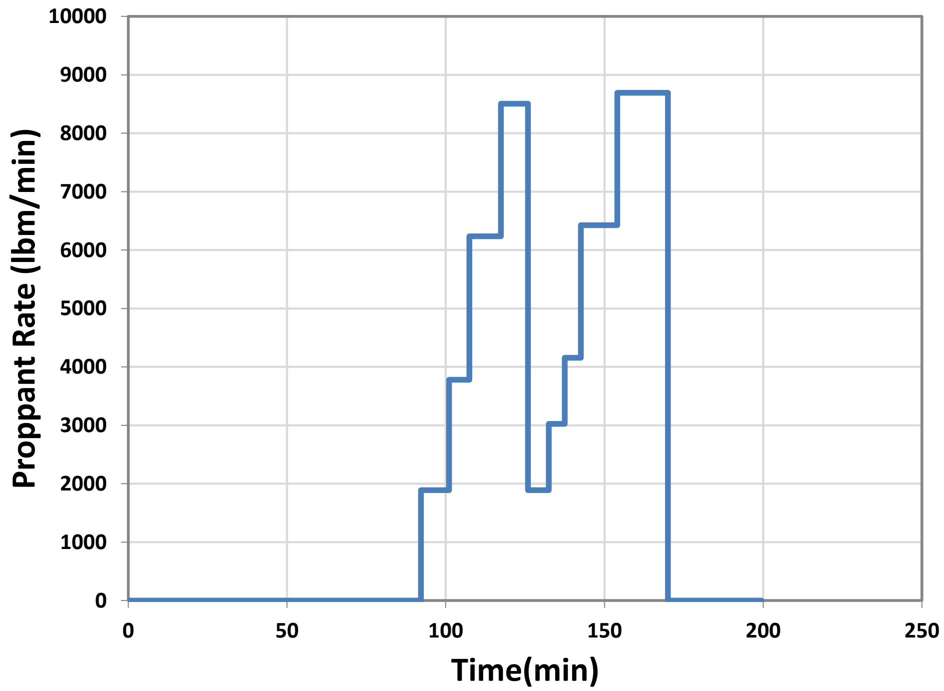


Figure 4.b.4: Idealized Proppant Rate vs Time for Stage 3 - MIP 3H

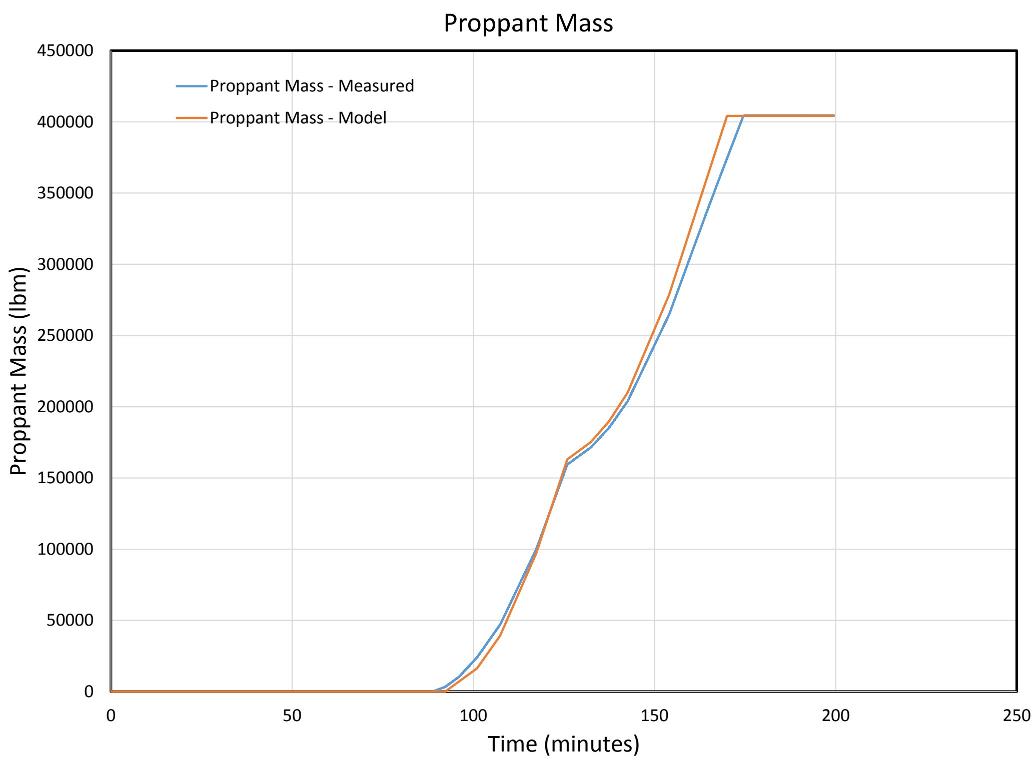


Figure 4.b.5: Proppant Mass vs Time for Stage 3 – MIP 3H

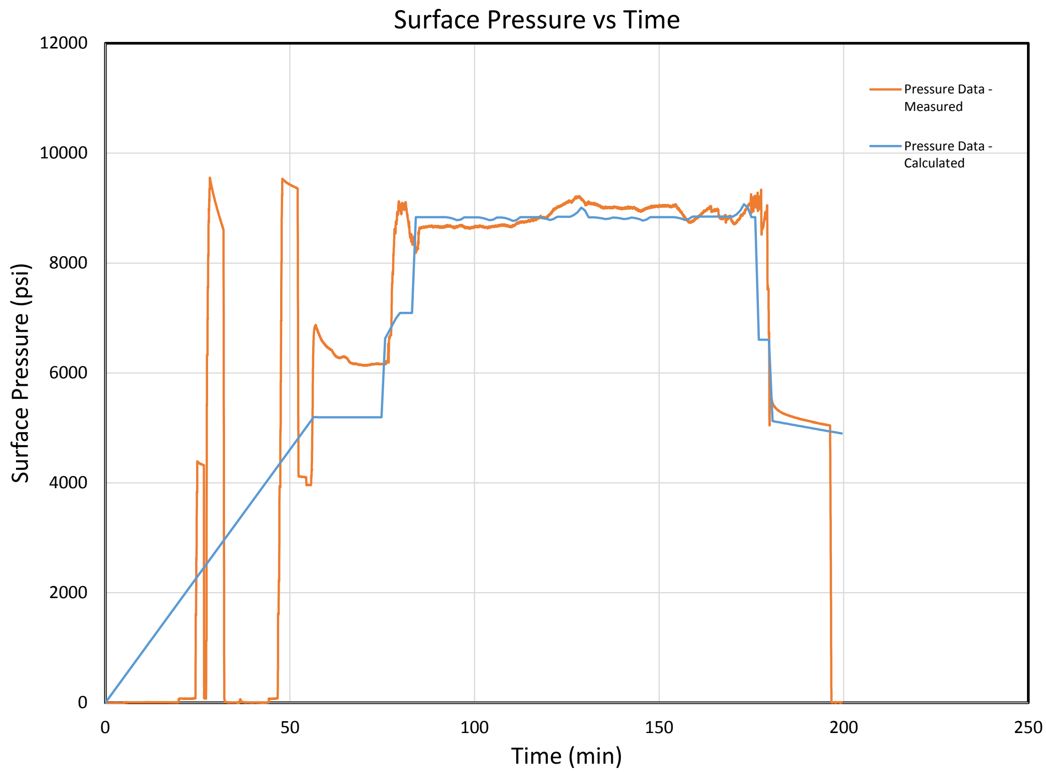


Figure 4.b.6: Surface Pressure vs Time for Stage 3 - MIP 3H

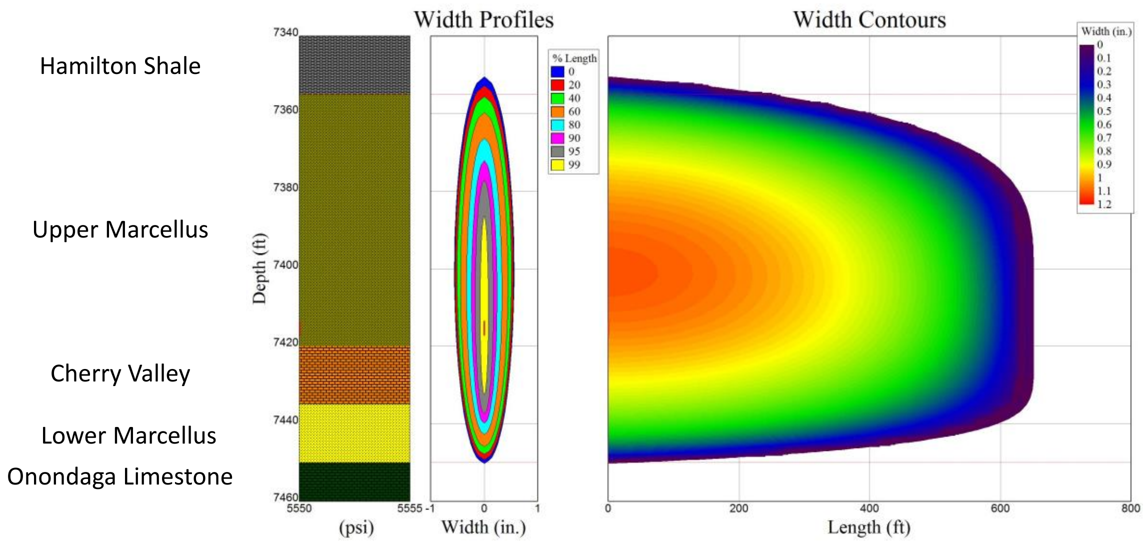


Figure 4.b.7: Fracture Geometry for Stage 3 - MIP 3H

Table 4.b.1: Comparison of Stages 1 - 3 Fracture Dimensions

MIP 3-H Stage #	Maximum Fracture Length (ft)	Maximum Fracture Height (ft)	Average Fracture Width (in)
1	749.5	100.7	0.7041
2	657	100.4	0.7050
3	651.4	100.9	0.7071

Products

Plan for Next Quarter

Task 4a – Geophysical:

Much of the following depends on available funding and student assistance.

1) The following paper will be submitted for review for inclusion in in the 2016 SEG meeting volume of expanded abstracts:

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, in prep.: **Microseismic and model stimulation of natural fracture networks in the Marcellus Shale, West Virginia,** 5p.

2) Additional experiments will be designed and incorporated into the zone set property grid as part of continued efforts to model fracture stimulation of reservoir intervals and better understand microseismic activity associated with HFT.
3) Fiber optic observations will be incorporated in the model studies noted in 1 and 2 above.
4) Direct geophysics student (if student and funds available) in the analysis of b-values stage-by-stage following the format of efforts undertaken by Zhu, Y., T. Wilson, P. Sullivan, 2016 (submitted) - Variations of microseismic b-values and their relationship to 3D seismic structure in the Marcellus Shale: Southwestern Pennsylvania: submitted for presentation at the 86th Annual International Meeting, SEG in Dallas, TX., 5p.

5) Direct geophysics student (if funding and student available) to assist with additional stage-by-stage simulations.

6) Use calculated seismic moment for microseismic events observed along the 3H and 5H wells to develop stage-by-stage 3D function to distribute intensity of stimulated fractures following the efforts of Wilson and Sullivan (submitted) - Microseismic energy density and event trend constraints on model DFN development for hydraulically fractured reservoirs: Marcellus shale, southwestern Pennsylvania, U. S. A.: submitted for presentation at the 86th Annual International Meeting, SEG in Dallas, TX, 5p.

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.

Products

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. Due to a shortage of funds for surface environmental monitoring, the Monongahela River surface water network was last sampled during the previous quarter on May 25, 2016.

