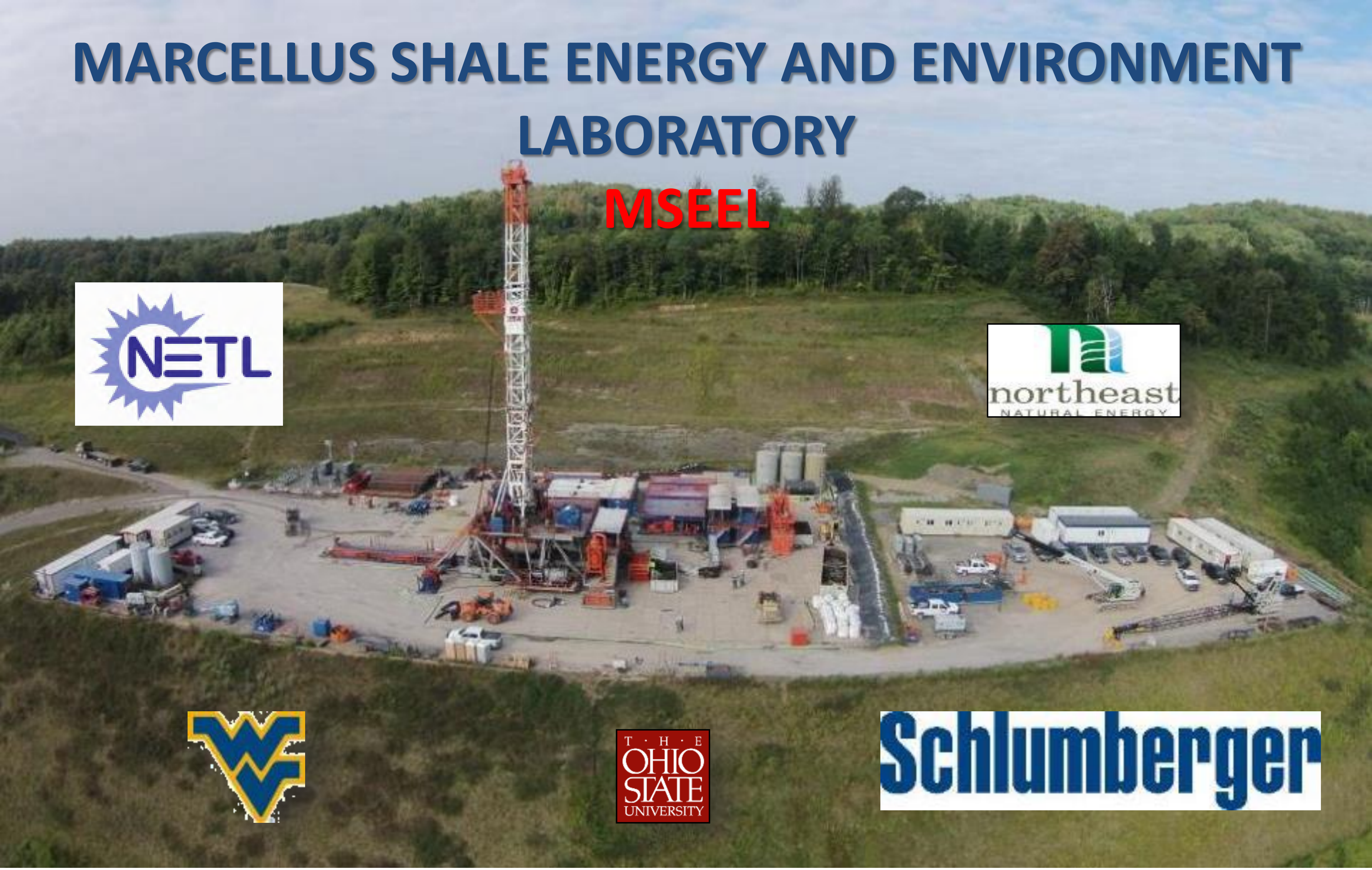
MARCELLUS SHALE ENERGY AND ENVIRONMENT LABORATORY

MSEEL



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northeast

NATURAL ENERGY

MSEEL Campaign

Dual-Fuel Diesel-Natural Gas Engine Activity, Fuel Flow, and Emissions

DE – FE0013689 and
DE – FE 0024297

Data Collected

- Emissions (Exhaust and Crankcase)
  - Pre-Catalyst Diesel Only
  - Pre-Catalyst Dual-Fuel
  - Post-Catalyst Diesel Only
  - Post-Catalyst Dual-Fuel
- Fuel Consumption
  - Diesel Flow IN and OUT
  - Natural Gas Flow IN
- Engine Activity
  - J1939 Broadcast Parameters
    - Engine Speed (RPM)
    - Engine Load (%)

Engines Tested

Caterpillar 3512C - 1101 kW

Caterpillar 3512B HD - 1678 kW

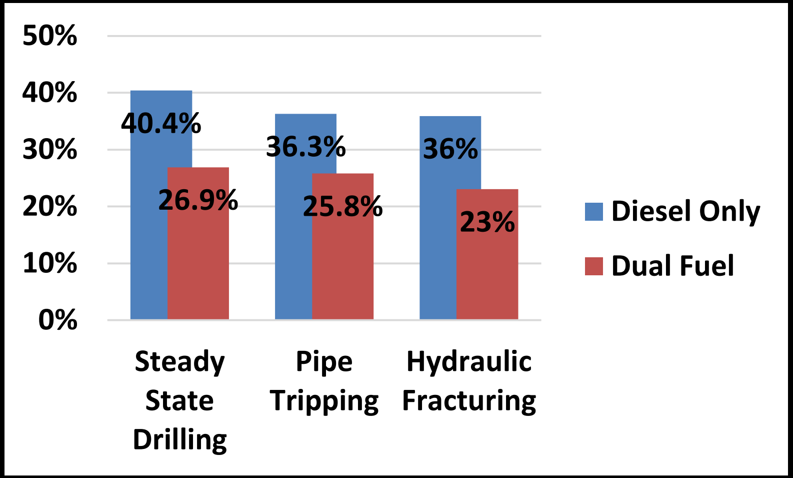
Both Engines Outfitted with Caterpillar Dynamic Gas Blending (DGB) Dual-Fuel Kit

Fuel Consumption & Conversion

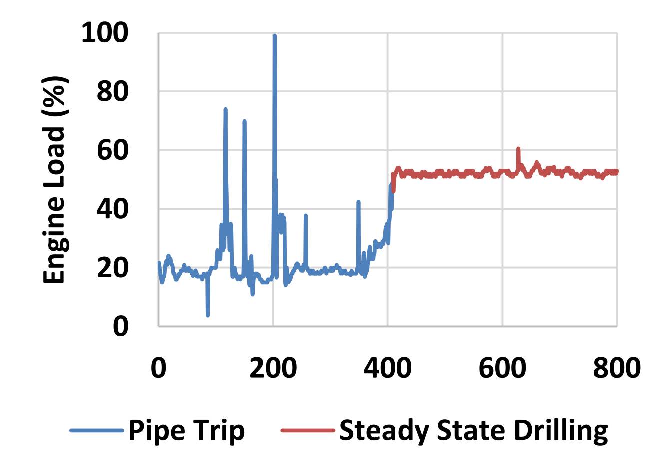
Fueling and Substitution

Fueling		Diesel	Dual
Steady State Drilling			
Percent Load	%	55.2	57.9
Diesel Flow	gal/hr	39.9	15.3
CNG Flow	DGE/hr	0.0	41.6
Substitution Ratio	%	**62%**	
Pipe Tripping			
Percent Load	%	24.4	23.2
Diesel Flow	gal/hr	19.7	15.0
CNG Flow	DGE/hr	0.0	9.8
Substitution Ratio	%	**24%**	
Hydraulic Fracturing			
Percent Load	%	72.2	74.8
Diesel Flow	gal/hr	89.6	45.2
CNG Flow	DGE/hr	0	86.6
Substitution Ratio	%	**50%**	

Fuel Energy Efficiency



Drilling Engine Activity >



KRAL Fuel Flow Meter on Diesel Return Line

Exhaust & Crankcase Emissions

Brake Specific

High Load Drilling

Steady State		Diesel	Dual
		Post-Cat	Post-Cat
CO_2	g/kw-hr	663.53	762.64
CO		0.02	0.14
NO_x		3.65	3.02
THC		0.01	26.02
CH_4		0.01	25.64

Hydraulic Fracturing

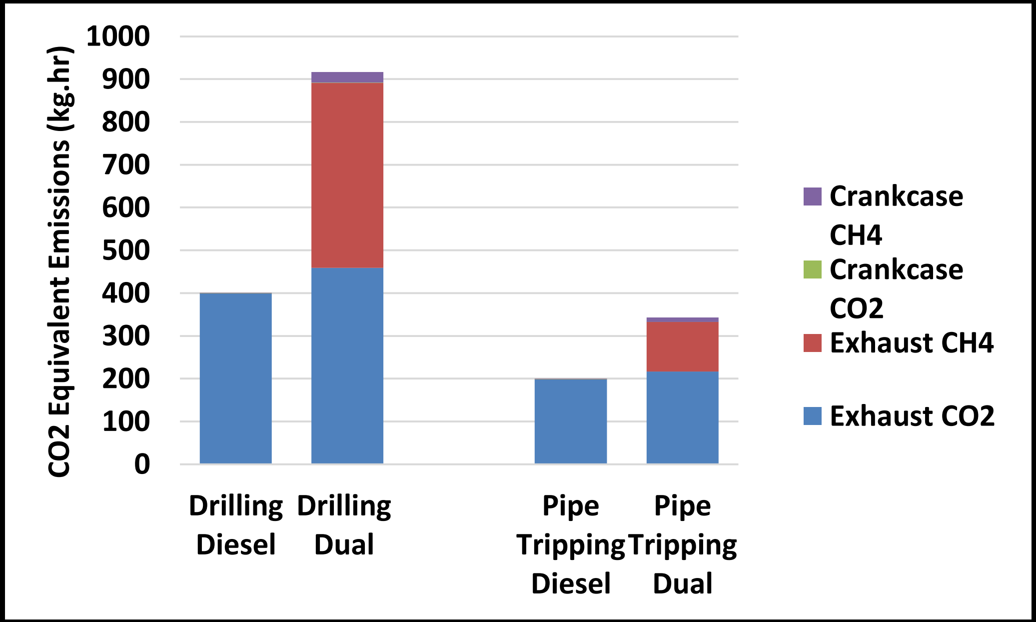
Steady State		Diesel	Dual
		Post-Cat	Post-Cat
CO_2	g/kw-hr	754.97	891.12
CO		0.04	0.57
NO_x		3.04	3.17
THC		0.01	43.46
CH_4		0.01	42.61

Methane Slip

- 16% during Steady State Drilling
- 20% during Pipe Tripping
- 23% during Hydraulic Fracturing

- 1-2% from Crankcase

Drilling GHG Emissions



Summary

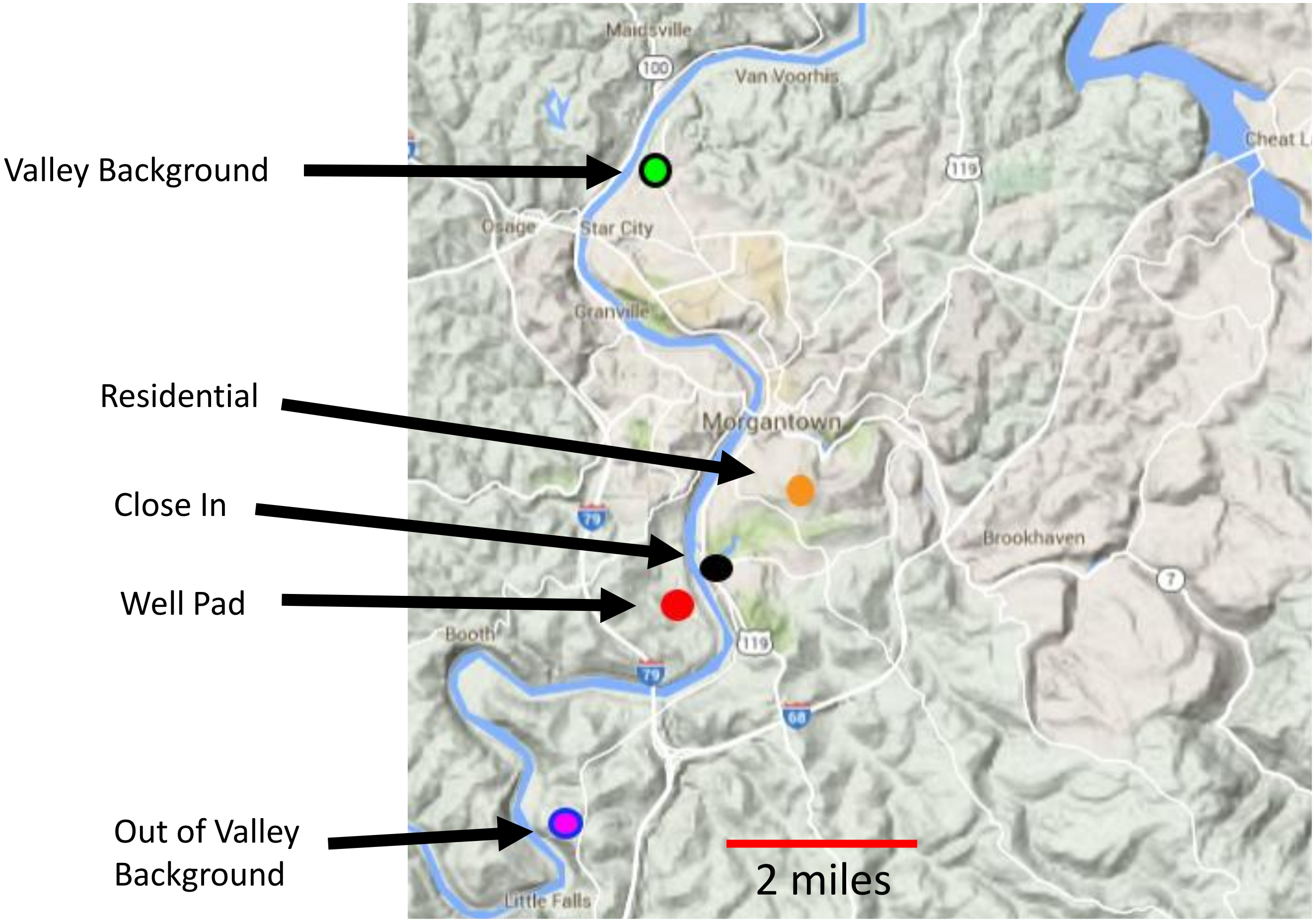
- **Dual Fuel Operation**
  - Between 6-16 % increase in CO_2 Emissions
  - Up to 3000 times higher CH_4 Emissions
  - 20-65% Substitution of Diesel Fuel
  - 15-25% Unburned Methane in Exhaust
  - Crankcase Methane 1-2% of Exhaust Rates
  - 2.5-3.0 times Higher GHG Emissions
    - CO_2 Equivalent
    - Based on Methane GWP of 25

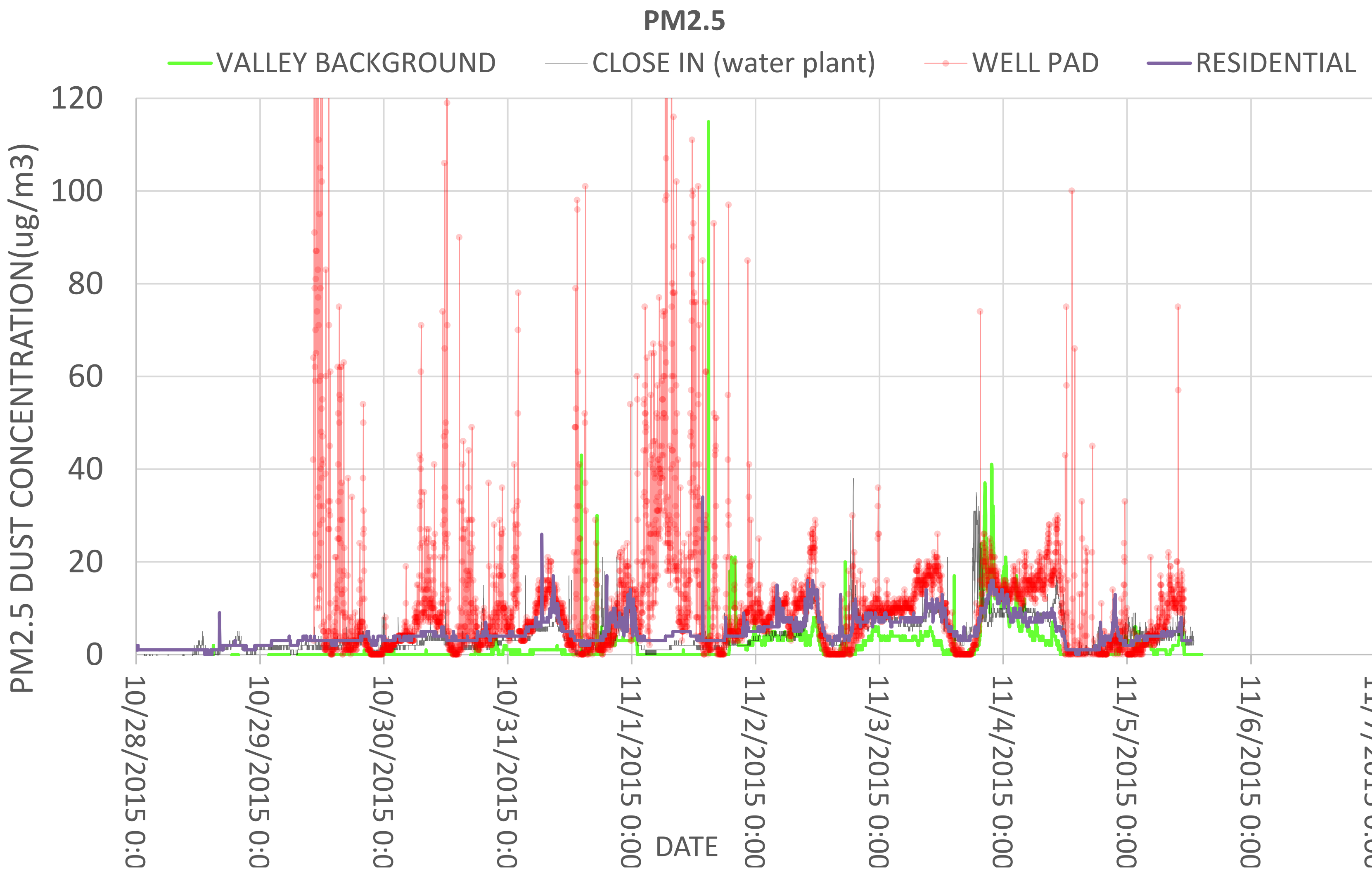
Thank You !

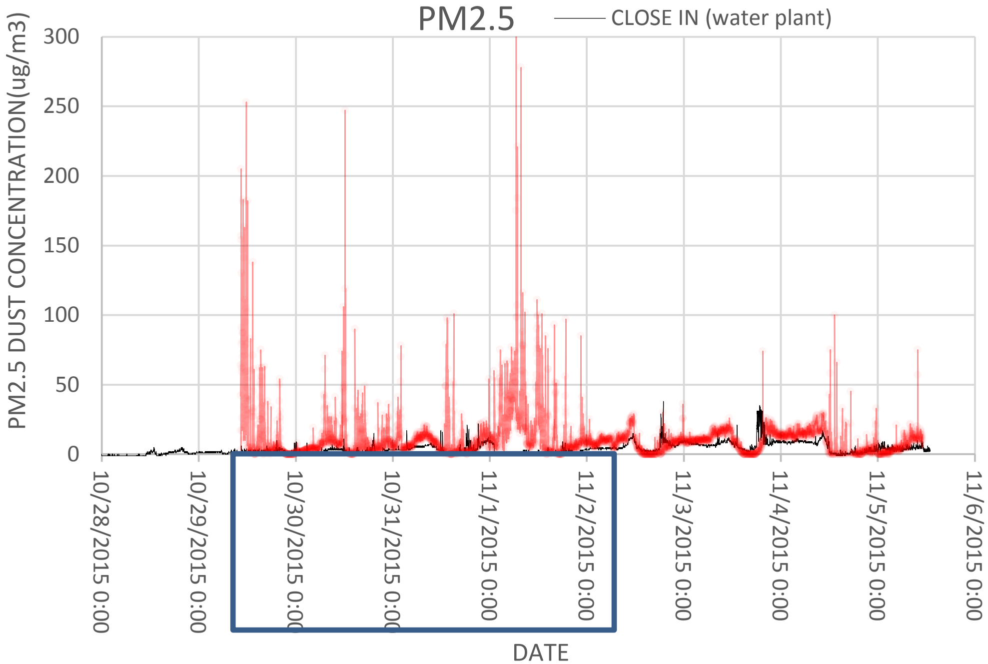
PAD SITE EMISIONS

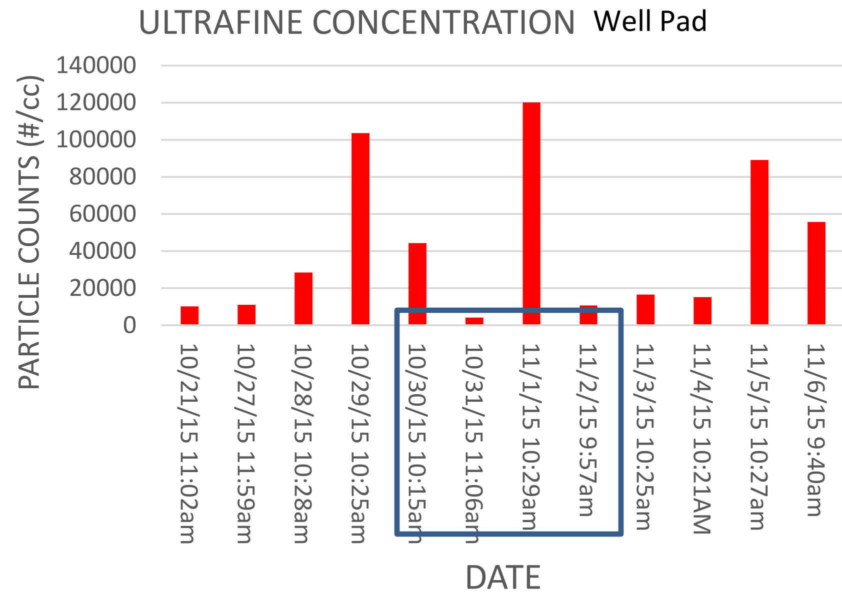
- Dust – PM2.5 & Ultrafines
- MSEEL
- Community Sampling
- Sampling Methods
- Results – PM2.5 “Plume”; Diesel Ultrafine Generation
- Conclusion – 1km ~ background concentration

Sampling Sites

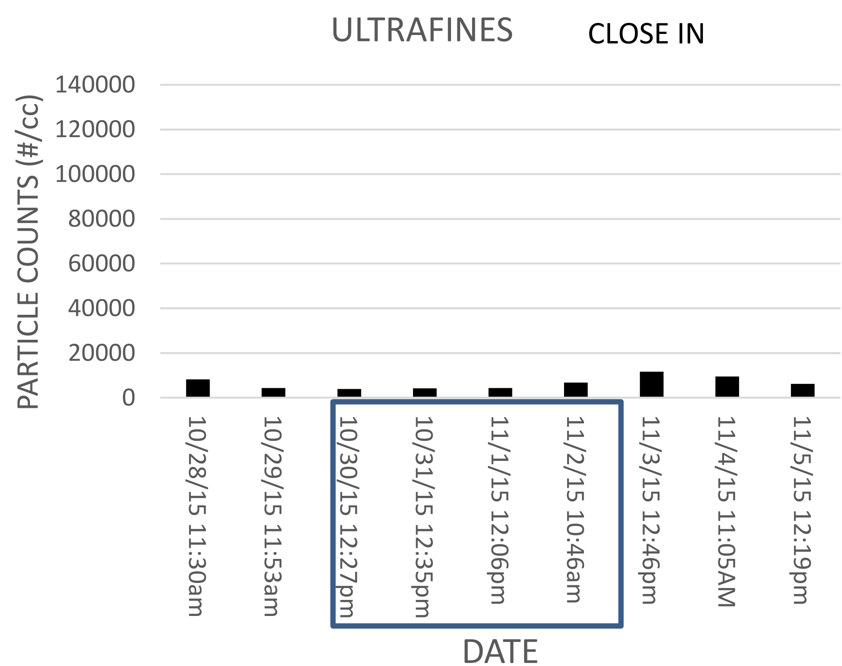



PM2.5
VALLEY BACKGROUND
CLOSE IN (water plant)
WELL PAD
RESIDENTIAL
PM2.5 DUST CONCENTRATION(ug/m3)
120
100
80
60
40
20
0
10/28/2015 0:0
10/29/2015 0:0
10/30/2015 0:0
10/31/2015 0:0
11/1/2015 0:00
11/2/2015 0:00
11/3/2015 0:00
11/4/2015 0:00
11/5/2015 0:00
11/6/2015 0:00
11/7/2015 0:00
DATE


PM2.5
CLOSE IN (water plant)
PM2.5 DUST CONCENTRATION(ug/m3)
300
250
200
150
100
50
0
10/28/2015 0:00
10/29/2015 0:00
10/30/2015 0:00
10/31/2015 0:00
11/1/2015 0:00
11/2/2015 0:00
11/3/2015 0:00
11/4/2015 0:00
11/5/2015 0:00
11/6/2015 0:00
DATE


ULTRAFINE CONCENTRATION
Well Pad
PARTICLE COUNTS (#/cc)
140000
120000
100000
80000
60000
40000
20000
0
10/21/15 11:02am
10/27/15 11:59am
10/28/15 10:28am
10/29/15 10:25am
10/30/15 10:15am
10/31/15 11:06am
11/1/15 10:29am
11/2/15 9:57am
11/3/15 10:25am
11/4/15 10:21AM
11/5/15 10:27am
11/6/15 9:40am
DATE


CLOSE IN
1 KM
WELL PAD
Morgantown Industrial Park
Harmony Grove
Mountaineer Mall Shopping Center
Google


ULTRAFINES
CLOSE IN
PARTICLE COUNTS (#/cc)
140000
120000
100000
80000
60000
40000
20000
0
10/28/15 11:30am
10/29/15 11:53am
10/30/15 12:27pm
10/31/15 12:35pm
11/1/15 12:06pm
11/2/15 10:46am
11/3/15 12:46pm
11/4/15 11:05AM
11/5/15 12:19pm
DATE

Marcellus Shale Energy and Environmental Laboratory: Water and Solid Waste

Year one findings

12 feb 16

- Flowback volume
- Produced water
- Hydrofrac fluid vs. flowback chemistry
- Drill cuttings
  - TCLP results
  - Drilling fluid
  - Radiochemistry

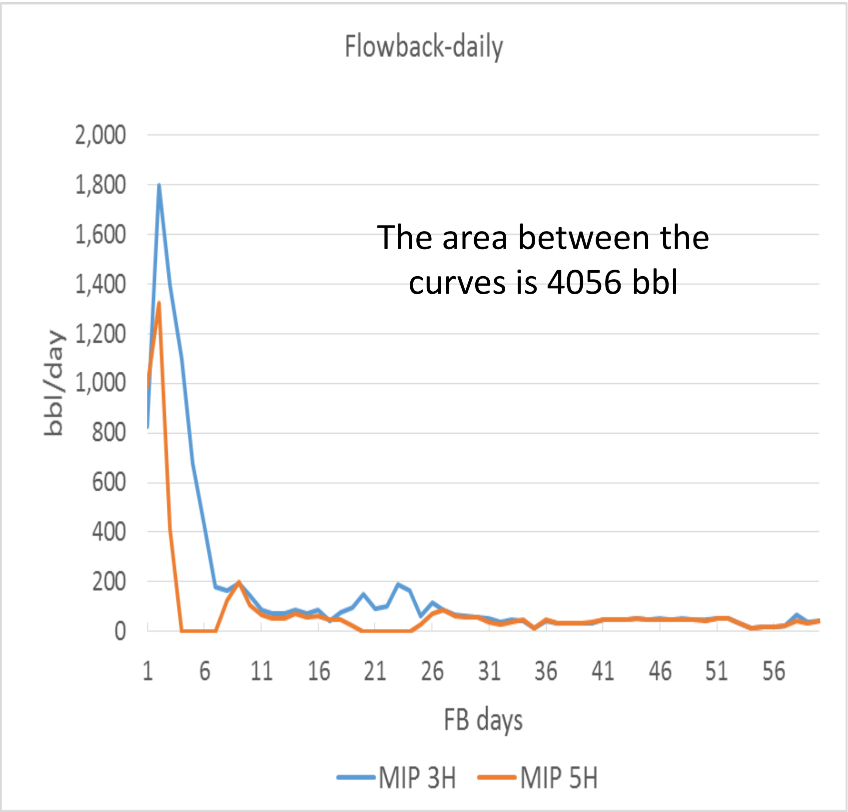
Paul Ziemkiewicz

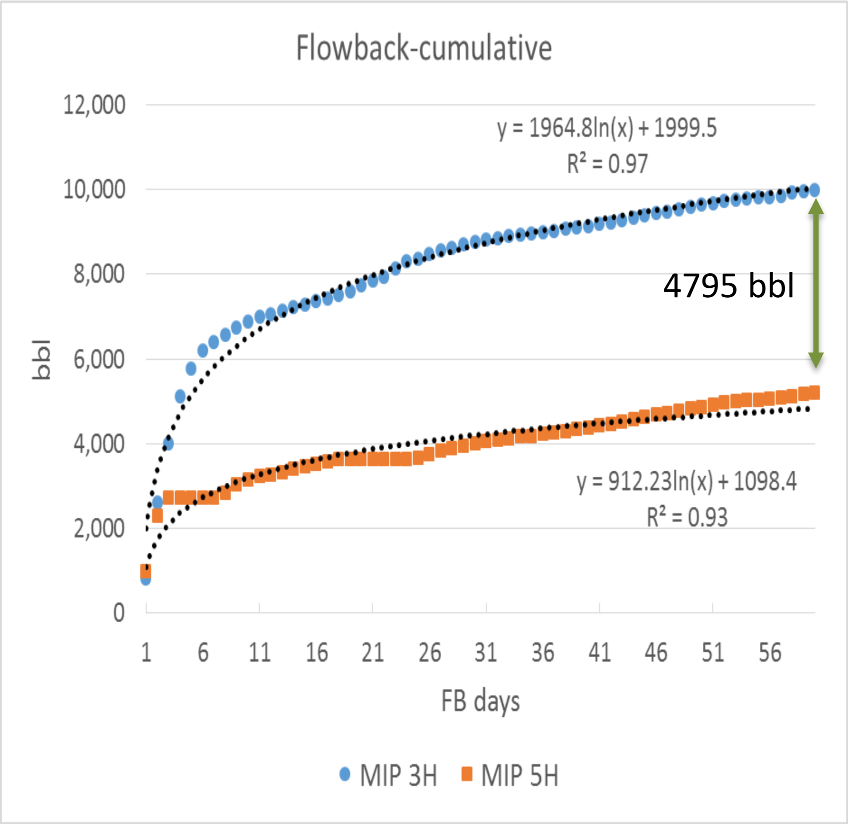
Water Research Institute

West Virginia University

Flowback volumes: MIP 3,5H

3H produced 92% more water, 30% more gas





Flowback day ~1,350

Produced water from old (MIP 4,6H) wells predominantly Na, Ca, Cl

	Produced water (mg/L)	
	MIP 4H	MIP 6H
Parameter	14-Apr-15	14-Apr-15
Chloride	59,300	34,700
Sodium	23,700	15,000
Calcium	9,480	5,550
Barium	4,970	3,040
Strontium	1,970	1,310
Magnesium	809	571
Bromide	643	416
Potassium	146	93
Lithium	93	53
Iron	93	155
Sulfate	63	63
Manganese	3	4
Aluminum	1	0
EC *	143,000	99,300
Alkalinity	124	180
TDS	104,000	65,100
TSS	75	99

* µS/cm

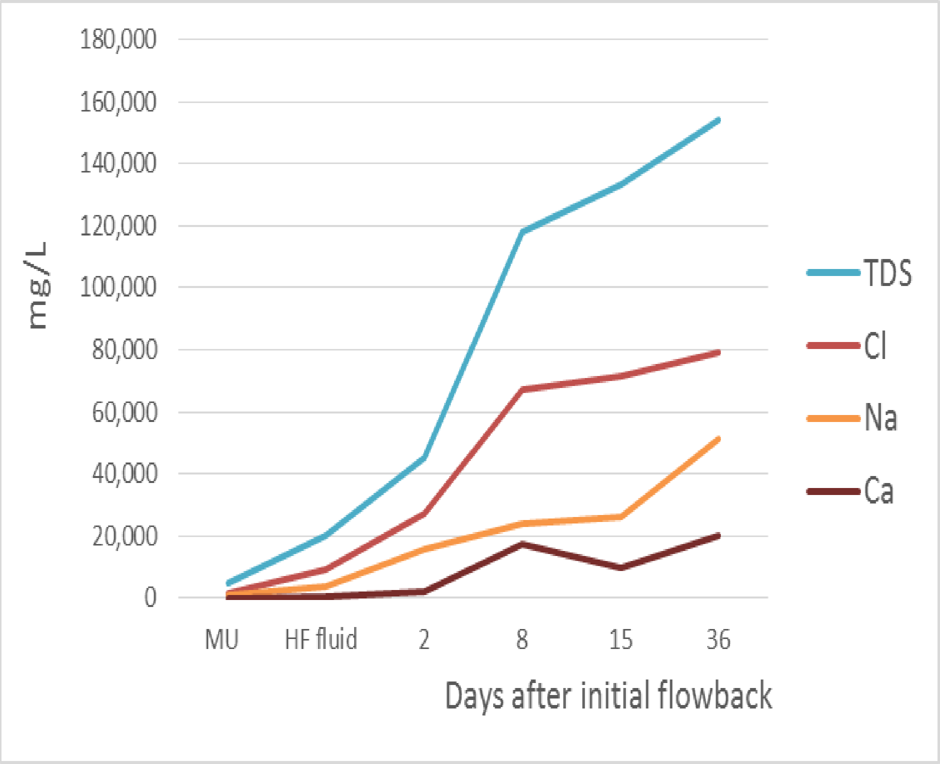
Nearly all parameters were higher in flowback than frac fluid

Pink: exceeds drinking water MCL

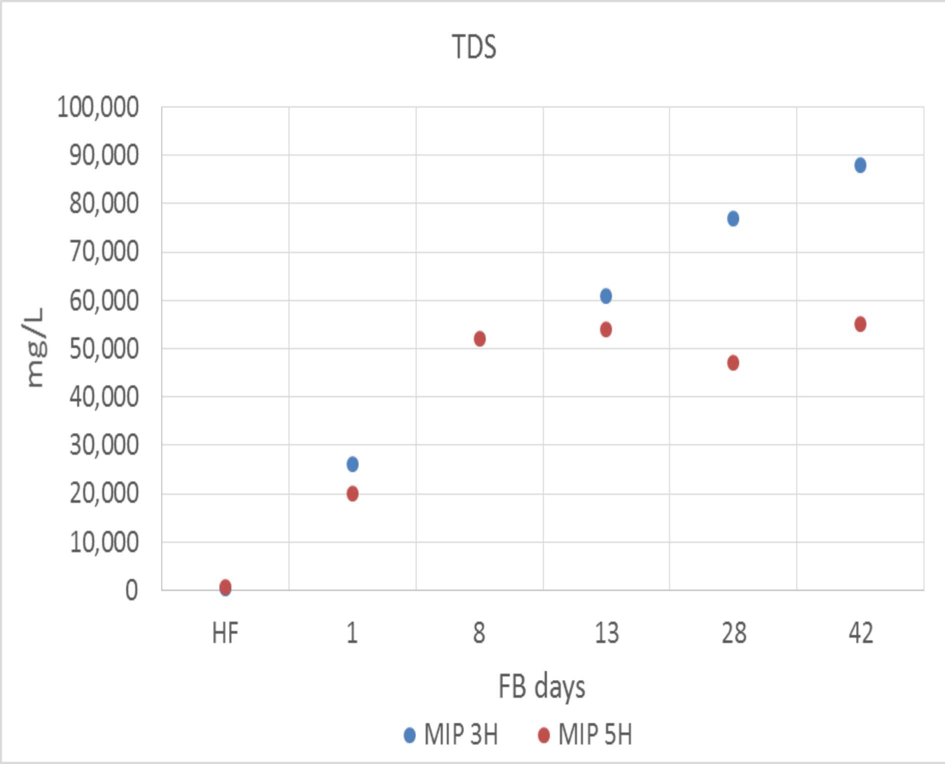
			SDWA	MIP 3H		MIP 5H	
MDL		units	MCL	HF	FB day 42	HF	FB day 42
0.0011	Al	mg/L	0.05	0.42	0.00055	0.02	0.00055
0.0007	As	mg/L	0.01	0.00	0.35	0.00	0.35
0.0002	Ba	mg/L	2	0.04	2500	0.048	1100
0.4	Ca	mg/L		35.5	6800	34	2900
0.0001	Cr	mg/L	0.1	0.003305	0.05	0.00005	0.05
0.01	Fe	mg/L	0.3	1.996	140	0.005	120
0.0001	Pb	mg/L	0.015	0.00	0.005	0.00	0.005
0.019	Mg	mg/L		9.70	710	8.00	330
0.0002	Mn	mg/L	0.05	0.11	11	0.00	1.8
0.0004	Ni	mg/L		0.01	0.2	0.00	0.2
0.03	K	mg/L		3.40	130	2.50	120
0.001	Se	mg/L	0.05	0.00	0.5	0.00	0.5
0.0001	Ag	mg/L	0.1	0.00	0.05	0.00	0.05
0.1	Na	mg/L		46.50	21000	30.00	13000
0.0003	Sr	mg/L		0.34	1400	0.27	630
0.02	Zn	mg/L	5	0.07	1.2	0.04	1.2
4.3	Alk	mg/L		70.00	140	64.00	240
0.09	Br	mg/L		0.17		0.95	
0.29	Cl	mg/L	250	31.50	61000	34.50	37000
3	SO4	mg/L	250	125.00	7	140.00	7
7.6	TDS	mg/L	500	340.00	88000	565.00	55000
0.25	Benzene	µg/L	5	0.13	10	0.13	27
0.2	Toluene	µg/L	1000	0.43	13	0.01	53
0.22	Ethylbenze	µg/L	700	0.11	1.1	0.11	4
0.62	Xylene tot	µg/L	10000	0.32	3.2	0.32	23
0.005	MBAS	mg/L	0.5	0.00	0.38	0.00	0.26