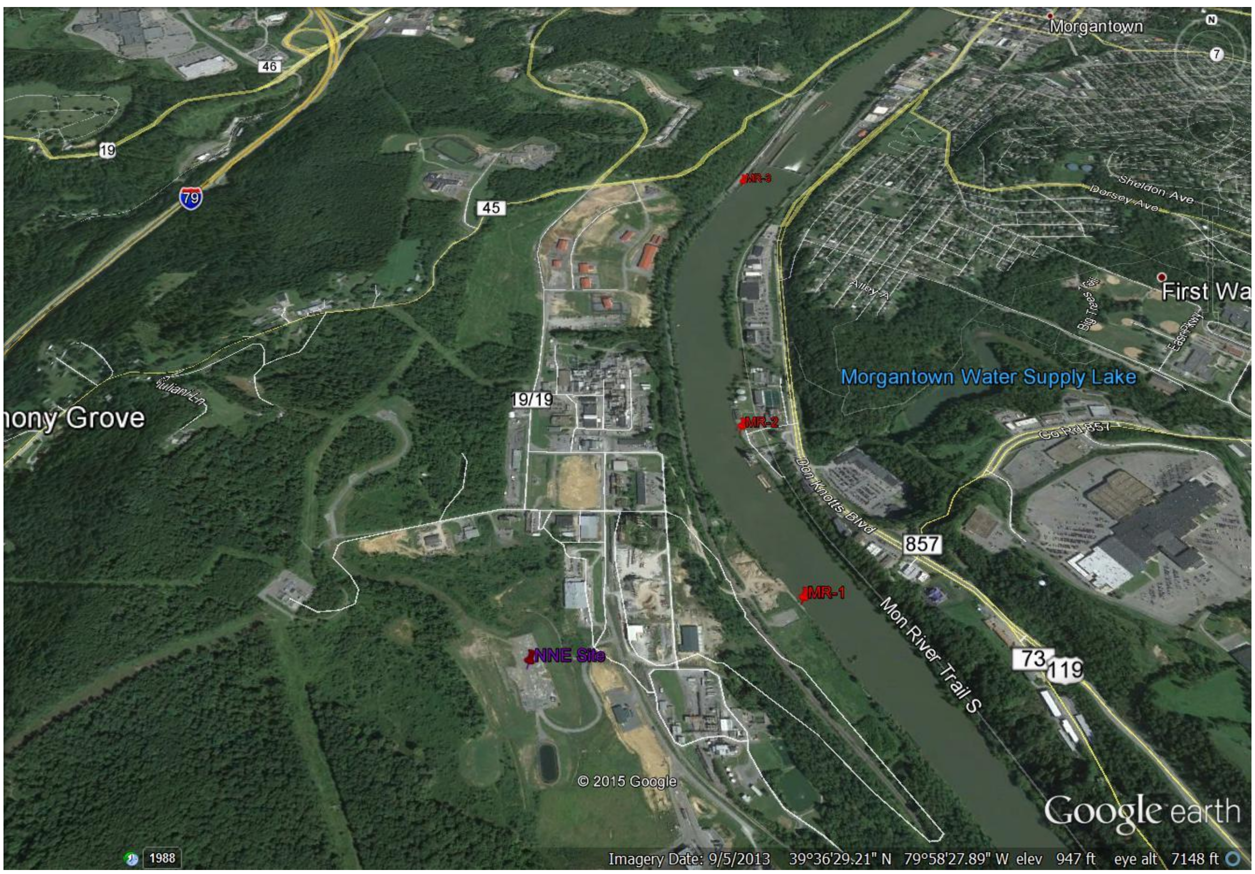


Figure 5.a.1: MSEEL surface water sampling locations

The sampling schedule for surface water and gas well development water/waste streams is detailed in Table 5.a.1.

Table 5.a.1: MSEEL sampling schedule

		Freshwater		Aqueous/Solids: drilling/completion/production									
		Mon River	ground water	HF fluid makeup	HF fluids	flowback/ produced	drilling fluids	drilling muds*	drilling cuttings	total aqueous	total solids	Sampling Dates	Notes
	Sampling Stations	3	0	2	2	2	2	2	2				
Subtask 1.4.1 Test surface sampling plan													
	ID and review existing GW/SW data	**Completed-flow path identification, otherwise no other value**											
	Finalize project surface sampling plan	**Completed-see below**											
Subtask 1.4.3 Develop water qualiity baseline													
	Groundwater baseline prior to drilling	**Access denied-groundwater will not be sampled**											
	Surface water baseline prior to drilling	3								3		6/12/2015	
		4								4		6/25/2015	Field duplicate taken
Subtask 2.1.1 Environmental monitoring-Drilling													
	Vertical drilling	3								3		7/8/2015	surface water only
									1		1		
									1		1		
	Horizontal drilling	3					1	1	1	5	2		liquids & solids fraction of muds
							1	1	1	2	2		liquids & solids fraction of muds
Subtask 2.2.1 Environmental monitoring-Completion													
	Hydraulic fracturing	3		2	2					7			
	flowback Initial	3				2				5			
	Flowback 1 week	3				2				5			
	Flowback 2 weeks	3				2				5			
	Flowback 4 weeks	3				2				5			
	Flowback 8 weeks	3				2				5			
Subtask 2.3.1 Environmental monitoring-Production													
	Production 3 stations x 3/yr x 4 yrs	36				24				60			