Flowback evolution-major inorganic ions

Ziemkiewicz et al., 2011

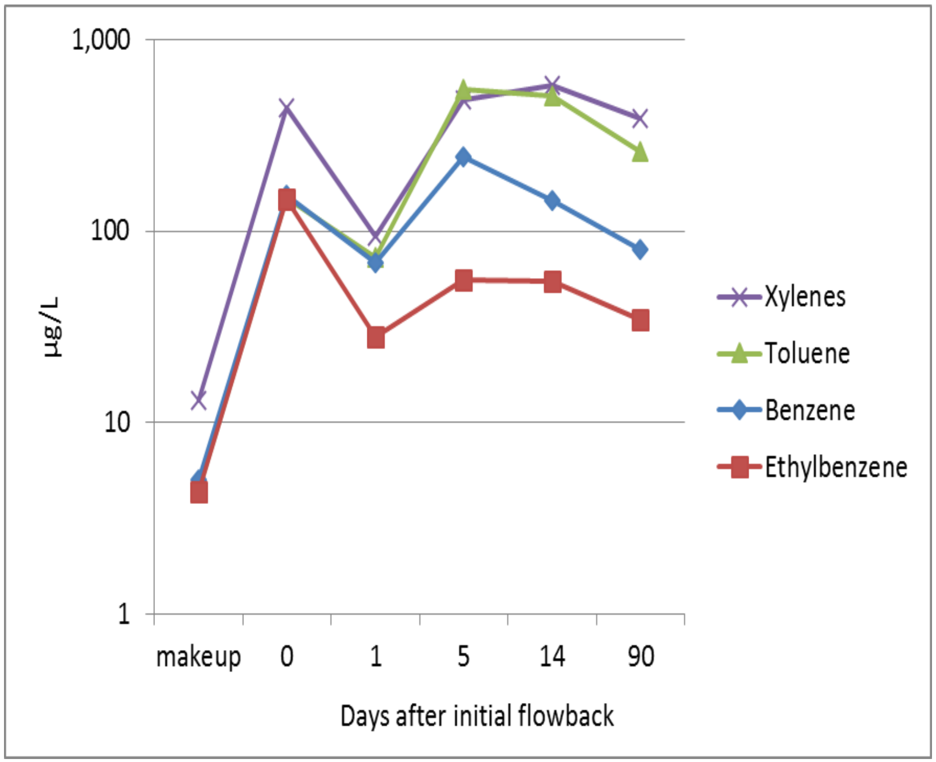


MSEEL



Flowback evolution-organics

Hayes, 2009



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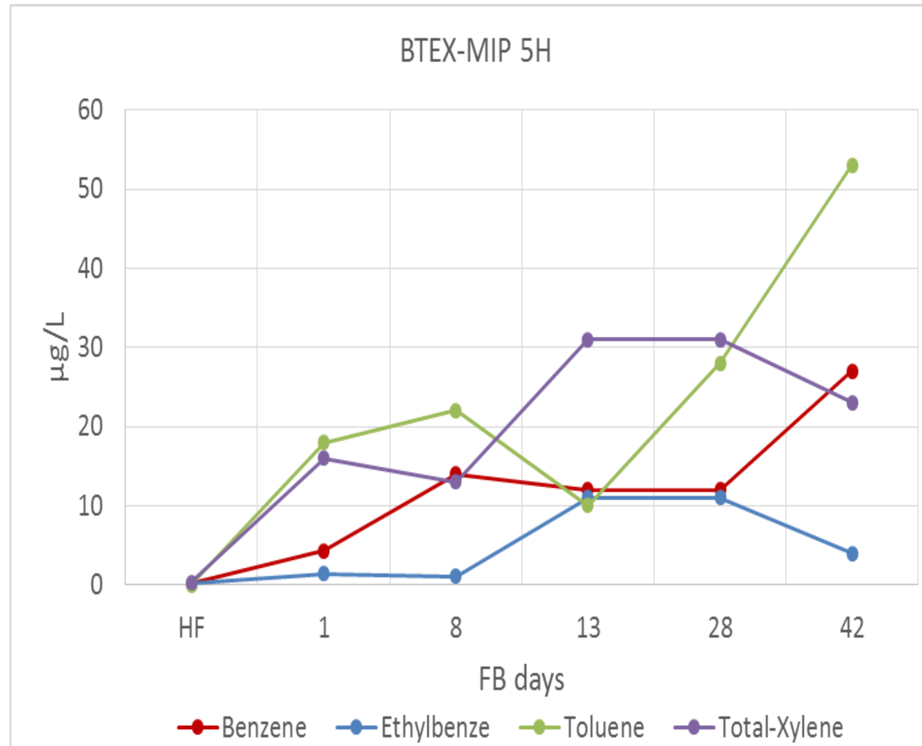
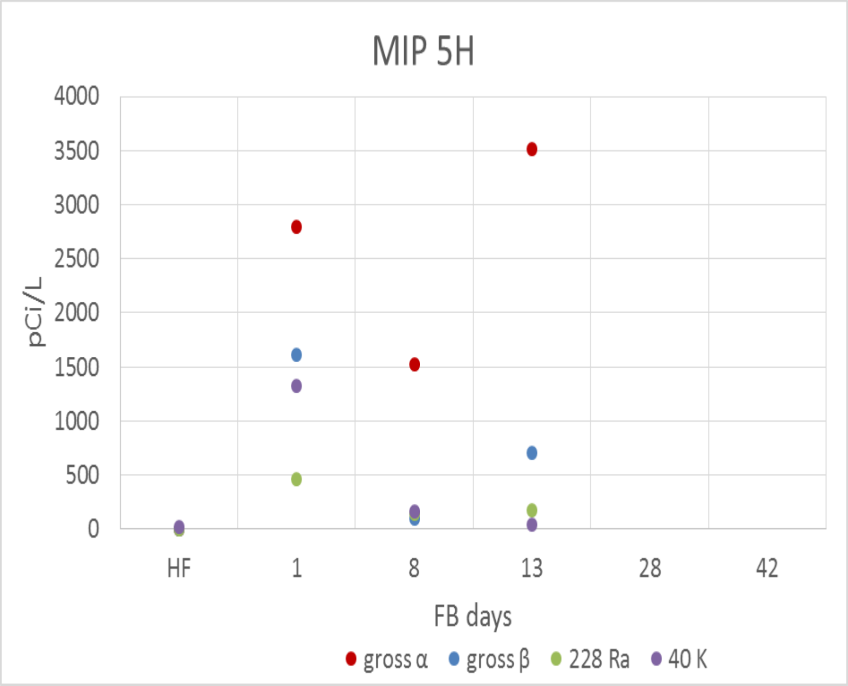
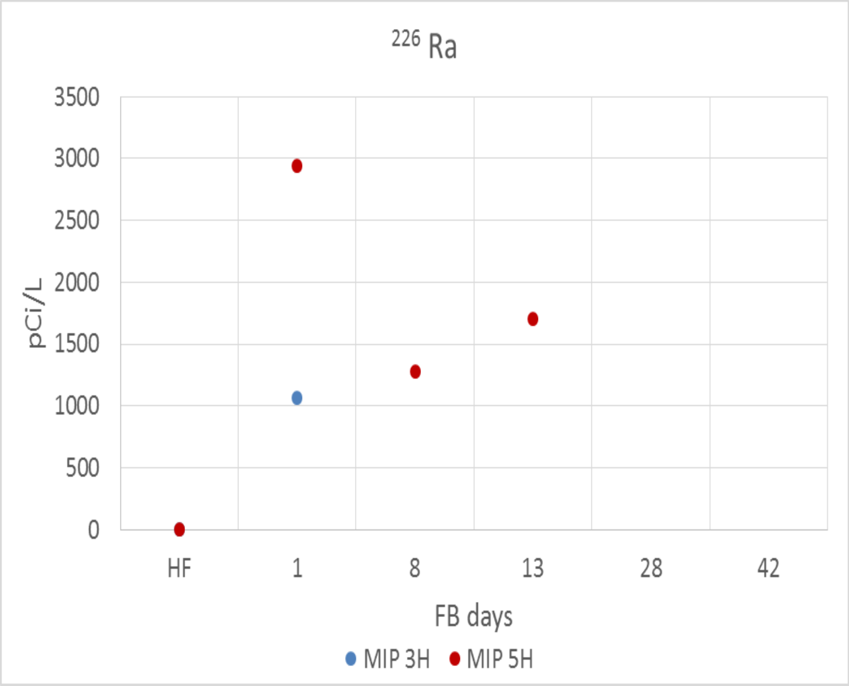


Radioactive isotopes in flowback

MSEEL



MSEEL



Conventional drilling mud

Drill Cuttings % samples (Liquid fraction) > TCLP limit

Drill Cuttings: Vertical Section

Drill Cuttings	%> TCLP	min	max	
Cr	100%	6.7	32.8	mg/L
As	90%	2.4	30.6	mg/L
Pb	80%	3.5	84.9	mg/L
Ba	70%	23.9	7,870.0	mg/L
Benzene	70%	0.0	300.0	µg/L
Se	40%	0.0	3.3	mg/L
Hg	10%	0.0	0.3	mg/L

Using ‘Green’ Drilling Mud no parameters exceeded TCLP

- In the Vertical and Horizontal (Marcellus) sections:
- TCLP organics-no exceedances
- TCLP inorganics-no exceedances

Drilling mud: Bio-Base^{tm} 365

Property	Unit	Value	Test Method
Physical state		Liquid	Visual
Biodegradation, 28 days	%m	55-60	OECD 301
Potential carcinogenic label	-	No	-
BTEX	mg/kg	< 1 *	ASTM 5790 mod.
PAH	mg/kg	< 0.1 *	EPA 8100

** Below the detection level of the method. BETX (Benzene, Ethylbenzene, Toluene, Xylene).*

Bio-Base 365 from MSDS:
Alkanes, Linear and Branched, Light paraffins

Product Name	CAS No.	Conc. (%)
Aliphatic Hydrocarbons	90622-53-0	70-95
– Undecane	1120-21-4	1-9
– Dodecane	112-40-3	1-14
– Tridecane	629-50- 5	1-9
– Tetradecane	629-59-4	1-11
– Impurities		1-8

Radiochemistry: drill cuttings

Brazil nuts are about 12 pCi/g

Radionuclides (pCi/g)

vertical	EPA 901.1									9310					
Marcellus	^{40}K			^{226}Ra			^{228}Ra			alpha			beta		
	Act	Unc	MDC	Act	Unc	MDC	Act	Unc	MDC	Act	Unc	MDC	Act	Unc	MDC
MIP 4400 3H	28	4.8	1.0	1.2	0.3	0.3	1.8	0.5	0.3	15.0	7.1	9.8	24.5	6.3	5.6
MIP 5026 3H	24	4.4	1.4	1.4	0.3	0.2	1.9	0.5	0.3	10.5	5.8	9.2	19.4	4.8	4.1
MIP 6798 5H	27	4.5	0.9	1.8	0.3	0.2	1.4	0.4	0.5	17.1	7.7	11.2	27.8	6.7	5.4
MIP 8555 5H	26	4.2	1.1	4.7	0.7	0.2	1.3	0.4	0.4	27.0	9.6	10.2	36.9	8.6	6.6
MIP 8555 5H DUP	25	4.6	1.5	4.6	0.7	0.3	1.1	0.6	0.6	38.1	11.1	9.1	29.8	6.8	4.9
MIP 9998 5H	17	4.3	2.7	9.2	1.3	0.3	0.5	0.9	0.9	46.8	11.0	4.7	42.9	9.0	5.9
MIP 11918 5H	22	3.7	1.1	4.0	0.7	0.2	0.7	0.5	0.5	24.4	9.2	10.3	23.0	6.2	6.2
MIP 11918 5H	20	3.4	1.1	4.2	0.6	0.2	0.8	0.4	0.6	23.8	6.8	5.2	28.7	6.3	5.1
MIP 13480 3H	18	3.2	1.2	9.2	1.3	0.2	0.8	0.6	0.5	55.7	14.7	11.5	35.4	8.2	5.8
MIP 13480 3H DUP	18	3.5	1.4	9.7	1.4	0.3	1.1	0.4	0.3	59.2	14.9	9.3	35.0	7.8	4.6
MIP 13480 3H Mud	13	3.0	1.1	5.6	0.9	0.2	0.5	0.3	0.8	60.0	15.9	10.5	42.5	9.6	6.1
MIP 14454 5H	20	3.8	1.1	5.8	0.9	0.2	1.3	0.5	0.6	28.8	7.9	6.5	37.5	8.0	5.4

FOR MORE INFORMATION PLEASE CONTACT:

Paul Ziemkiewicz, Director
WVU Water Research Institute
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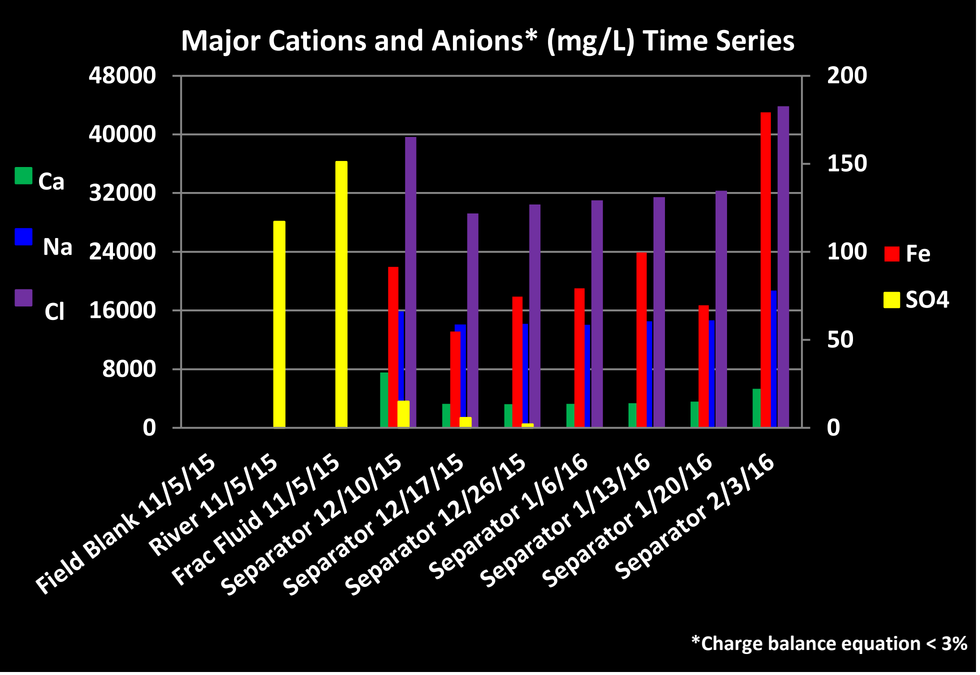
USGS team objectives
unconventional oil and gas development (UOG)

- Focus is on human and environmental health of waste materials from UOG development
- Identify potential contaminants in waste materials: drill cuttings, flowback/produced water.
- Conduct mass balance on injected chemicals.
- Examine partitioning of contaminants between liquid, solids.
- Focus on MSEEL Well 5H
- Results used to identify UOG contaminants in environmental samples, and substances that may affect water reuse



-River water and fracturing fluid contain > 100 mg/L SO_4^{2-}

-SO_4^{2-} in wastewater has decreased to bdl

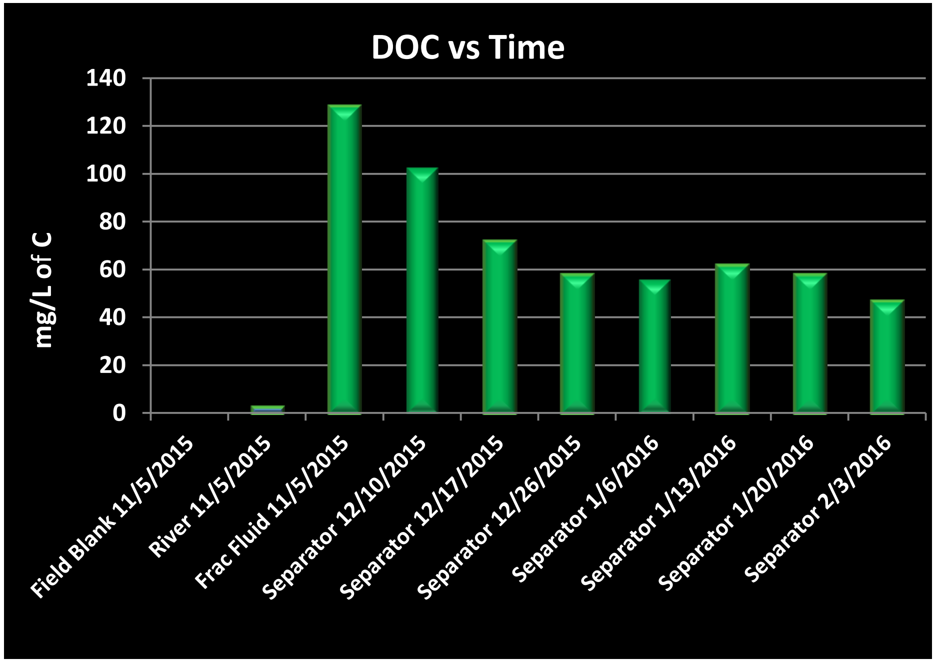
-Fe is bdl in fracking fluid but has reached 180 mg/L in wastewater; precipitates in wastewater likely to be hydrous ferric oxide

-Cl^-, Na^+, Ca^{2+} in PW are variable with no clear trends

-Dissolved organic carbon (DOC) low levels in river water

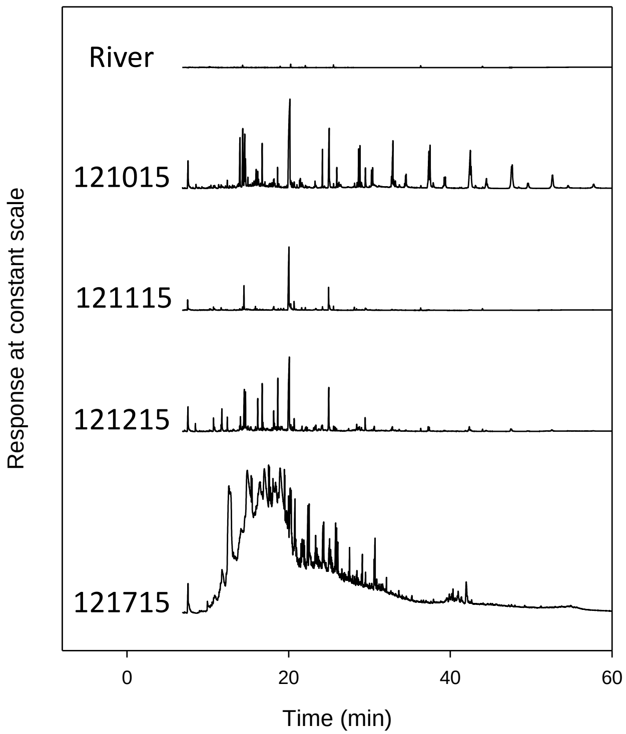
-DOC over 120 mg/L in frac fluid and over 100 mg/L in initial flowback

-Gradual decline in DOC to levels of 40-60 mg/L

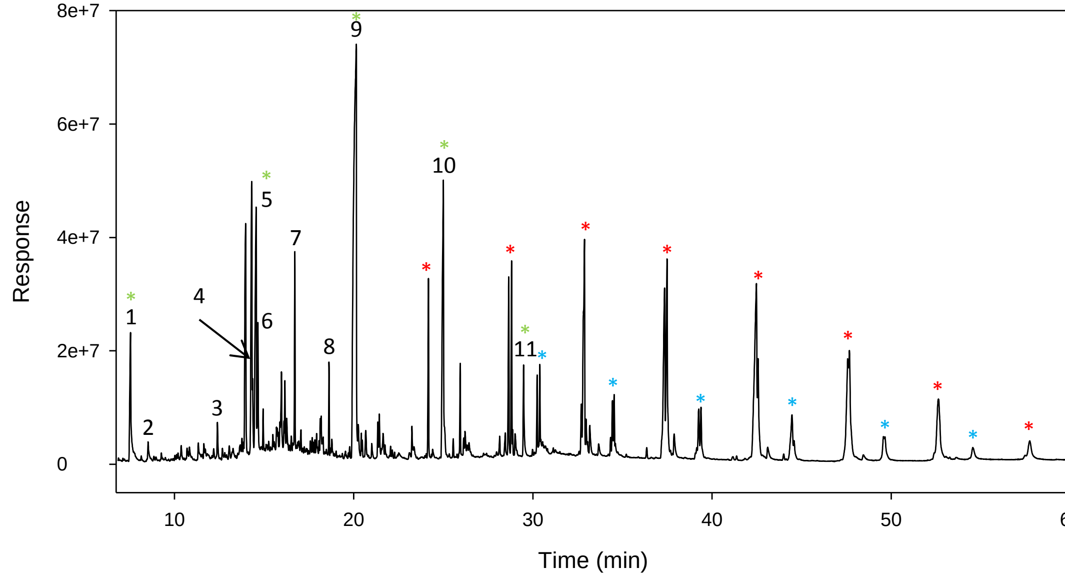


Extractable Hydrocarbons in MSEEL 5H Wastewater

Total ion chromatograms from extracted MIP 5H flowback water

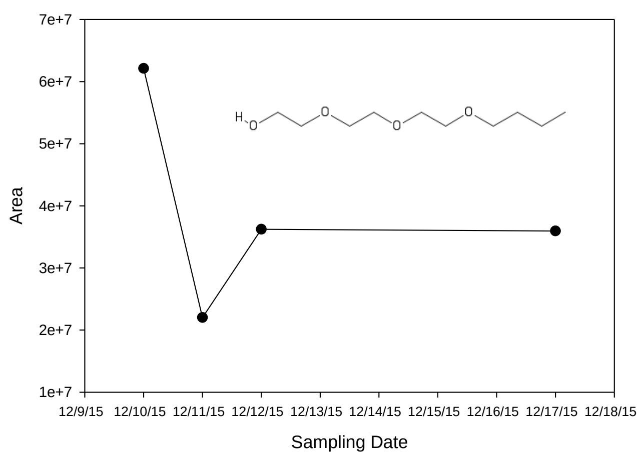


MSEEL-121015-F



1. 2-butoxy-ethanol
2. 4-methyl-cyclohexanol
3. undecane
4. naphthalene
5. butoxydiglycol
6. dodecane
7. tridecane
8. tetradecane
9. butoxytriglycol
10. butoxytetraglycol
11. butoxypentaglycol

Butoxytriglycol
Area of m/z 89 at 20.3 min

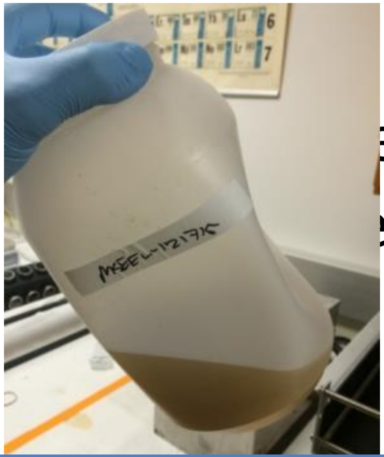


-Initially, mostly glycol ethers and alcohols in flowback with some n-alkanes.

-Huge increase in alkanes on 12/17/15 with about constant amount of glycol ethers.

-Many unidentified (series of) compounds in flowback water. Red and blue * series drop off after first day of flowback.

MSEEL plans



Ferric hydroxide precipitates in wastewater collected 12/17/15

- Understand partitioning of inorganic es between aqueous phase and s that form in wastewater

- Identify changes in organic during production; what what injected organics are lost to the ground, and what organic substances are sourced from shale

- Link USGS results to other datasets to develop understanding of processes and reactions impacting wastewater composition

BIOGEOCHEMICAL CHARCATERIZATION OF CORE, FLUIDS AND GAS

Isotopic/molecular/microbial characterization of sidewall core

WVU - Sharma ; OSU - Mouser, Wrighton, Wilkins, Cole, Darrah

Isotopic/molecular/microbial characterization of produced fluids

WVU - Sharma ; OSU - Mouser, Wrighton, Wilkins, Cole, Darrah

NETL - Hakala, Crandall, Phan

Molecular characterization of produced gas

WVU - Sharma ; OSU - Darrah

Sidewall Core Analysis

Collaborators:
Mouser, Wrighton, Wilkins, Cole,Darrah

THE OHIO STATE UNIVERSITY

WestVirginiaUniversity

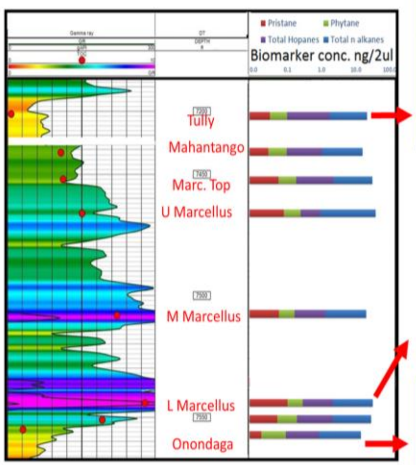
SHARMA ISOTOPE LAB

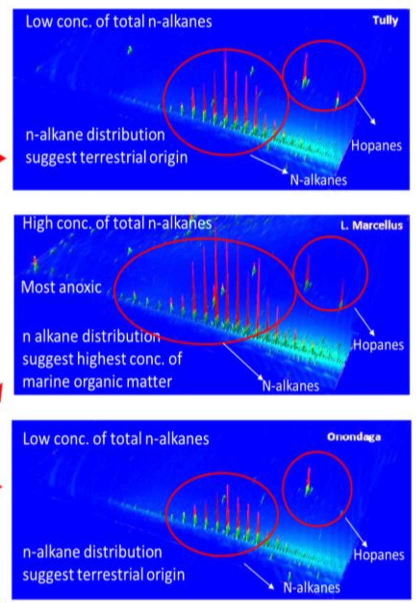
What are geological controls on microbial distribution, diversity and function ?

- **Gas productivity and well infrastructure**
- **Potential for fracture and pore clogging**
- **Microbial life/adaptations**

Aliphatic biomarker distribution

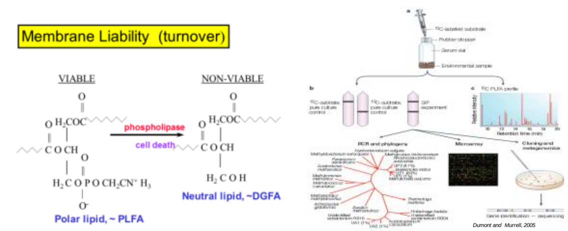
Vikas Agrawal
PhD. Student





CSIA & Fatty Acid biomarker distribution

Rawlings Akondi
PhD. Student



S. Pfiffner
UTK

P. Mouser
OSU

- ❑ Ratios of physiological stress DGFA/FAME and DGFA/PLFA/FAME lipid biomarkers
- ❑ Changes in the PLFA and DGFA profiles during nutritional & thermal stress
- ❑ CSIA will be used to identify microbial populations involved in methanogensis, methanotrophy, sulfate reduction etc.

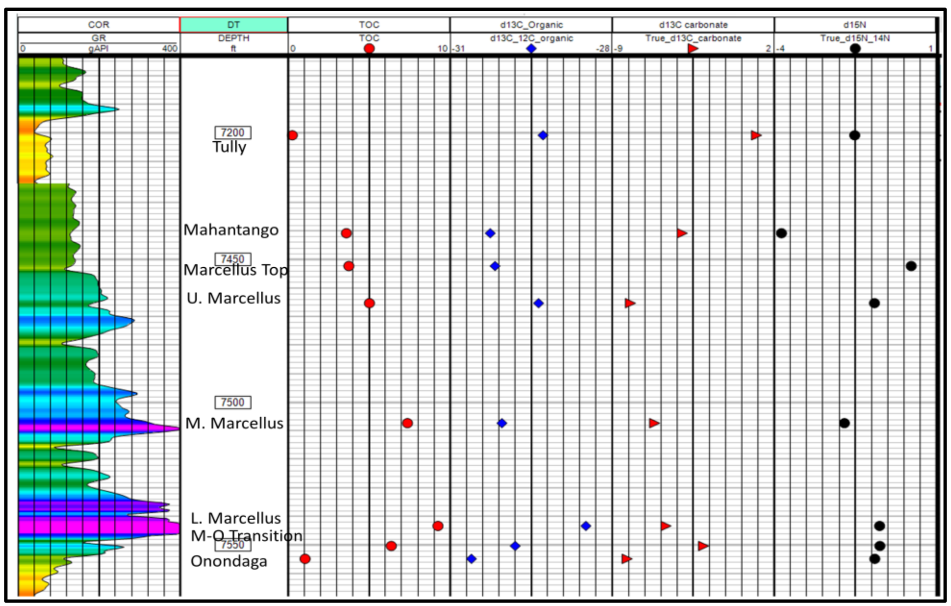
Sidewall Core Analysis

Collaborators:
Mouser, Wrighton, Wilkins, Cole, Darrah

Sample preparation | Sample Analysis | Data Integration

What are major controls on TOC variation and source/type of organic matter?

- Identification of sweet spots
- Oil vs gas production
- Frackability/Re-stimulation



Gamma Ray log with TOC and isotope ($\delta^{13}C_{org}$, $\delta^{13}C_{carb}$, $\delta^{15}N$) variations of 8 sidewall core samples collected from well MIP 3H. Shifts in $\delta^{13}C_{org}$, $\delta^{13}C_{carb}$ and $\delta^{15}N$ values will be used to understand controls on variations in TOC , sources of organic matter, and microbial recycling of carbon and nitrogen

Kerogen Analysis

West Virginia University · SHARMA ISOTOPE LAB

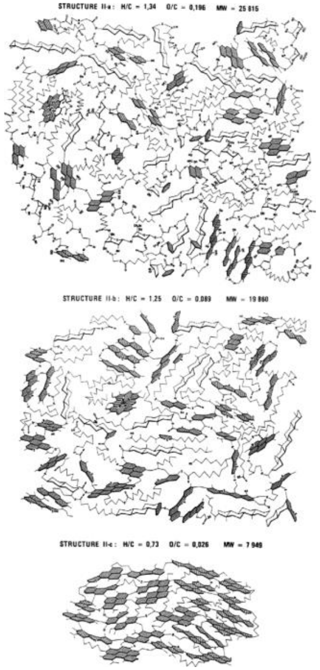
Collaborators:

Pacific Northwest NATIONAL LABORATORY

Hoyt, Walter, Malak

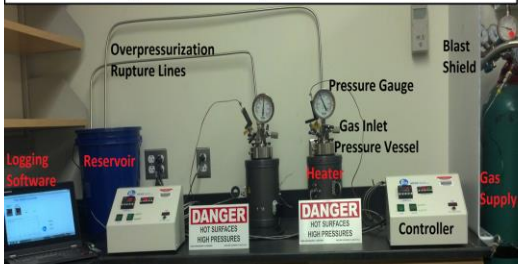
DECODING KEROGEN STRUCTURE AND ITS INTERACTIONS

Vikas Agrawal
PhD. Student



Behar & Vandenbroucke, 1987

West Virginia University Static Reactor System



Electron Paramagnetic Resonance

NMR

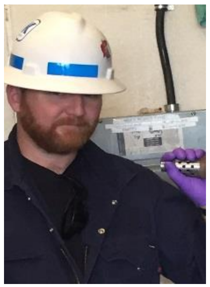
Frac water-shale experiments to be conducted high pressure/temperature static systems to understand:

- ❑ **Changes in kerogen structure and composition on interaction with frac fluids under simulated subsurface conditions.**
- ❑ **Effect of changes in kerogen on chemistry and flow of produced water and gases**

Produced Water Analysis

Collaborators:

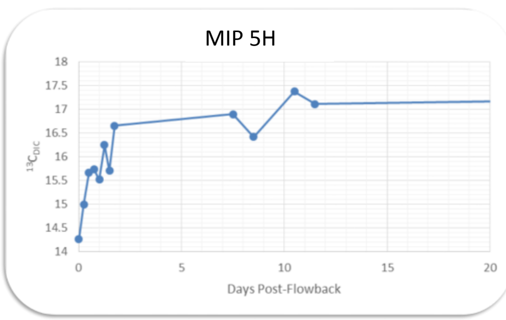
Hakala	Mouser, Wrighton
Phan	Wilkins, Cole
Crandall	Darrah

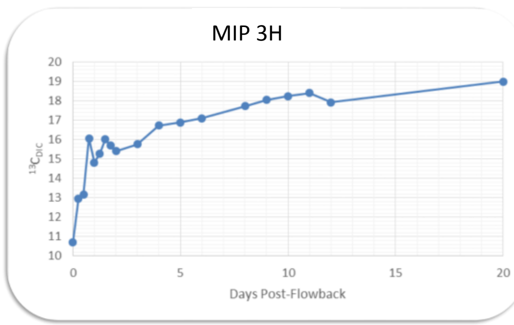


Travis Wilson
MS Student

What are the plausible fluid-rock-microbe interactions?

- Evolution of produced water chemistry
- Secondary biogenic methanogenesis
- Well infrastructure & souring

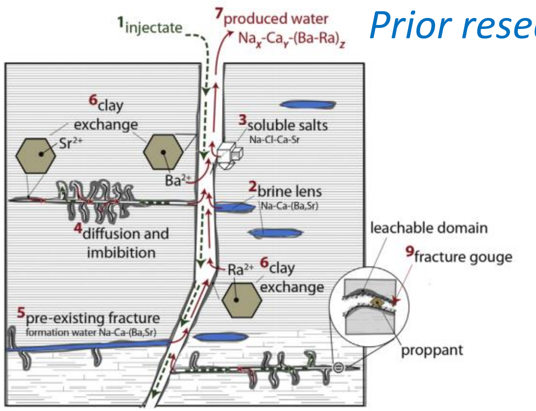




Initial $\delta^{13}C_{DIC}$ enrichment trend in wells 5H and 3H during first few hours to days indicates dissolution of carbonates in reservoir after injection of hydraulic fracturing fluids. High $\delta^{13}C_{DIC}$ values indicate carbonates were precipitated during initial phase of biogenic methanogensis in the reservoir. The C and S isotope trends will be monitored over several months to understand microbial reactions induced in the reservoir after injection of hydraulic fracturing fluids

Extraction of Sulfate and sulfur and oxygen isotope analysis in progress

Using geochemistry to track hydraulically-fractured reservoir evolution



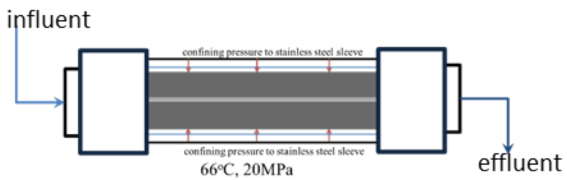
Renock et al., 2015

Prior research showed multiple chemical and physical processes can affect the reservoir.

Outstanding questions

How does the reservoir chemistry change during flowback?

How do fluid/gas flow pathways change during flowback and hydrocarbon production?



Approaches

Evaluate redox changes (which could affect organic and microbiological reactions in the reservoir) through analysis of iron and sulfur species

Distinguish fluid-rock reaction versus physical transport of materials through analysis of truly dissolved versus colloidal loads in produced water

Methods

Analysis of MSEEL produced water sample splits for time-series concentrations of cations, anions, and isotope ratios for Sr, Li, and B

Conduct laboratory flow-through experiments to evaluate fluid-rock interactions using MSEEL core

OSU-WVU Deep Biosphere Collaborative Research

Microbiology

Mike Wilkins
Earth Sciences, OSU

Geology

Kelly Wrighton
Microbiology, OSU

Shikha Sharma
Geology, WVU

Tom Darrah
Earth Sciences, OSU

David Cole
Earth Sciences, OSU

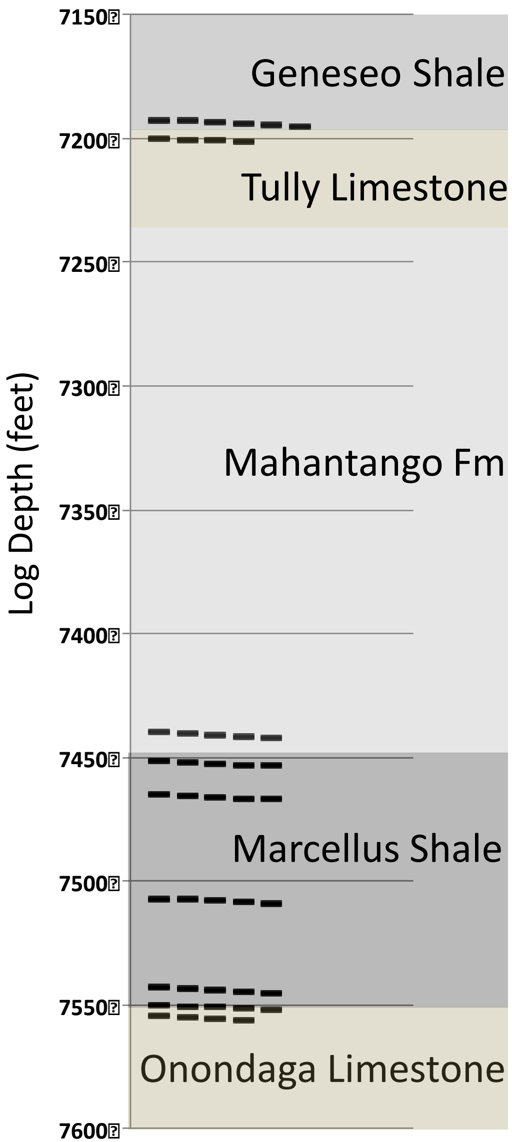
Engineering

Paula Mouser
Envr Engr, OSU

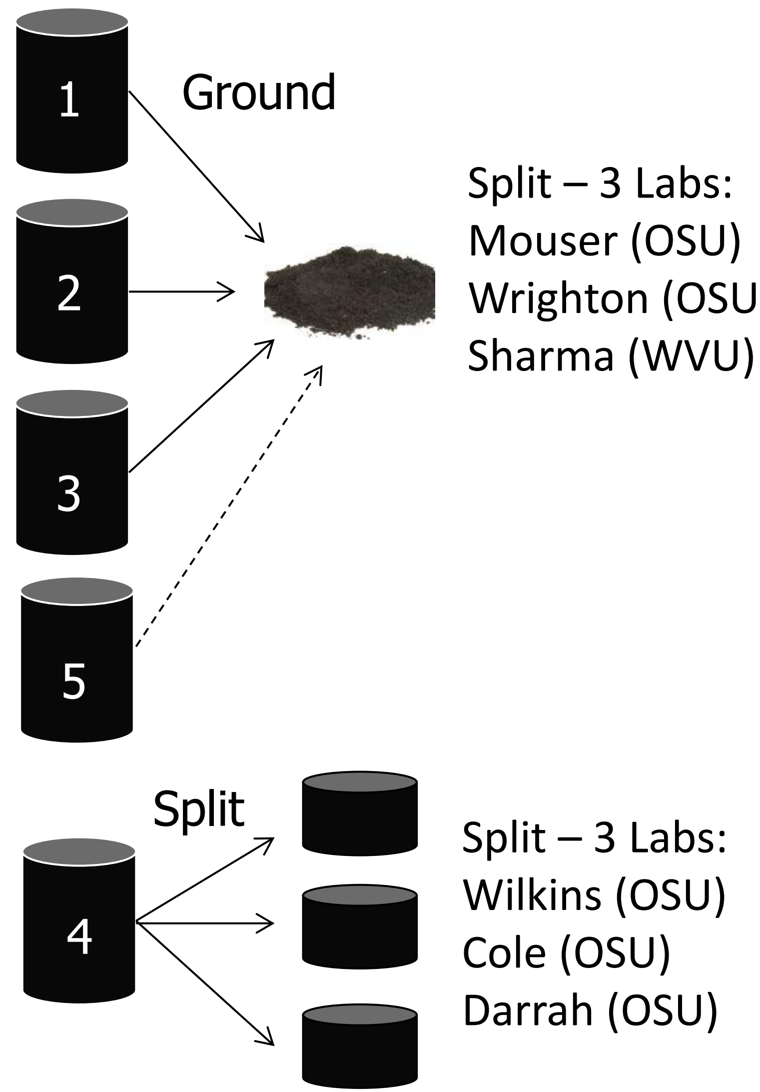
Jeff Daniels,
PI – OSU Team

Sidewall Cores

MIP-3H
(44 cores)