Surface water samples are being analyzed for the following parameters, see Table 5.a.2.

Table 5.a.2: Analytical parameters

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

Results and Discussion

Parameters analyzed for FPW are listed in Table 5.1. Makeup water was pumped from the Monongahela River and mixed with the hydraulic fracturing fluids. FPW samples were taken at the upstream end of each well's separator.

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
Flowback @ 29 weeks - 3H					1			1		6/29/2016 and 7/1/2016	one sample 3H
Flowback @ 29 weeks - 5H					1			1		6/29/2016	one sample 5H
Surface water sampling								0		scheduled for 7/6/2016	surface water sampling after 29 weeks production, plus 1 dup
Flowback @ 36 weeks - 3H					1			1		8/17/2016	one sample 3H
Flowback @ 36 weeks - 5H					2			2		8/17/2016	one sample 5H + duplicate
Surface water sampling								0		scheduled for 8/17/2016	surface water sampling after 35 weeks production, plus 1 dup
Flowback @ 41 weeks - 3H					1			1		9/21/2016	one sample 3H
Flowback @ 41 weeks - 5H					1			1		9/21/2016	one sample 5H
Surface water sampling								0		scheduled for 9/28/2016	surface water sampling after 41 weeks production

Products

Table 5.a.4 Third Quarter Products, Publications, Outreach Activities

Date	Location	Event	Presentation
7/15/16	Morgantown WV	Issue press release	MSEEL Water and Waste Findings
7/20/16	Cannonsburg PA	RPSEA Onshore Workshop	MSEEL Water and Waste Findings
7/26/16	Morgantown WV	WAJR Radio 'Inside Shale'	MSEEL Water and Waste Findings
8/22/16	Charleston WV	Joint Committee on Energy WV Legislature	MSEEL Water and Waste Findings
8/25/16	Bridgeport WV	Meeting with Antero	MSEEL Water and Waste Findings
8/29/16	Morgantown WV	Meeting with Senators Capito and Manchin staff	MSEEL Water and Waste Findings
8/31/16	Morgantown WV	Meet with Maryland Legislature and MDE staff	MSEEL Water and Waste Findings

9/26-27/16	Lexington KY	Eastern Sec. AAPG annual meeting	MSEEL Water and Waste Findings
9/27/16	Lexington KY	Meet with UK desalination researchers	MSEEL Water and Waste Findings

Products

None this quarter.

Plan for Next Quarter

Activities moving forward will continue to include sampling of flowback/produced water (FPW) from 3H and 5H only.

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. Phase 1 of the initial methane emissions audits was completed, due to concurrent use of sampling systems the direct quantification portion of the audit will occur in the following quarter.

Results and Discussion

Researchers collaborated with Dr. Natalia Pekney of NETL to use a FLIR GF-320 oil and gas-imaging camera to complete a leak and loss audit of the MSEEL site. Additional scanning of components was completed with hand-held methane detectors.

The following items were determined to be leaking natural gas or to have methane emissions as a part of normal operation (losses).

- Leaks
    - Fittings within glycol heater units – 3 total leaks found
    - Uncapped vent tube – field gas supply to onsite thermoelectric power generator
    - Random well head leaks, all leaks were below the threshold of 500 parts per million (ppm)
- Losses
    - Open tank thief hatch/tank vent
    - Glycol boiler exhaust stacks
    - Onsite natural gas powered thermoelectric power generator exhaust

Figure 5.b.1 shows an example of a leaking fitting within the boiler unit. For all detectable leaks and small losses, the FFS system described in the previous quarterly report will be employed to quantify the mass rate of methane emissions. However, researchers have developed alternative methods to quantify the mass rate of methane emissions for small wellhead leaks and for the exhausts of the glycol boilers.