Sample Distribution For Each Transect



Contamination controls for sidewall cores

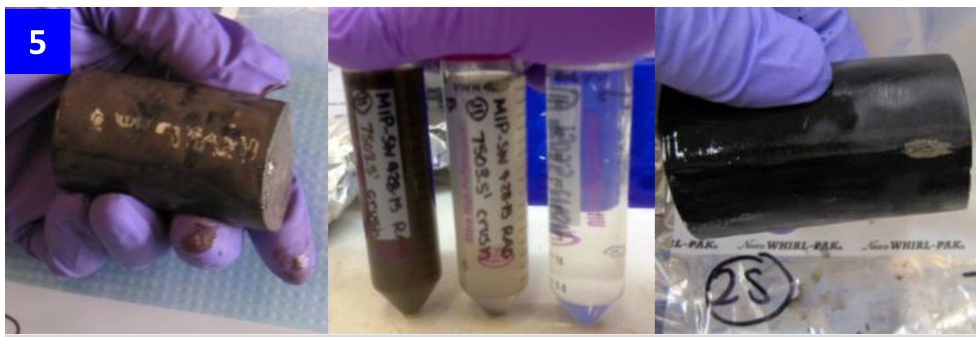
Wrighton Lab

Sample all input fluids (drill mud, brine, etc.) for DNA extraction and sequencing

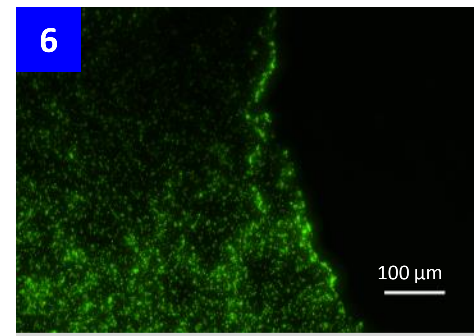
Add tracer to drill mud

Bagged cores, transported anaerobically to OSU

Sterile hood to process cores



Clean cores, keep washes for DNA extraction and sequencing



Quantify tracer removal

flame sterilize & grind shale

Ground shale distributed for:

- metagenomic sequencing
- culturing
- lipid analyses

DNA Extraction and Sequencing Efforts

Pristine core material:
9 depths in and surrounding the Marcellus for metagenomic sequencing

Contamination control:
DNA extraction and sequencing from ~375 core washes and input fluids

***First batch of DNA from pristine cores submitted to DOE for sequencing!!!**

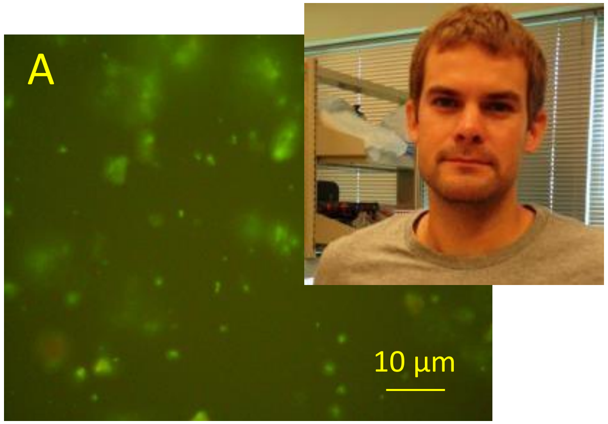
Pristine Shale Enrichments

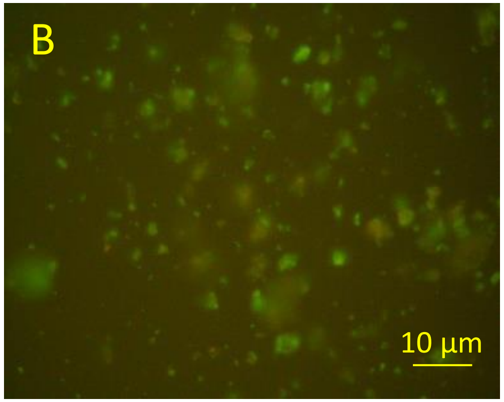
Wilkins Lab

Enrichment Strategy

Depth
- Genesseo 7194.5'
- Tully 7200'
- Mahantango 7440'
- Top Marcellus 7451.5'
- Upper Marcellus 7467'
- Middle Marcellus 7509'
- Lower Marcellus 7543'
- Marcellus Onondaga Transition 7552'
- Onondaga 7555'

Enrichment → **Pressure**
- Carbohydrate Fermenters → Atmospheric and 8,000 psi
- Iron Reducing Bacteria
- Sulfate Reducing Bacteria → Atmospheric and 8,000 psi
- Acetoclastic Methanogens
- Hydrogenotrophic Methanogens
- Hydrocarbon Fermenters → Atmospheric and 8,000 psi
- Hydrocarbon Oxidizers (Aerobic)
- Hydrocarbon Oxidizers (Anaerobic)





↑ Atmospheric enrichments (both aerobic and anaerobic)

← High pressure vessel and enrichment tube

SYBR Gold (fluorescent DNA stain) dyed Mahantango formation enrichments targeting for (A) Sulfate Reducing Bacteria and (B) Carbohydrate Fermenters. 100x. These are the most promising enrichments thus far.

Biological Signs of Recent Pristine Rock-Hosted Life, PLFA Measurements

Mouser Lab

Solvent Extraction

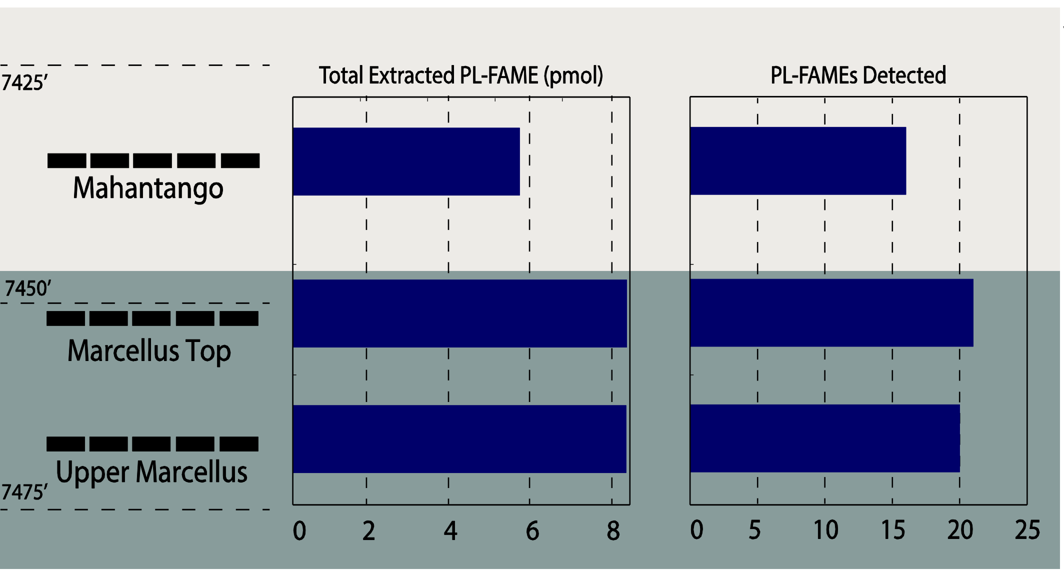
Total Lipid Isolation

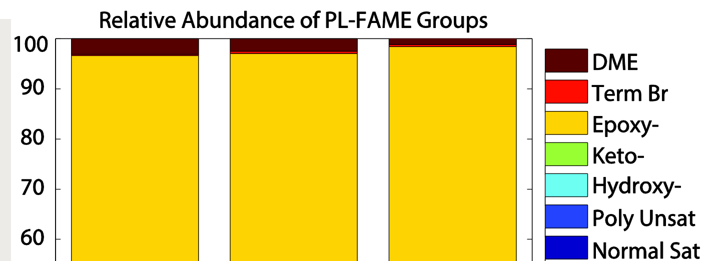
Silicic Acid Chromatography

Polar Lipid Methanolysis

Fatty Acid Methyl Ester GC–MS

Quantification and Analysis





S. Pfiffner, UTK

--Highest Biomass Recovered from Interface

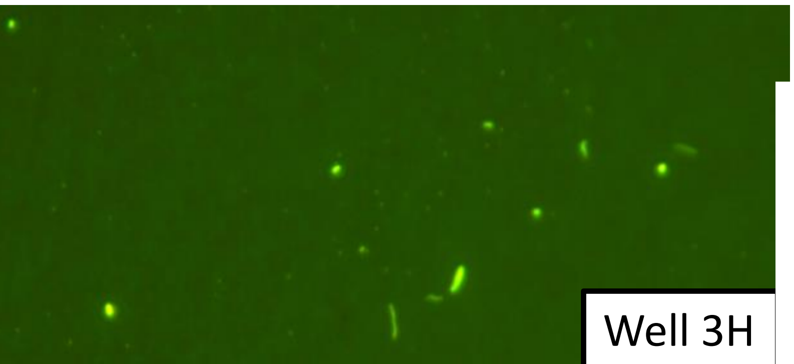
--Largest Number of Unique PL-FAMEs at Interface

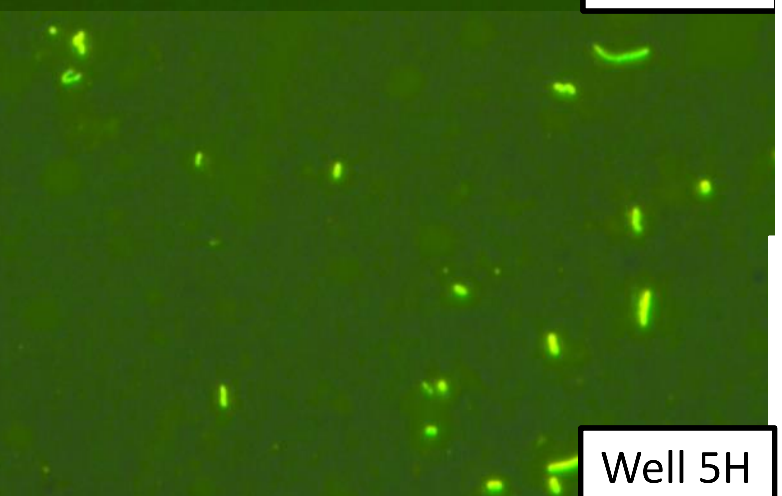
--Sidewall Core Profiles Differ Between Rocks

--Cores PLFAs Differ from Muds/Washes

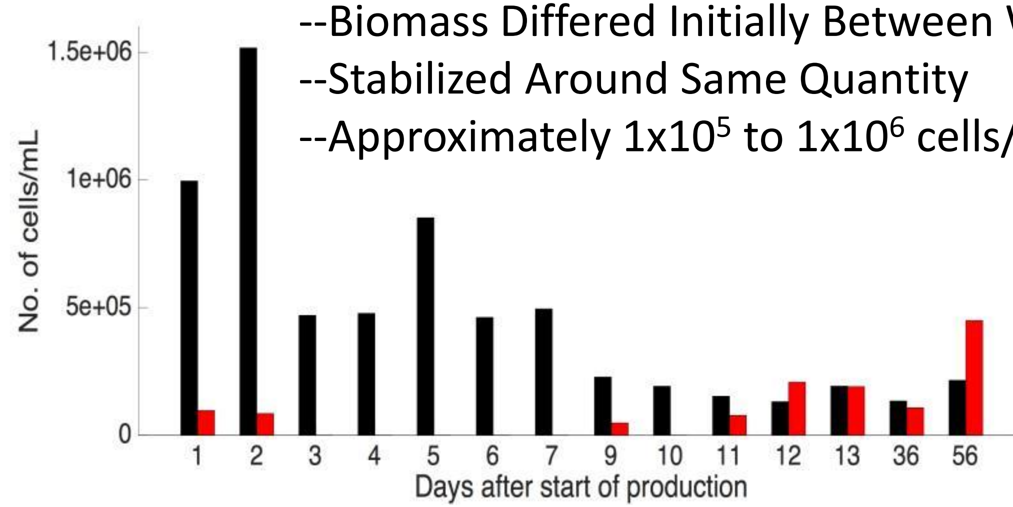
Mouser Lab

Evidence of Life in Marcellus Wells



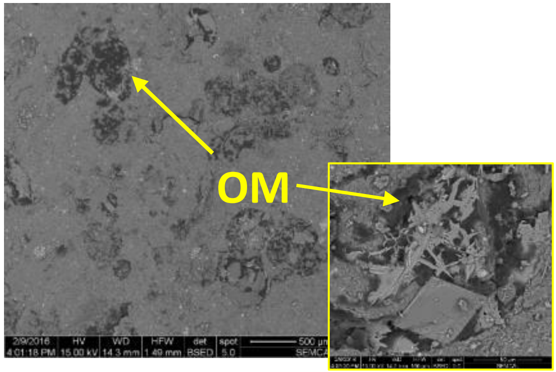


--Biomass Differed Initially Between Wells
--Stabilized Around Same Quantity
--Approximately $1x10^5$ to $1x10^6$ cells/ml

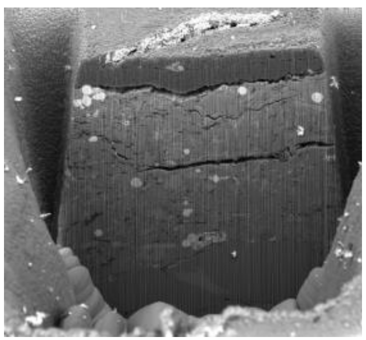


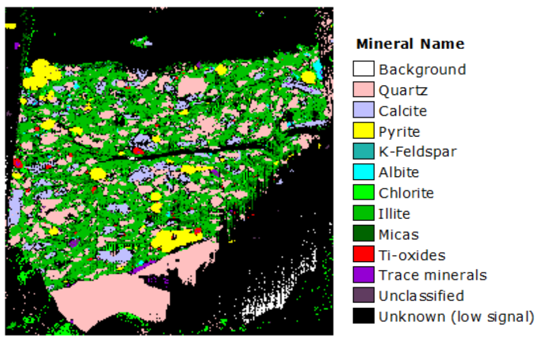
Flowback fluid samples were fixed in 2.5 % paraformaldehyde, stored at 4°C and enumerated within one week of sampling. Counting: Samples were filtered through a black 0.22 µm PCTE filter, stained *in situ* with SYBR-Gold fluorescent nucleic acid-specific stain and imaged with a 40X objective under 480 nm excitation. Bacterial cells were manually counted and averaged from images of 10-20 fields per filter. **Upper and lower left:** Images of flowback fluid samples collected on Feb 3, 2016 (Day 56) from wells 3H (up) and 5H (bottom). **Right:** Summarized bacterial counts through the most recent collection time point, February 3, 2016. **Note:** Both wells received the same source water but different hydraulic fracturing treatments.

Core and Filter analysis

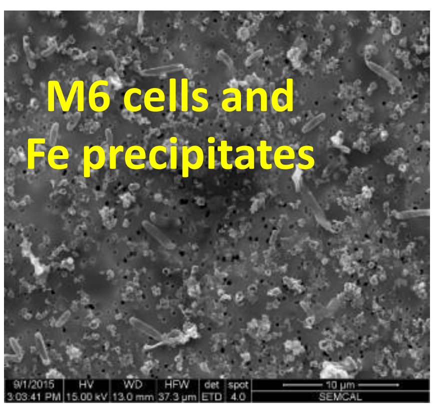


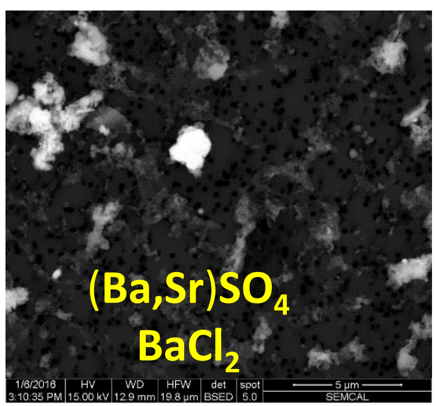
Characterize mineralogy,
organic matter and pore distribution





Dual Beam FIB/SEM and QEMSCAN to relate mineralogy to 3D pore network





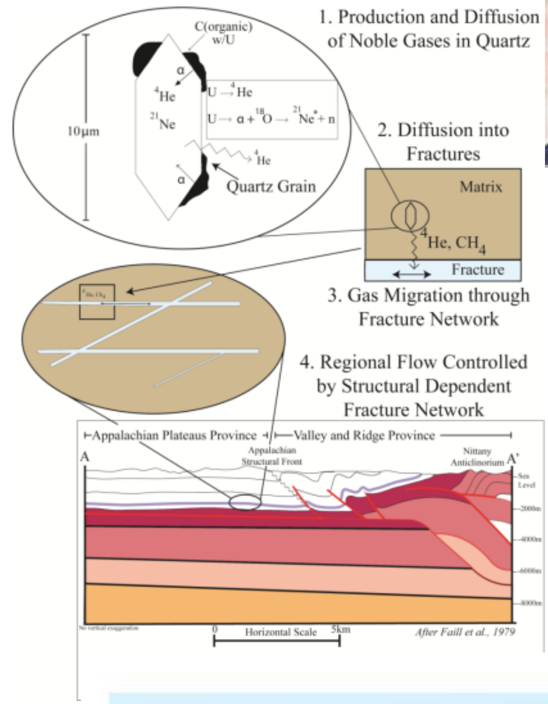
Analysis of filters from flowback to characterize mineral precipitates and microbes.

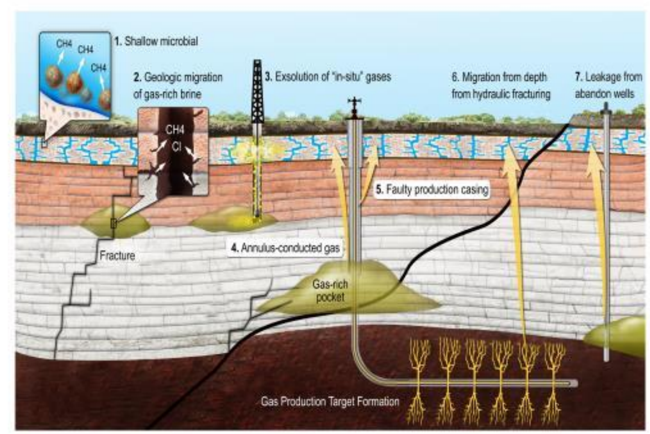
Darrah Lab

Noble Gasses in Core and Fluids

- Tracers for crustal fluid migration
- Samples show no air contamination
- Testing New Multicollector NG-MS Instrument: Only 2 in world for hydrocarbon analysis (Oxford)
  - Determines residence time in natural gases and pore waters
  - Provides increased precision of measurements.
- Beginning analysis on cores and fluid inclusions

  -See poster Grove, Whyte, Darrah
- Data will provide information on extent of fluid migration, permeability, and thermochronology





Driving Innovation ♦ Delivering Results

Scanning of the MSEEL MIP 3H Core

Dustin Crandall

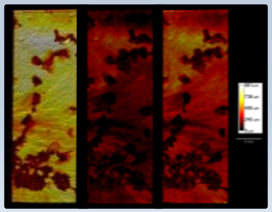
2/12/2016

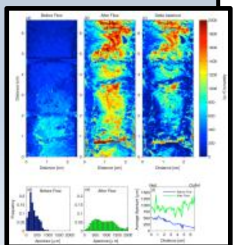
From left to right: Isolated pore space in sandstone; medical CT scanner; Cover of JPT from Jan 2015 highlighting NETL's foamed cement work; Core flow apparatus; Simulated flow velocities in fracture geometry

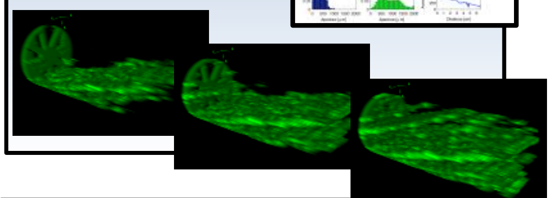
U.S. DEPARTMENT OF ENERGY | National Energy Technology Laboratory

Multi-Scale CT Flow and Imaging Facility

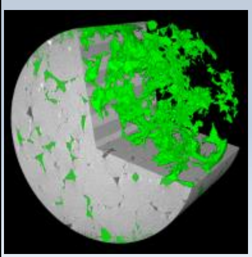
Measuring flow at in situ P, T, stress, and geochemical conditions

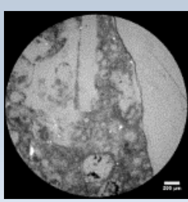




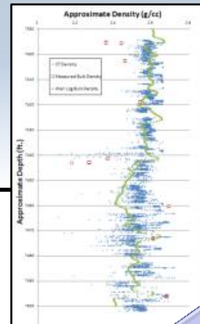


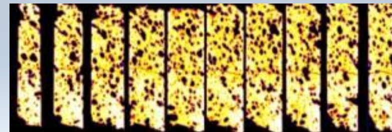
Simulating flow through pore and fracture networks

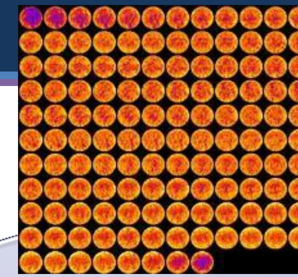




CT/well log comparison



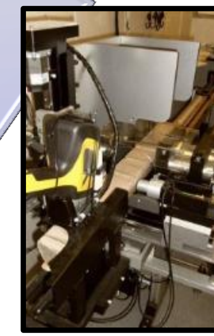




Micro CT Scanner
- Resolution 10^{-6} to 10^{-5} m
- Pore scale

Industrial CT Scanner
-10^{-6} to 10^{-3}m
- Pore & core scale
- Pressure & flow controls

Medical CT Scanner
-10^{-4} to 10^{-2}m
- Core scale
- Pressure, temperature, and flow controls

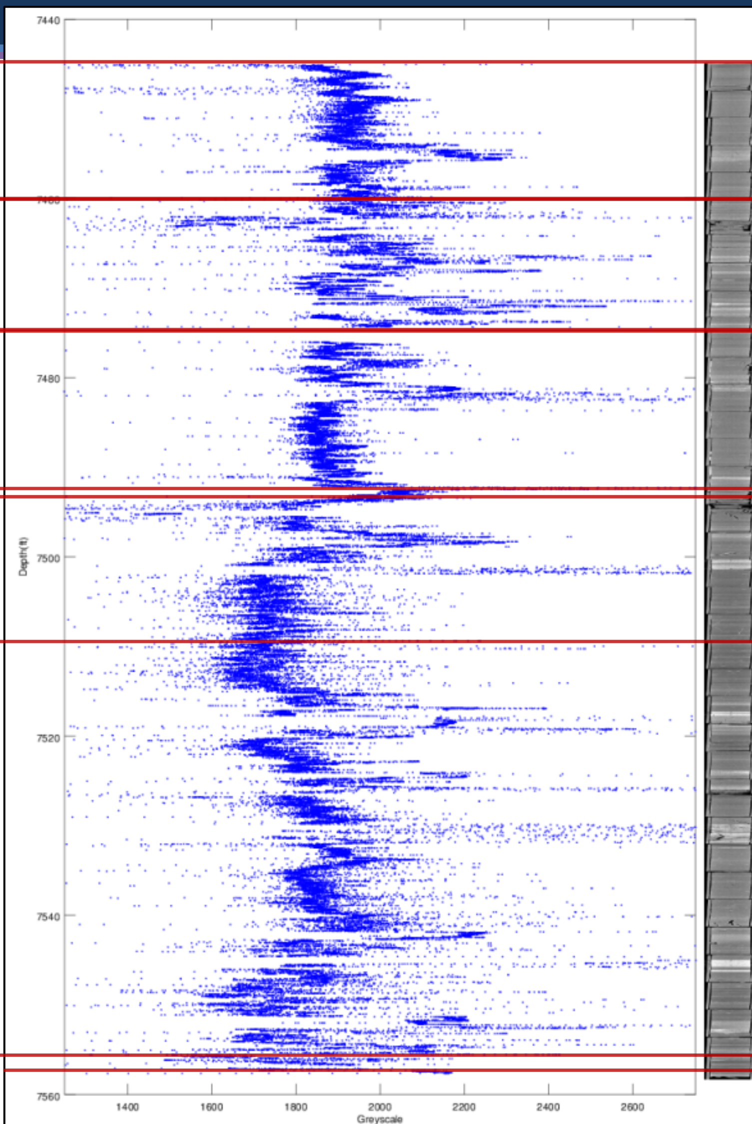


MSCL for geophysical logging

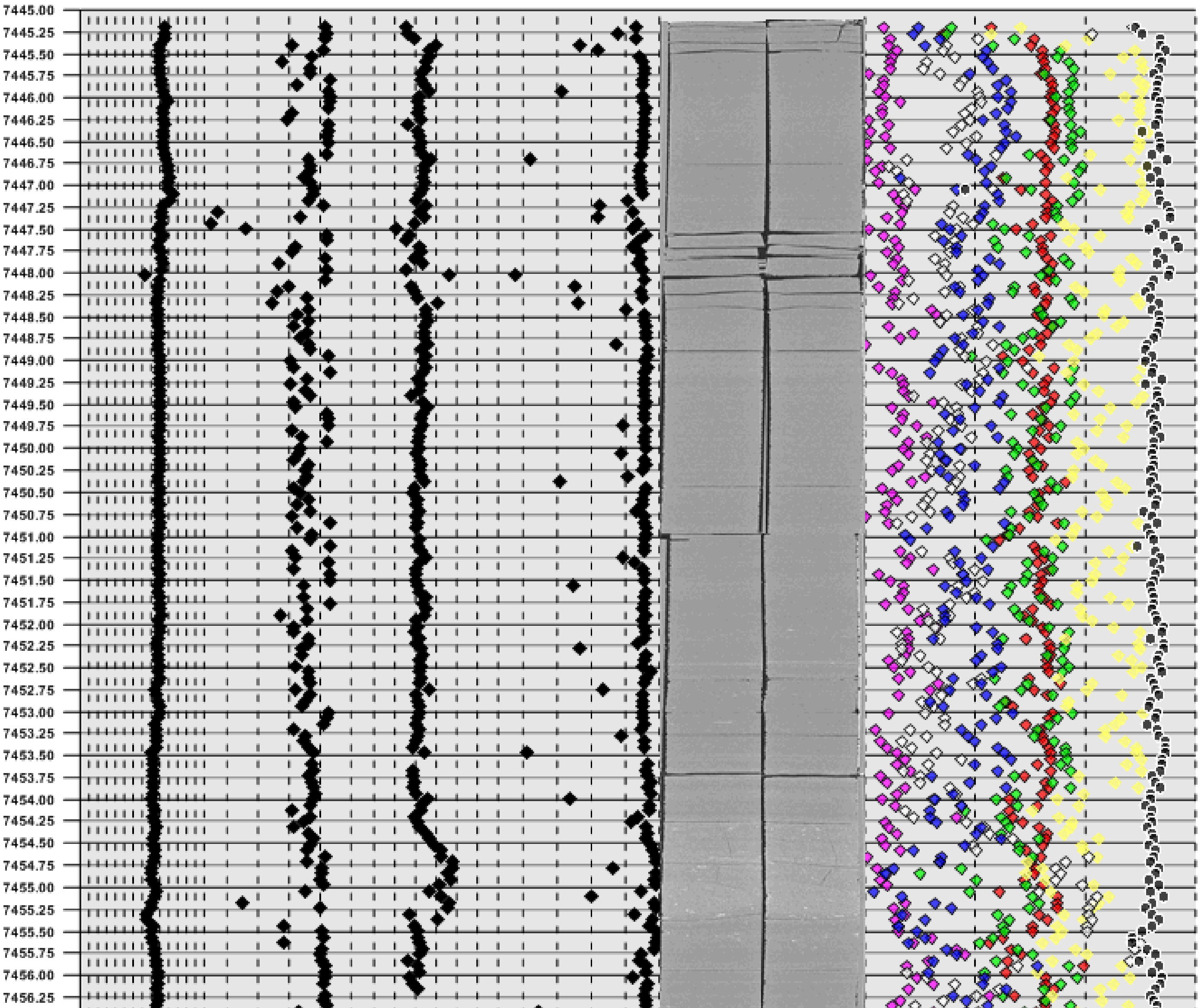
Collaborations

Los Alamos National Laboratory; BR Petrobras; glori energy; Washington University in St. Louis; Pacific Northwest National Laboratory; Princeton University; Berkeley Lab; Baker Hughes; Lawrence Livermore National Laboratory; 中国科学院 Chinese Academy of Sciences; ORMAT; Halliburton; Schlumberger; EERC

High Resolution Scanning



Combined with MSCL Data



Data Available

- If you want any of this data, we really want to get it to you!
  - Medical CT scans are already on MSEEL.org
  - Poster at this meeting
    - Title “Preliminary CT and High Resolution Log Data, Johnathan Moore and myself”
  - Data on disc available
    - We’ve burned a couple of discs for those who want to look at this weekend

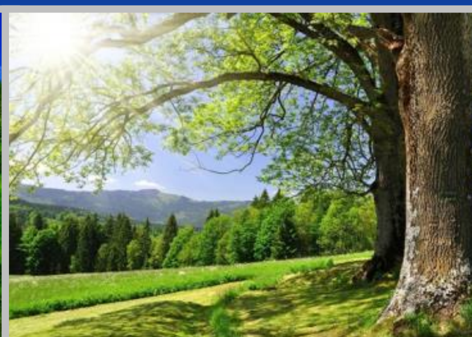
- Thank you!




For More Information, Contact NETL

the ENERGY lab

Delivering Yesterday and Preparing for Tomorrow

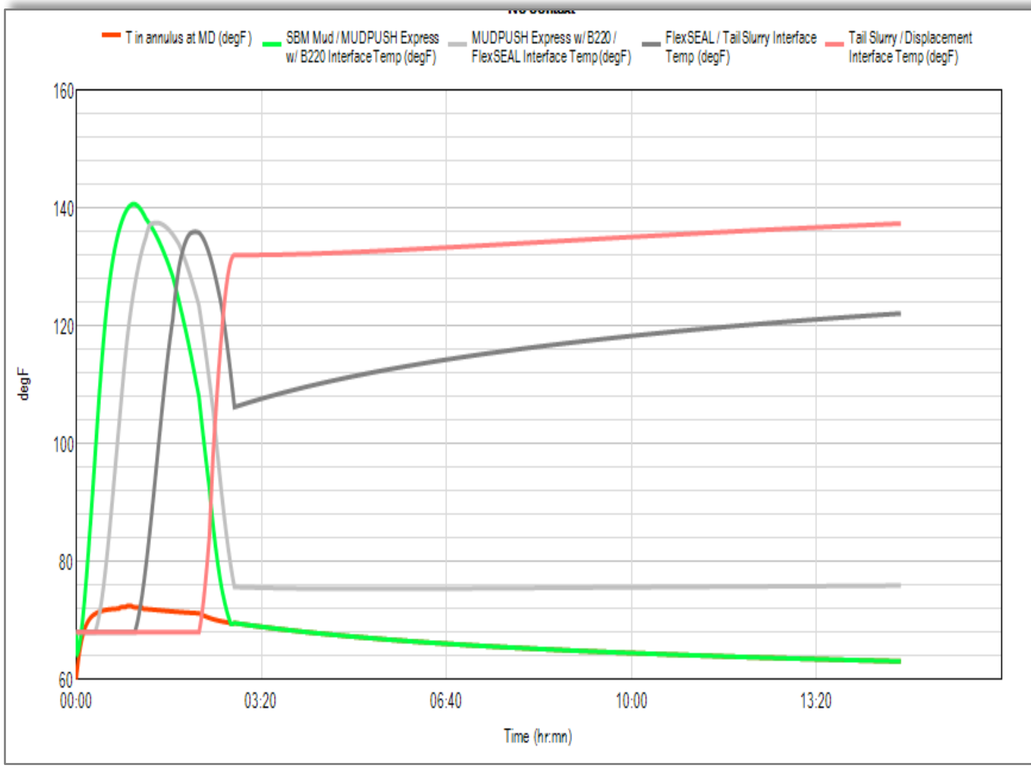



Schlumberger Technology Corporation

- Provided array of products and services to Northeast Natural Energy on MIP wellsite
- Drilling Group
- Characterization Group
- Production Group

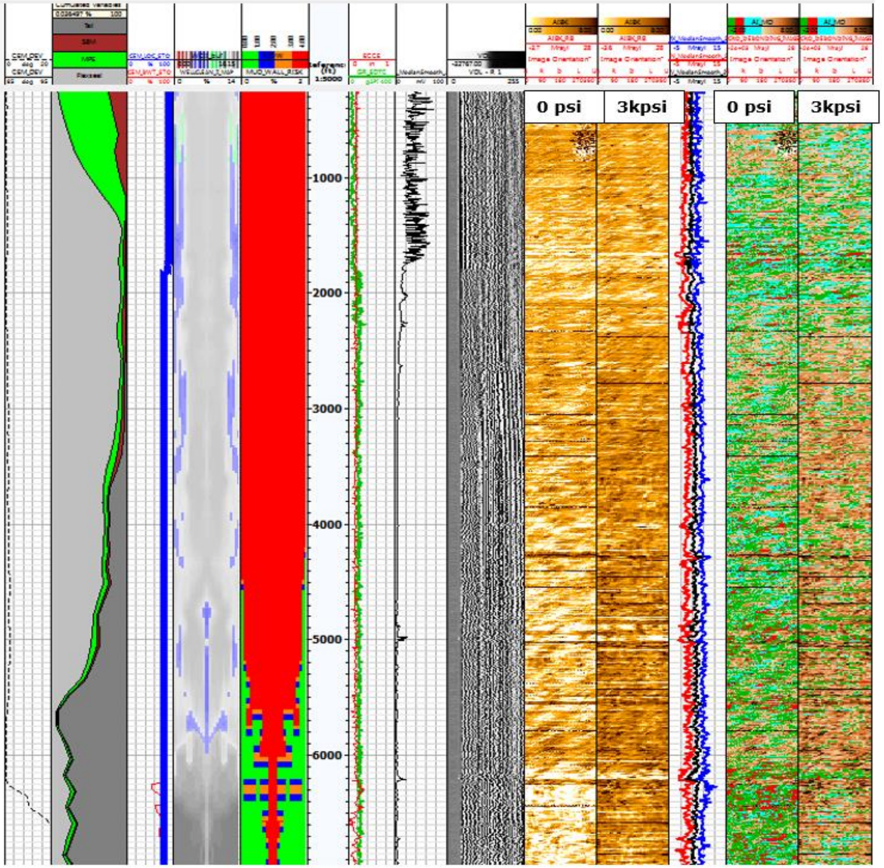
Cement Temperature Finite Element Model Validation using Fiber Optic Field DTS Data

- Validate/calibrate current temperature model with Distributed Temperature Survey (DTS)
- Possibility to include temperature behavior during drilling and post placement cement Heat of Hydration effect



Wellbore Integrity Through Engineered Design, Evaluation and Monitoring

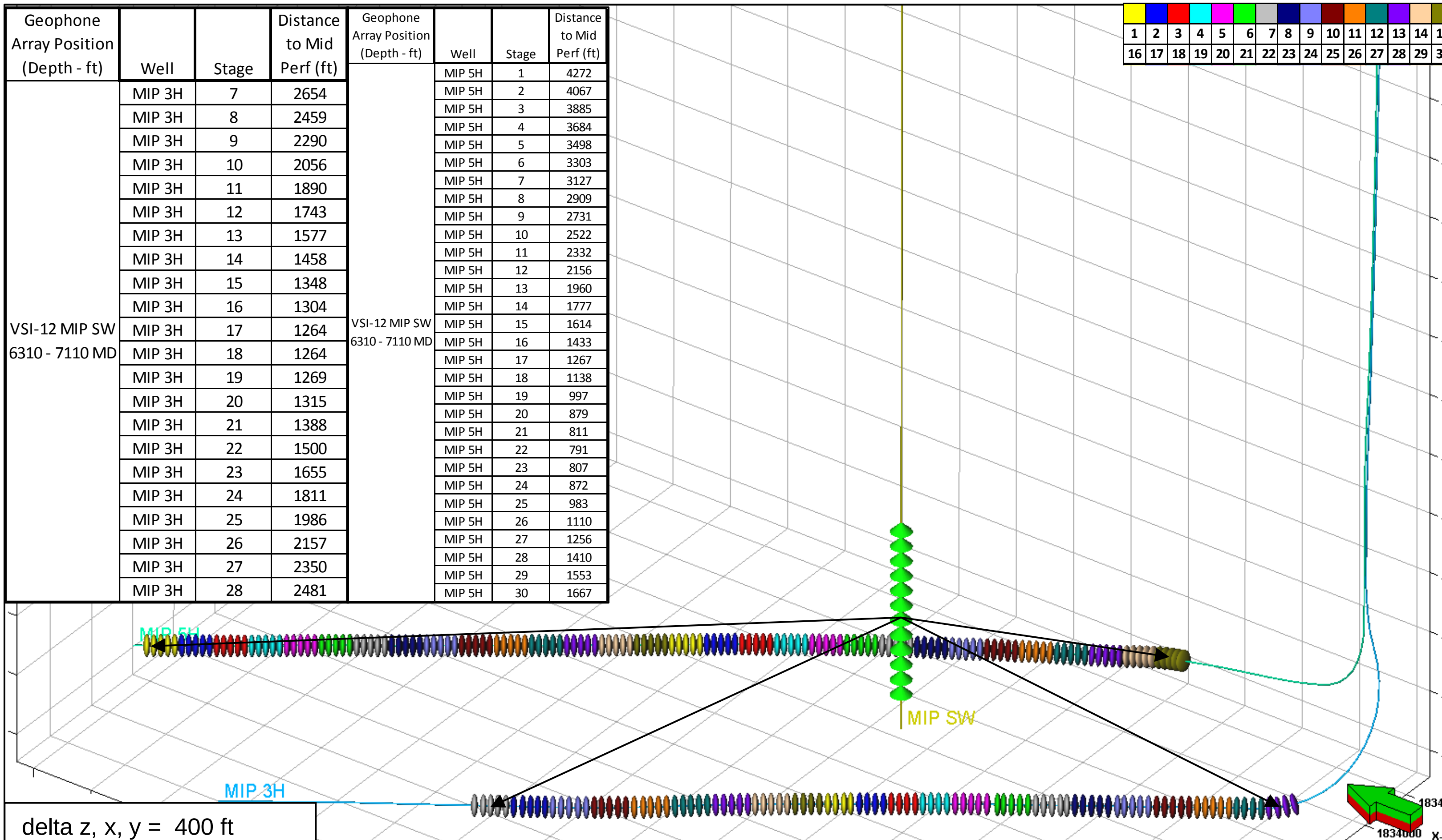
- Design optimization by incorporating formation/borehole data acquired before cement job
- Forecast and measure wellbore integrity
- Identify mechanism of defects in cement placement