Since the wellhead leaks were all below a handheld detector threshold of 500 ppm, researchers have obtained a tent structure that will be installed over each wellhead. The FFS system will be ducted to the top of the tent and operated for periods of up to 1 hour per wellhead. This method will determine the sum of all small leaks for presentation as a net emission rate or flux for each wellhead (both active and inactive wells).

To measure the mass rate of methane emissions from the glycol boiler exhausts, the sample port cap on the exhaust stack will be removed. A stainless steel pitot tube has been made which fits within the sampling ports inner diameter. This pitot tube has been calibrated against a NIST traceable laminar flow element at CAFEE laboratories. The pitot-tube will be connected to a Heise handheld pressure-monitoring device to measure the average differential and stagnant pressures within the exhaust flow to determine the net exhaust volume flow rate. A long and cooled sampling tube will be connected to the UGGA to measure the CO_2 and CH_4 concentration within the exhaust stream. The concentration and volumetric flow rates will be used to calculate a mass based emissions rate of methane emissions from these units.

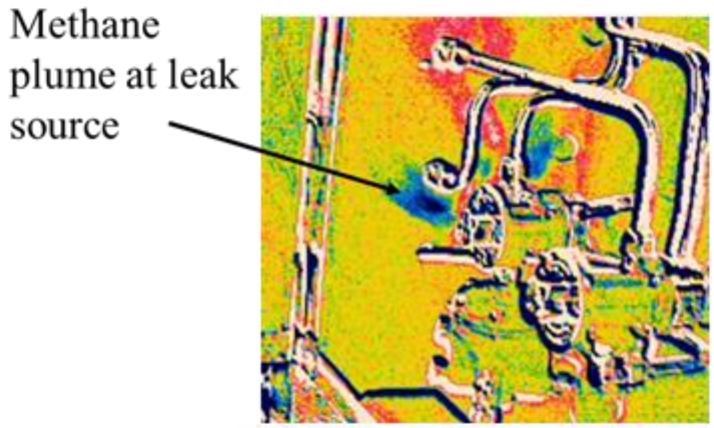


Figure 5.b.1: Identified methane leak at fitting.

Additional Proposed work at MSEEL

CAFEE are currently in discussions with Dr. Gil Bohrer of the Ohio State University and NNE to conduct additional research on the effects of hydraulic well stimulation on methane fluxes at, on, or near, fracture well sites. This project would include the installation of two eddy-covariance flux towers near the MSEEL site in order to assess anthropogenic and biogenic methane fluxes. Secondly, CAFEE researchers have collaborated with LI-COR Biosciences in developing a proposal just submitted to the National Science Foundation's Environmental Engineering Program. This project would build upon current site audits and also utilize eddy-covariance flux techniques. The goal of this program is to assess the validity of employing these techniques to highly heterogeneous emissions sources such as wells sites.

Products

The data summary that was presented in the previous quarter has been integrated with data under DE-FE0013689. The initial publication has been submitted, peer-reviewed and published in the Journal of Air and Waste Management Association. The citation follows.

- 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.

Plan for Next Quarter

- Complete quantification phase of the site wide leak and loss audit
- Continue to highlight MSEEL with new collaborators

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 as outlined in the original proposal provides a general overview of the regional and state economic conditions at the inception of the experimental science well. We do not expect to be able to attribute changes to the health and welfare of the local or state economy directly to the activities related to a single well site, but the report describs the economic context for the experimental well activities. The report will be published in the Regional Research Institute (RRI) Resource Document Series (http://rri.wvu.edu/resource-documents/).

STATUS: Draft under final review. Abstract reproduced below.