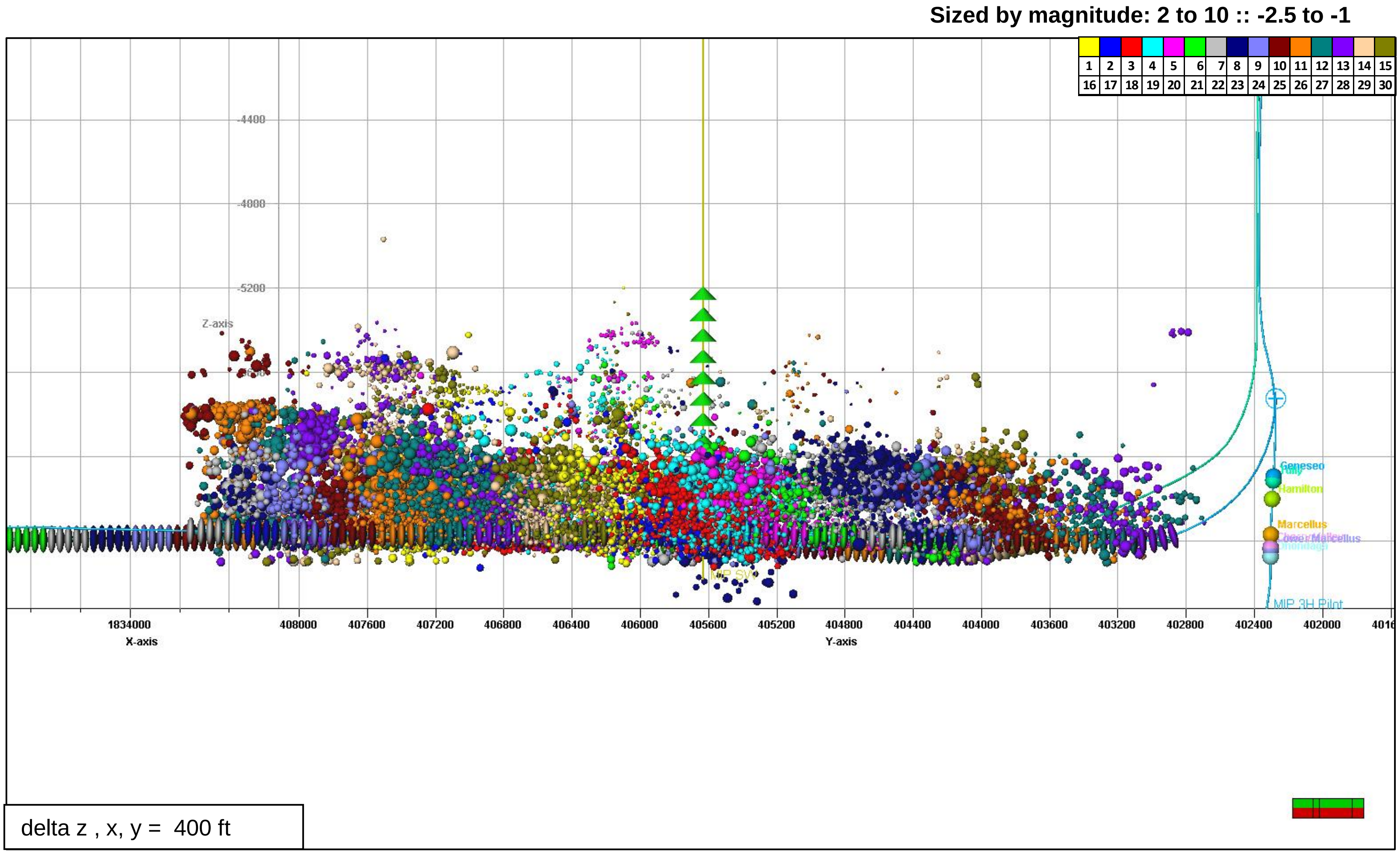
MIP 3H & 5H Microseismic Configuration

Geophone Array Position (Depth - ft)	Well	Stage	Distance to Mid Perf (ft)
VSI-12 MIP SW 6310 - 7110 MD	MIP 3H	7	2654
	MIP 3H	8	2459
	MIP 3H	9	2290
	MIP 3H	10	2056
	MIP 3H	11	1890
	MIP 3H	12	1743
	MIP 3H	13	1577
	MIP 3H	14	1458
	MIP 3H	15	1348
	MIP 3H	16	1304
	MIP 3H	17	1264
	MIP 3H	18	1264
	MIP 3H	19	1269
	MIP 3H	20	1315
	MIP 3H	21	1388
	MIP 3H	22	1500
	MIP 3H	23	1655
	MIP 3H	24	1811
	MIP 3H	25	1986
	MIP 3H	26	2157
	MIP 3H	27	2350
	MIP 3H	28	2481

Geophone Array Position (Depth - ft)	Well	Stage	Distance to Mid Perf (ft)
VSI-12 MIP SW 6310 - 7110 MD	MIP 5H	1	4272
	MIP 5H	2	4067
	MIP 5H	3	3885
	MIP 5H	4	3684
	MIP 5H	5	3498
	MIP 5H	6	3303
	MIP 5H	7	3127
	MIP 5H	8	2909
	MIP 5H	9	2731
	MIP 5H	10	2522
	MIP 5H	11	2332
	MIP 5H	12	2156
	MIP 5H	13	1960
	MIP 5H	14	1777
	MIP 5H	15	1614
	MIP 5H	16	1433
	MIP 5H	17	1267
	MIP 5H	18	1138
	MIP 5H	19	997
	MIP 5H	20	879
	MIP 5H	21	811
	MIP 5H	22	791
	MIP 5H	23	807
	MIP 5H	24	872
	MIP 5H	25	983
	MIP 5H	26	1110
	MIP 5H	27	1256
	MIP 5H	28	1410
	MIP 5H	29	1553
	MIP 5H	30	1667



Side View Radius Filtered Events – 2,500 ft



Executive Summary of Conclusions

- MIP 3H Average Half Length: 784ft, Average Height: 496ft, Average Azimuths N76°E
- MIP 5H Average Half Length: 618ft, Average Height: 540ft, Average Azimuths N63°E
  - Generally displays higher fracture height growth indicating the jobs were placed in geologically similar zones as well as creating similar geometries and pressure responses
- Overall event complexity indicates higher stress anisotropy when compared to other unconventional plays.
- Higher amounts of 40/70 sand resulted in larger fracture geometries.
- Higher viscosity fracturing fluid leads smaller fracture height growth, although it will deliver better proppant transport properties.
- Microseismic, lateral logs, and pumping data can be used to create a calibrated DFN model with synthetic microseismic.
- Normalized production comparison recommended in order to determine the effect of slight fluid and completion alteration

Enhanced Perforation Design, Performance and Monitoring

Challenge

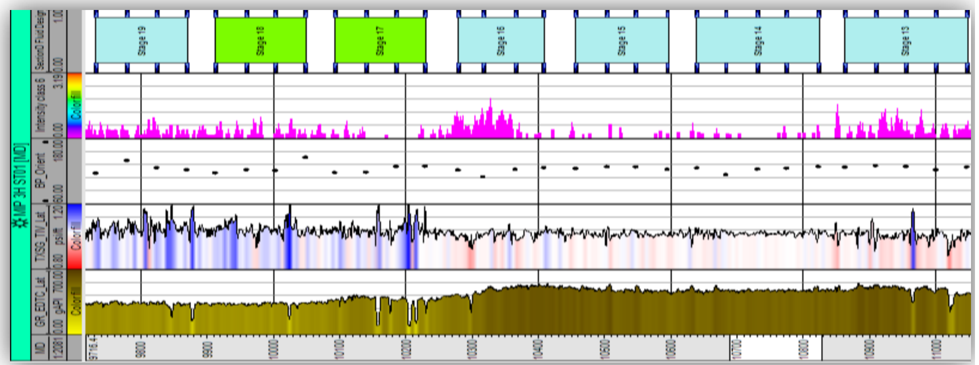
- Ensure optimal lateral coverage while improving efficiency and EUR

Goal

- Predict and optimize perforation cluster efficiency while monitoring performance

Key Enablers

- Lateral measurements (SSCAN, QGEO, USIT)
- Fiber optics monitoring (hDVS, DTS)
- SLB proprietary engineering workflows



Steps

- Strategic stage placement based on rock fabric and mechanical properties
- Limited entry perforation design based on estimated breakdown pressure
- Performance monitoring with Fiber optics (hDVS, DTS)

Preliminary Results

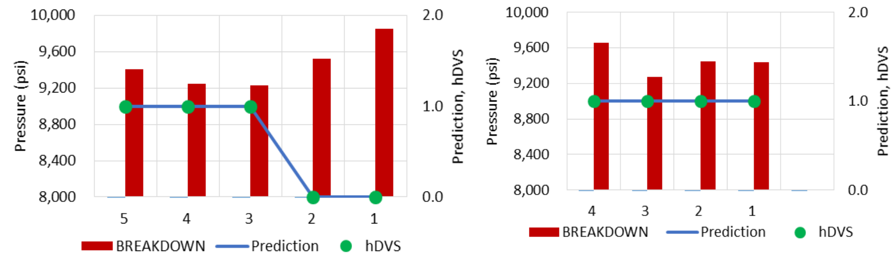


Figure 1: Estimated breakdown pressure, predicted and actual (hDVS) cluster efficiency. Geometric design (left) versus Limited Entry design (right).

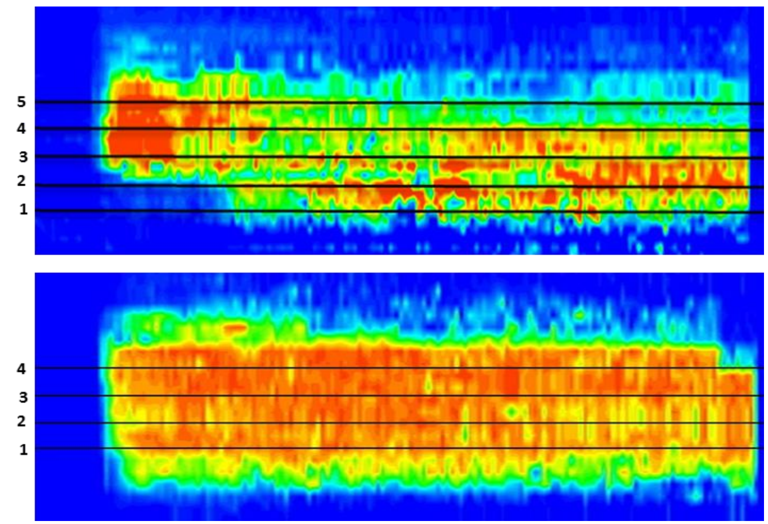


Figure 2: Fiber optics hDVS data comparing Geometric design (top) versus Limited Entry design (bottom). Limited entry design show better activity distribution across treatment stage.

Complex Fracture Modeling in Marcellus Shale with Slickwater and Visco-Elastic Stimulation Fluids

Challenge

- Improve frac placement and EUR with reduce water usage

Goal

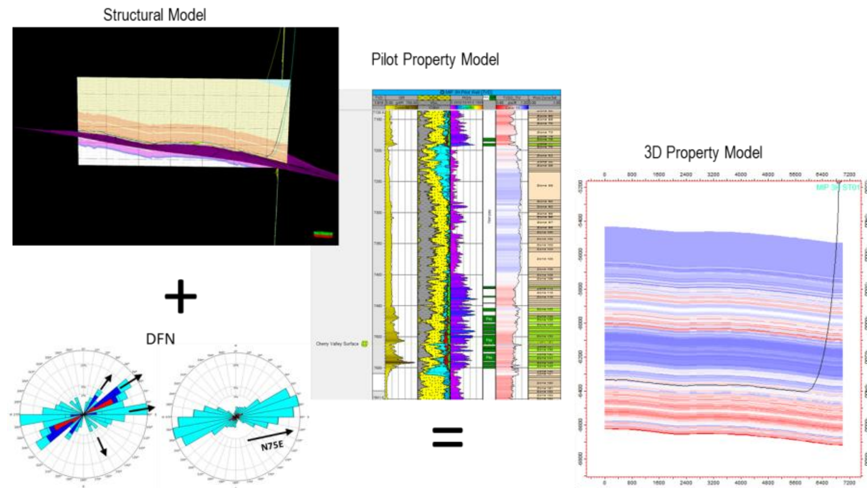
- Evaluate Slickwater and Sapphire VF fluid systems and provide recommendations based on operational risk and production performance

Key Enablers

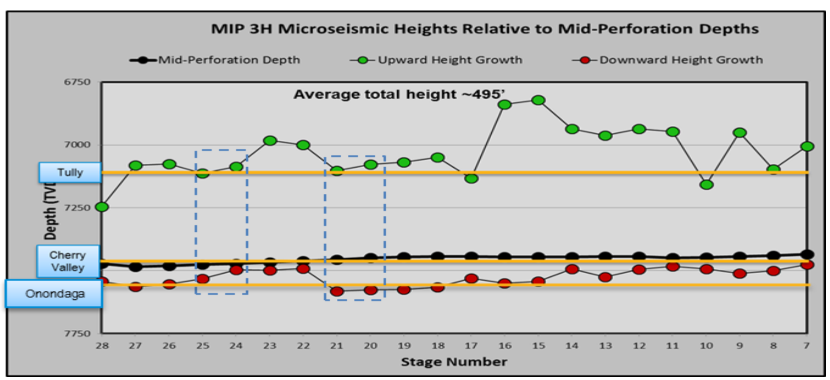
- Geomechanical and Petrophysical measurements
- Mangrove and SLB engineering workflows
- Sapphire VF, Microseismic monitoring

Preliminary Results

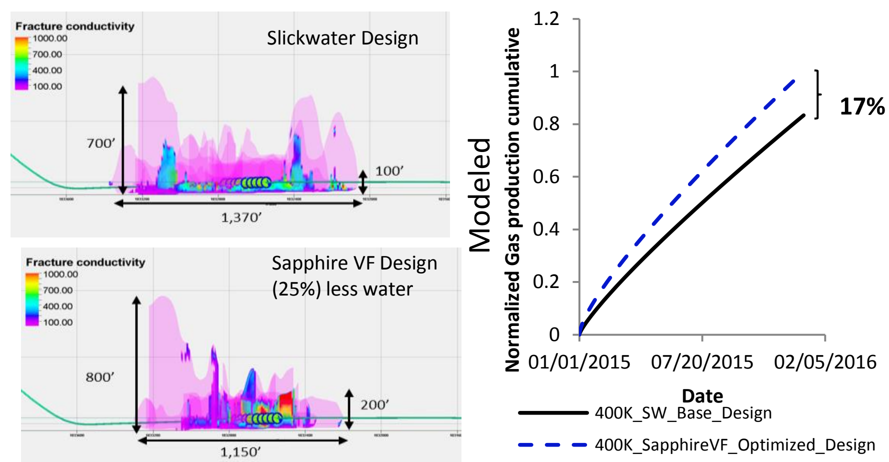
- Decreased water usage by 25% with 30% increase in avg. PPA (1.33 to 1.75) and 100% placement



3D property modeling. Initial framework for hydraulic fracture simulation



Sapphire VF stages (blue rectangle) well contained within the Marcellus



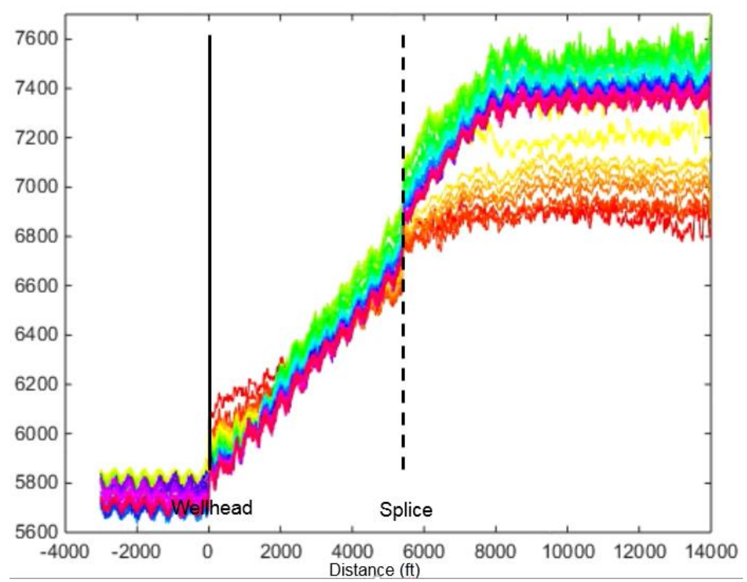
Sapphire VF design (bottom left) showing better conductivity distribution compared to Slickwater design (top left)

Monitoring static strain while casing running in hole with Fiber Optic Cable

- Identify well deviation and tension applied on the cable while running casing in hole using DSTS (Dynamic Strain and Temperature Sensing) technology.

Monitoring temperature and strain during cure after cementing

- Strain and temperature measurements from fiber optic cable were used to monitor cement job and post-job curing period. Analysis will be performed during the cure after cementing to better understand how the cure is behaving.



Monitoring cementing job using fast update BOTDR

- This publication will explain the physics of the technology and possible applications for better understanding in real time the impact on cement volumes or post cement integrity

Influence of Completion Deployment Techniques on DTS response during Frac Monitoring

DTS has historically been obtained by deploying a fiber on a control line strapped to tubing inside a wellbore. More recently, control lines are being deployed exterior to casing for plug-and-perf jobs.

The DTS response during injection is completely different in the two cases!! Paper would present mathematical and field-cases demonstrating what is going on, including the NNE dataset

Influence of Gauge Length on results from Fiber Acoustics during Frac Stimulation

Fiber Acoustics relies on backscatter of Rayleigh waves. The raw data is sampled in the time domain and over a continuous length of deployed fiber. For each time and depth, the amplitude and phase of that backscatter is computed in real-time. This computation requires a window of depth called the gauge-length. Long gauge lengths give blurry images if too long, short gauge lengths introduce numerical artifacts if too short. This paper would examine the interplay of depth-sampling and gauge length on the NNE dataset.