Socioeconomic Conditions at Marcellus Shale Energy and Environmental Laboratory Inception

Abstract. The Marcellus Shale Energy and Environmental Laboratory, or MSEEL, is the nation's first integrated research initiative on shale gas drilling. An experimental hydraulic fracturing gas well is the centerpiece of the MSEEL project, "which West Virginia University launched in fall 2014 in partnership with Northeast Natural Energy, the National Energy Technology Laboratory of the U.S. Department of Energy and Ohio State University. The five-year, $11 million project is the first-ever long-term, comprehensive field study of shale gas resources in which scientists will study the process from beginning-to-end." Because one dimension of the MSEEL analysis is the economic impacts and implications of well drilling activity, this report has been prepared to provide a statistical overview and description of the local and regional economies leading up to the the initiation of the MSEEL project, and to set the stage generally for subsequent socioeconomic analyses. The report includes various graphs and tables that describe the local economy during the 2001 to 2014 period, providing a context within which to view the role of gas extraction activities in the economy.

[1] "Drilling to begin at experimental science well to be monitored by WVU, OSU researchers," *Posted: Jun 26, 2015 10:55 AM EDT, Updated: Jul 26, 2015 10:55 AM EDT*State Journal. http://www.statejournal.com/story/29416633/drilling-to-begin-at-experimental-science-well-to-be-monitored-by-wvu-osu-researchers

Drilling Expenditures Data

Northeast Natural Energy has provided us with their detailed operating expenditures for the experimental well. We have used these data to compile a generalized cost tool for estimating well-drilling costs by industry for Marcellus drilling operations. These data can be used to populate a production cost function that can be embedded in regional economic systems models (e.g., economic input-output models). By varying well-specific parameters, the resulting production functions will be valuable contributions to the impacts assessment community for use in estimating economic benefits of drilling operations. The cost function is be scalable and sensitive to the extent possible to a number of variables such as well pad size and accessibility, number of wells, and depth of wells. The spreadsheet based production cost function estimation tool will be archived at the Regional Research Institute and implemented by RRI staff to protect NNE's proprietary data. The procedure is documented in a report that will be published in the Regional Research Institute Resource Document Series (http://rri.wvu.edu/resource-documents/).

STATUS: Draft under final review. Abstract reproduced below.

A Marcellus Well Drilling Cost Estimation Tool

Abstract. This report summarizes the transformation of financial data on the MSEEL shale gas well provided by Northeast Natural Energy (NNE) management into a data based tool that can be used to estimate a generalized non-linear production function for subsequently embedding within an economic systems model. The processing required the identification and assignment of supplying industry classification and a determination for each input cost regarding the extent to which it varies by well or well characteristics. The initial data and transformation process are described along with issues confronted in data preparation and how they have been addressed.

Impact estimates for the MSEEL well provided by NNE formed the basis for the development of a tool for estimating Marcellus shale gas well-drilling costs. The data provided were assigned to 4-digit NAICS industry classifications for each input expenditure, and were then embedded within a spreadsheet model that estimates industry-specific well production costs that vary with well-specific parameters. These production costs can form the basis for parameterizing an economic input-output model to estimate the wage and employment impacts of drilling activities.

By distinguishing between variable and fixed costs, we enable the development of a non-linear production function where many input expenditures are not proportional to total cost. The resulting non-linear production function is particularly useful for adapting to other well drilling scenarios and assessing impacts other Marcellus wells and well-sites. The production cost functions that are generated are analogous to various different production recipes that are tied directly to varying well configurations and characteristics, The production function model has been generalized to the extent that is supported by the data and the expertise of MSEEL participants.

The format of the resulting production cost report is shown below.

Table 6.1 Production cost report

Item	Phase	Total	NAICS	Cost Type	Cost Driver
Footage Drilling - Vertical Rig	Top Hole	######	213111	V	Vertical Rig Drilling Footage
Gyro	Top Hole	######	213111	V	Tophole Days
Drilling Consulting	Top Hole	######	213111	V	Tophole Days
Contract Drilling - Horizontal Rig	Horizontal	######	213111	V	Horizontal Days
Directional Drilling Services	Horizontal	######	213111	V	Horizontal Days
Drilling Mud & Chemicals	Horizontal	######	213111	V	Horizontal Depth
Rig Mobilization & Rigup Horizontal Rig	Horizontal	######	213111	V	Distance Rig Travels
Drill Bits	Science	######	213111	F	None
Contract Drilling - Horizontal Rig	Science	######	213111	V	Science Days
Directional Drilling Services	Science	######	213111	V	Science Days
COPUS/Misc/Reporting	Science	######	213111	V	Science Days
Mud Logging & Geosteering	Science	######	213111	V	Science Days
Drilling Consulting	Science	######	213111	V	Science Days + 2
Water	Top Hole	######	221300	V	Tophole Depth
Water	Horizontal	######	221300	V	Horizontal Depth
Fuel	Top Hole	######	324110	V	Tophole Days
Fuel	Horizontal	######	324110	V	Horizontal Days
Fuel / Diesel	Stimulation	######	324110	V	Stimulation Days
Production Casing	Horizontal	######	331200	V	MD
Flowline & Pipeline	Production Equi	######	331200	V	Pad size
Valves, Fittings& Couplings	Production Equi	######	331200	F	None
Tanks	Production Equi	######	332420	F	None
Casing Head	Top Hole	######	333130	F	None
Intermediate	Top Hole	######	333130	V	Intermediate Depth
Surface Casing	Top Hole	######	333130	V	Surface Casing Depth
Misc Consumables	Top Hole	######	333130	F	None
Float & Centralizers Equipment Sur	Top Hole	######	333130	F	None
Float & Centralizers Equipment Int	Top Hole	######	333130	F	None
Casing Head	Horizontal	######	333130	F	None
Casing BHA	Horizontal	######	333130	F	None
Threading	Horizontal	######	333130	f	None
Misc Consumables	Stimulation	######	333130	F	None
BOP/Pump/Swivel	Drillout	######	333130	F	None
Misc Consumables	Drillout	######	333130	F	None
Misc Service & Consumables	Flowback	######	333130	F	None
Casing - Tubing	Conpletions	######	333130	V	Tophole Depth + 1500
Drillout Tubing	Conpletions	$ -	333130	V	Total Depth
Tubing Head	Conpletions	######	333130	f	None
Tubing Accessories	Conpletions	######	333130	f	None
Production Tree	Conpletions	######	333130	F	None
Metering & Measurement Equipment	Production Equi	######	333130	f	None
GPU/Separator	Production Equi	######	333130	F	None
Tank Containment	Production Equi	######	333130	F	None

Public Awareness, Risk Perception, and Policy

Public attitudes toward fracking are an important dimension of the development of a social contract in the transition toward a natural gas driven economy. To assess public perception and attitudes toward acceptance of this technology, we used a quantitative approach that allows for the estimation of subnational opinion from national-scale data.

Status: Manuscript in preparation for journal submission. Abstract reproduced below.

Subnational Support for Hydraulic Fracturing

Abstract. Energy and environmental policies enacted at the state and local levels are influenced by current public opinion. Public awareness, risk perception, and policy support all affect the decision making calculus of elected officials. Yet despite the proliferation of public opinion polls, state-level and subnational surveys remain quite rare. To comprehensively assess the feasibility of state and local policies toward energy and the environment, it is necessary to have

accurate estimates of subnational public opinion on energy and environmental attitudes, their perceptions of risk, and support for particular policies. To address this need, this study uses national-scale data and a methodology known as multilevel regression and poststratification (MRP) to estimate subnational opinion. I find that estimates produced with MRP are comparable to state-specific surveys on issues like hydraulic fracturing, support for pipelines, and attitudes toward emissions limits. On an issue like hydraulic fracturing, I find that in both state-specific surveys and MRP estimates, political partisanship and race are the strongest predictors of support for the practice. In states with few respondents in national polls, especially those from energy-rich states like West Virginia and Wyoming, MRP provides a more efficient and cost-friendly manner of estimating subnational opinion.

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, which is estimated to be a response rate of roughly 50% of well-site workers. Unfortunately, many of the questionnaires were not filled out in their entirety, and it is unclear whether responses to specific questions will be useful in any meaningful way (e.g., some respondents chose to rephrase questions and or provided responses that cannot be coded). The overall value of the survey is limited because of the non-response rate and the incomplete and inaccurate questionnaire participation.

Status: The survey responses have been coded and compiled and we are continuing to try to identify ways to use the expenditures summaries to improve the accuracy of drilling impacts assessments generally, or as part of the basis for an economic impacts assessment for the science well.

Cost Status

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)
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: 09/30/2015

Baseline Reporting Quarter	Q5 (12/31/15)	Q6 (3/30/16)	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

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