Monitoring frac job using combined DAS and DTS

This publication will examine the DAS and DTS data obtained from the NNE data set and provide insight into the physics of distributed data during stimulation. In particular, it will give an answer to the question of why are there apparent time intervals of DTS warming in the middle of each frac stage

Real-Time Interactive Remote Display of DTS and DAS Data for Optimization of the Well Treatment Process

In this paper we describe a novel solution to the remote display of DTS and DAS data to facilitate real-time decision making. Wellsite data is processed automatically onsite to produce a light-weight data format suitable for transmission over cellular and VSAT links to remote servers. A graphical interface provides an interactive display and interpretation of data on a web browser. This can then be made available to distributed experts and clients anywhere in the World. This approach is demonstrated using data from a stimulation treatment in US Land.

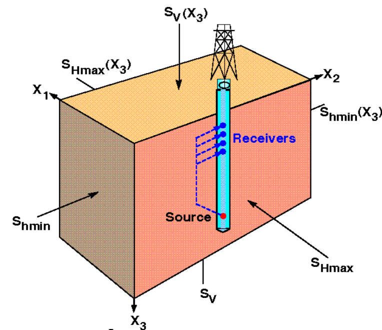
Improving Geomechanics Model with New Dipole Flexural Inversion Workflow

Objective

- Improve characterization of elastic properties and stress profiles in Marcellus using the new dipole flexural inversion workflow to better predict hydraulic fracture growth

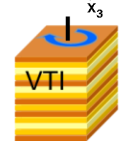
Key Benefits

- Additional Cij parameters estimated from the new workflow
- Lower uncertainty in Stoneley modeling due to sensitivity to mud slowness
- Better understanding of formation anisotropic elastic properties
- Improvements in closure stress estimation



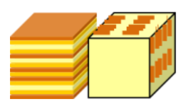
$$C_{33} = \rho_b V_P^2$$
$$C_{44} = \rho_b V_{slow-shear}^2$$
$$C_{55} = \rho_b V_{fast-shear}^2$$
$$C_{66} = \rho_b V_{Stoneley-shear}^2$$

$$C_{ij} = \begin{bmatrix} C_{11} & C_{12} & C_{13} & 0 & 0 & 0 \\ C_{12} & C_{22} & C_{23} & 0 & 0 & 0 \\ C_{13} & C_{23} & C_{33} & 0 & 0 & 0 \\ 0 & 0 & 0 & C_{44} & 0 & 0 \\ 0 & 0 & 0 & 0 & C_{55} & 0 \\ 0 & 0 & 0 & 0 & 0 & C_{66} \end{bmatrix}$$



$$\sigma_h - \alpha_h P_p = \frac{E_h}{E_V}\frac{\nu_V}{1-\nu_h}\left(\sigma_V - \alpha_V P_p\right) + \frac{\varepsilon_h E_h}{\left(1-\nu_h^2\right)} + \frac{\varepsilon_H \nu_h E_h}{\left(1-\nu_h^2\right)}$$

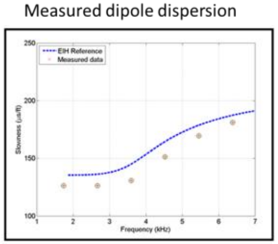
K_o



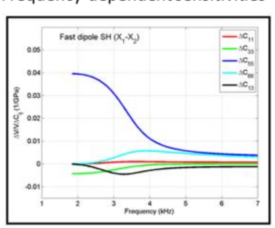
$$\sigma_h - \alpha_h P_p = \frac{C_{13}}{C_{33}}\left(\sigma_V - \alpha_V P_p\right) + \left(C_{11} - \frac{C_{13}C_{13}}{C_{33}}\right)\varepsilon_h + \left(C_{12} - \frac{C_{13}C_{23}}{C_{33}}\right)\varepsilon_H$$

Example

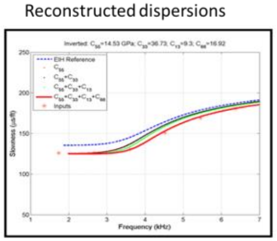
Measured dipole dispersion



Frequency-dependent sensitivities



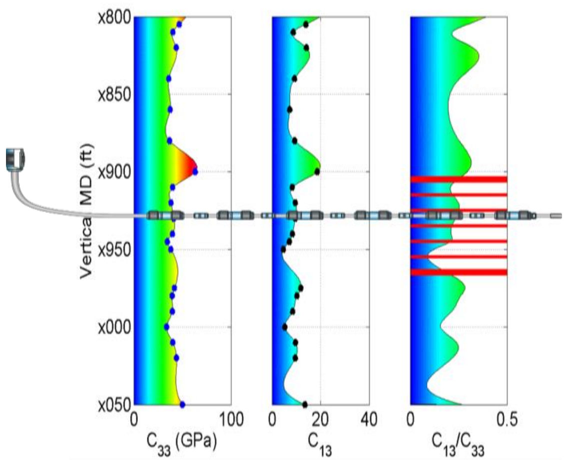
Reconstructed dispersions



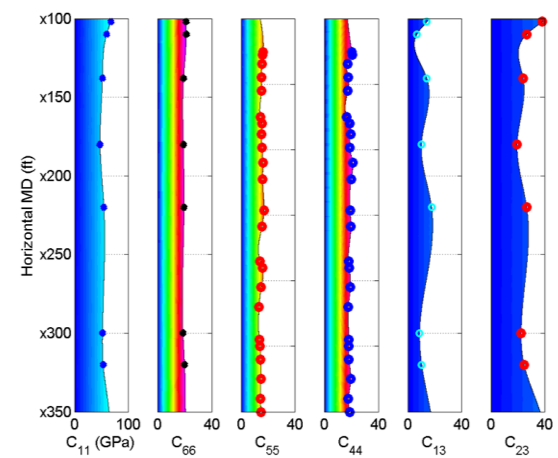
Sequential inversion of TI-constants
C55=14.5 GPa
C33=36.7
C13=9.3
C66=16.9

C55=C44; and C13=C23

Pilot

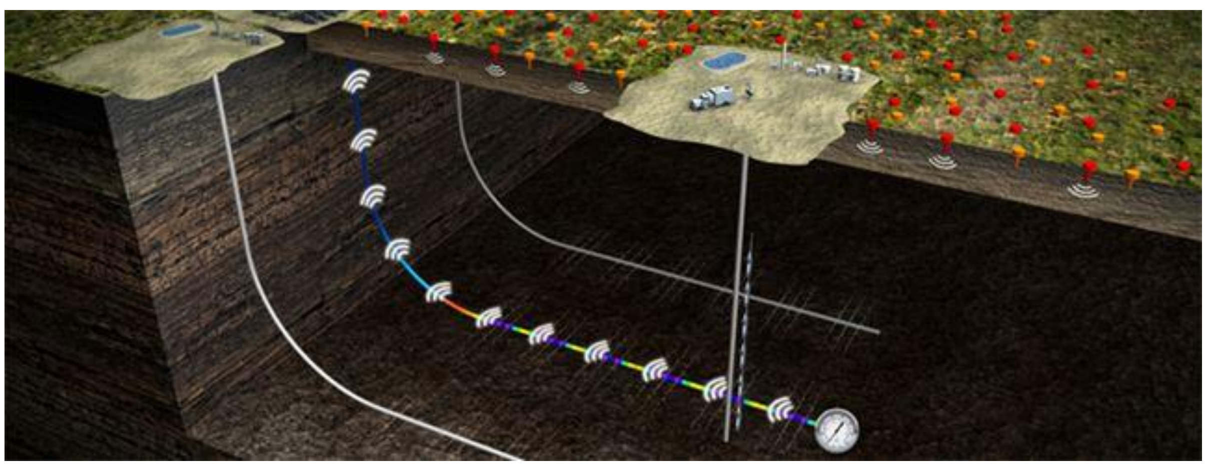


Lateral



Mapping Fiber-optic Cable and Perforation Placement

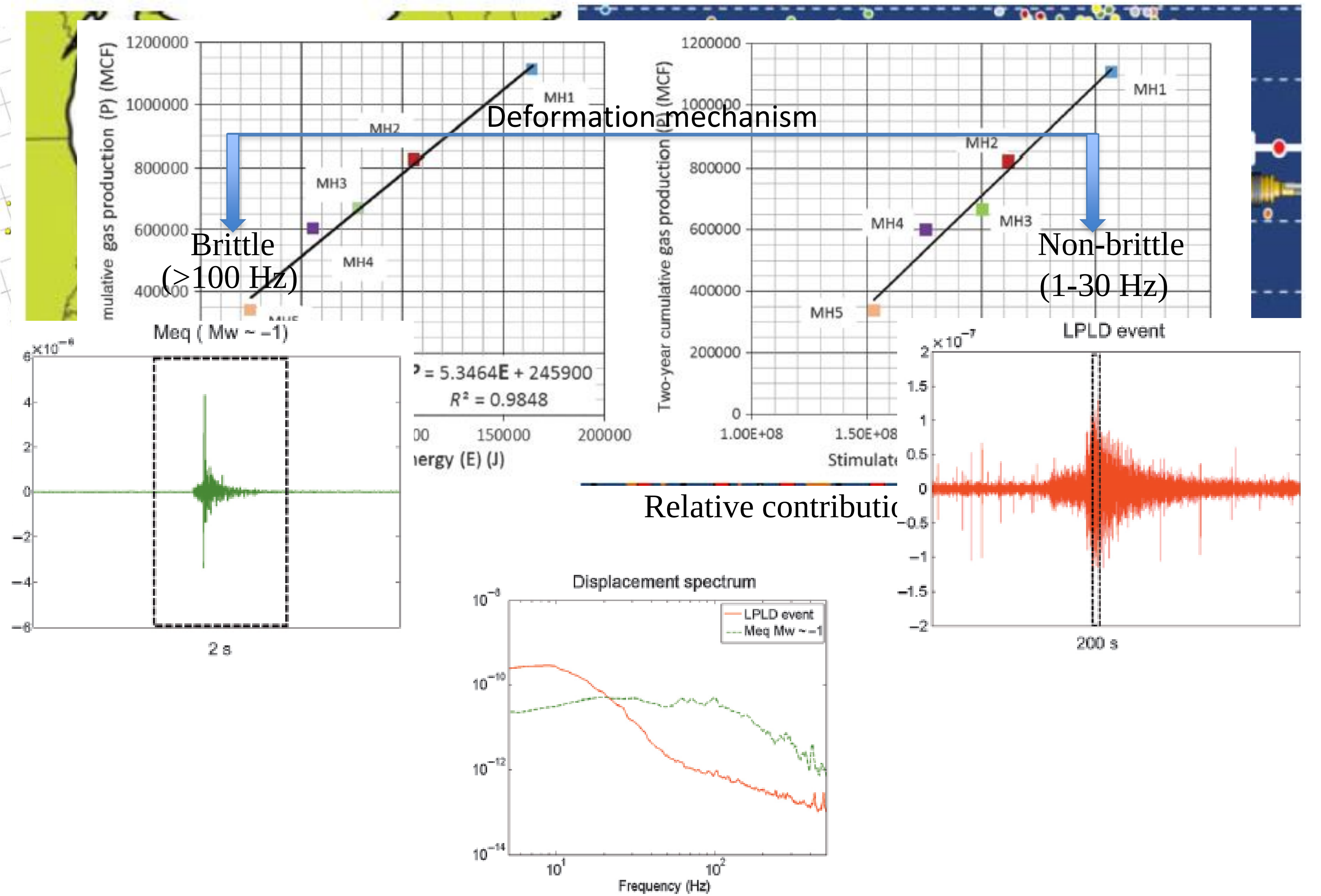
- Monitors connected through fiber optic cables
- Capable of monitoring temperature and pressure downhole remotely and in real-time
- Identifying downhole conditions related to production
- Acute and Chronic flow patterns

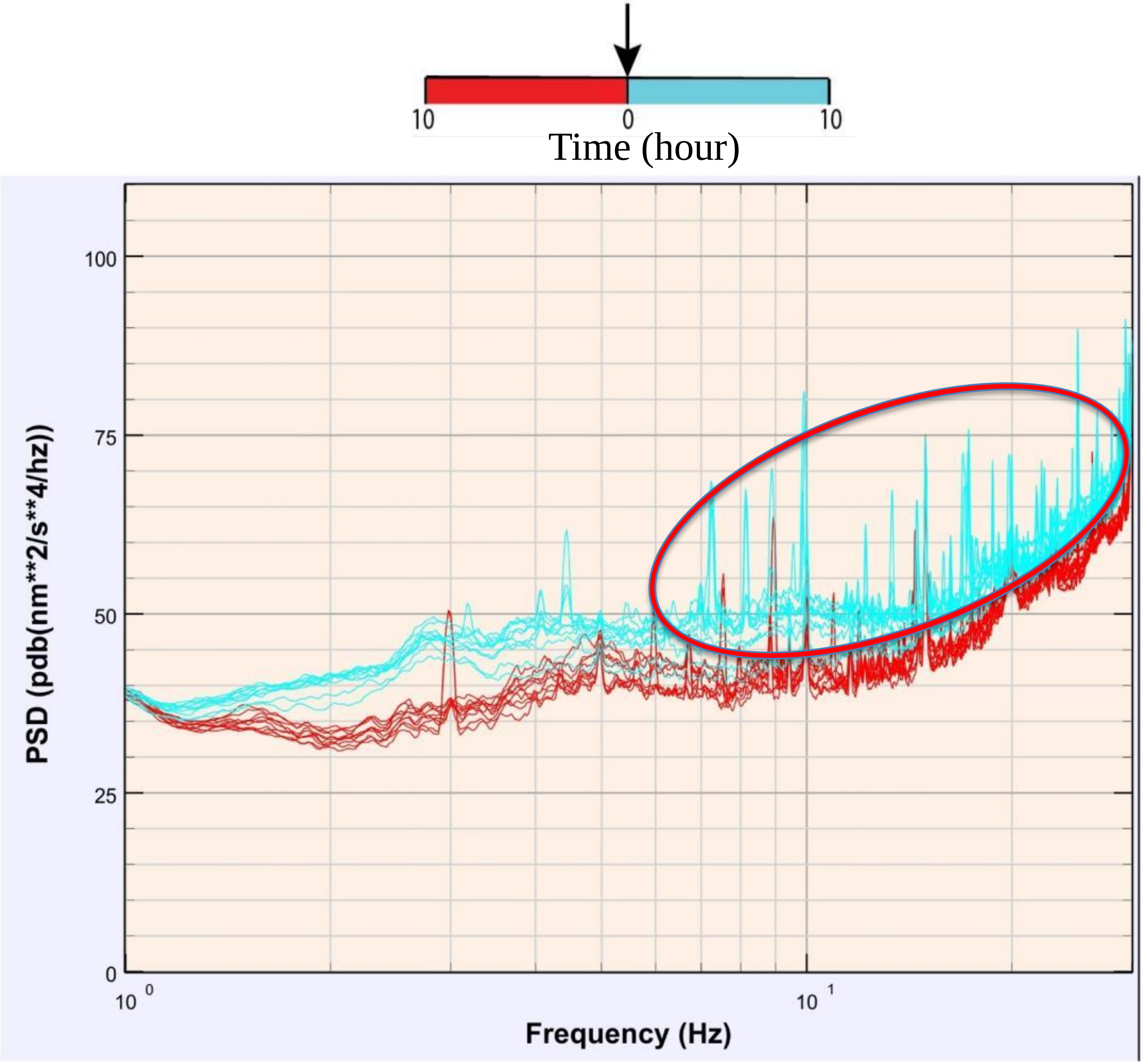


Mapping Fiber-optic Cable and Perforation Placement

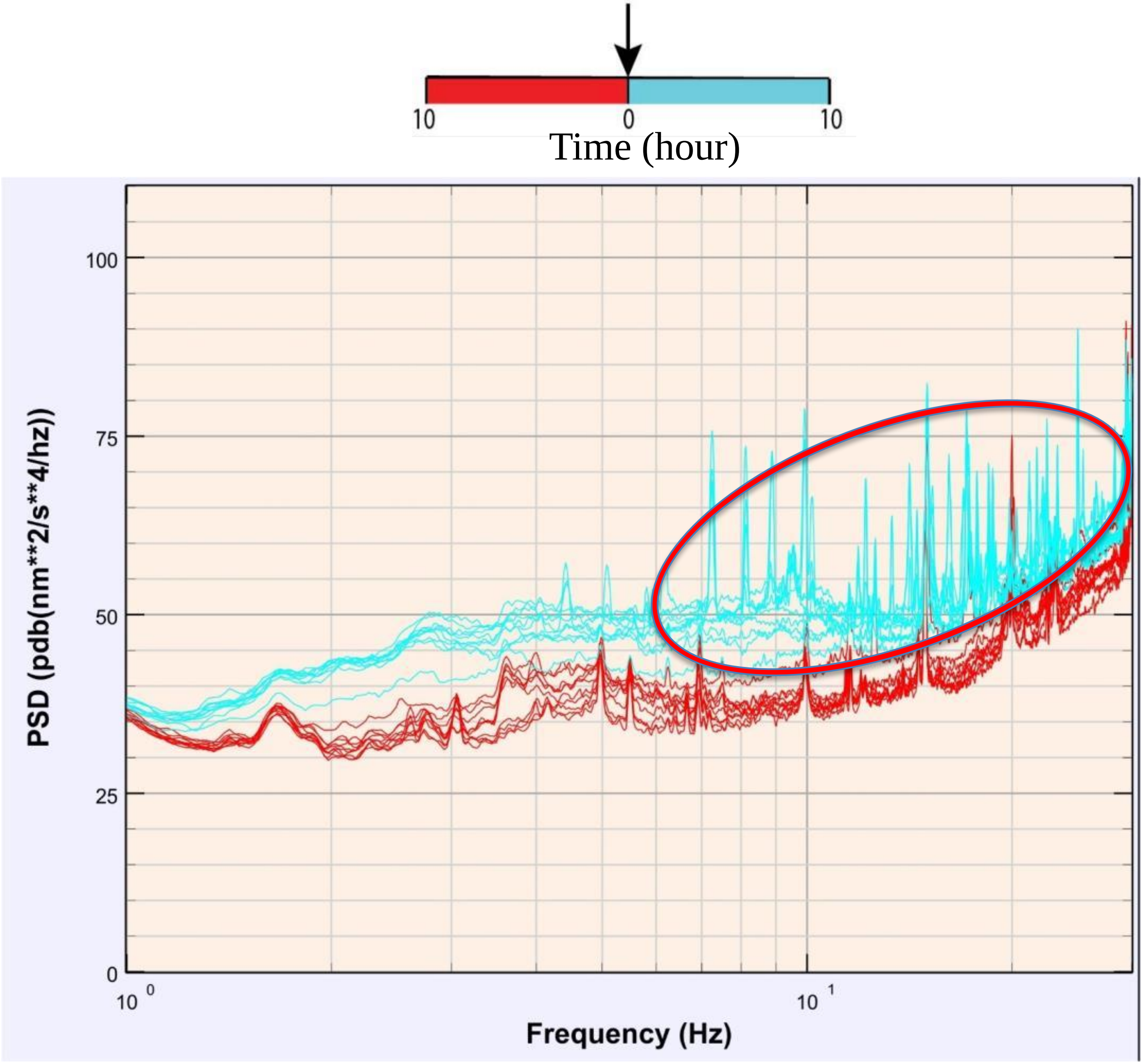
- Wireline Perforating Platform – Toolset allowing measurements while perforating
- Originally used for orienting perforations in multi-string completions. Currently being used to detect fiber optics outside of casing.
- Run to ensure orientation of perforations away from destructible monitoring and signal transporting elements
- Integrating Standard Operating Procedures for new use in horizontal Pumpdown environments

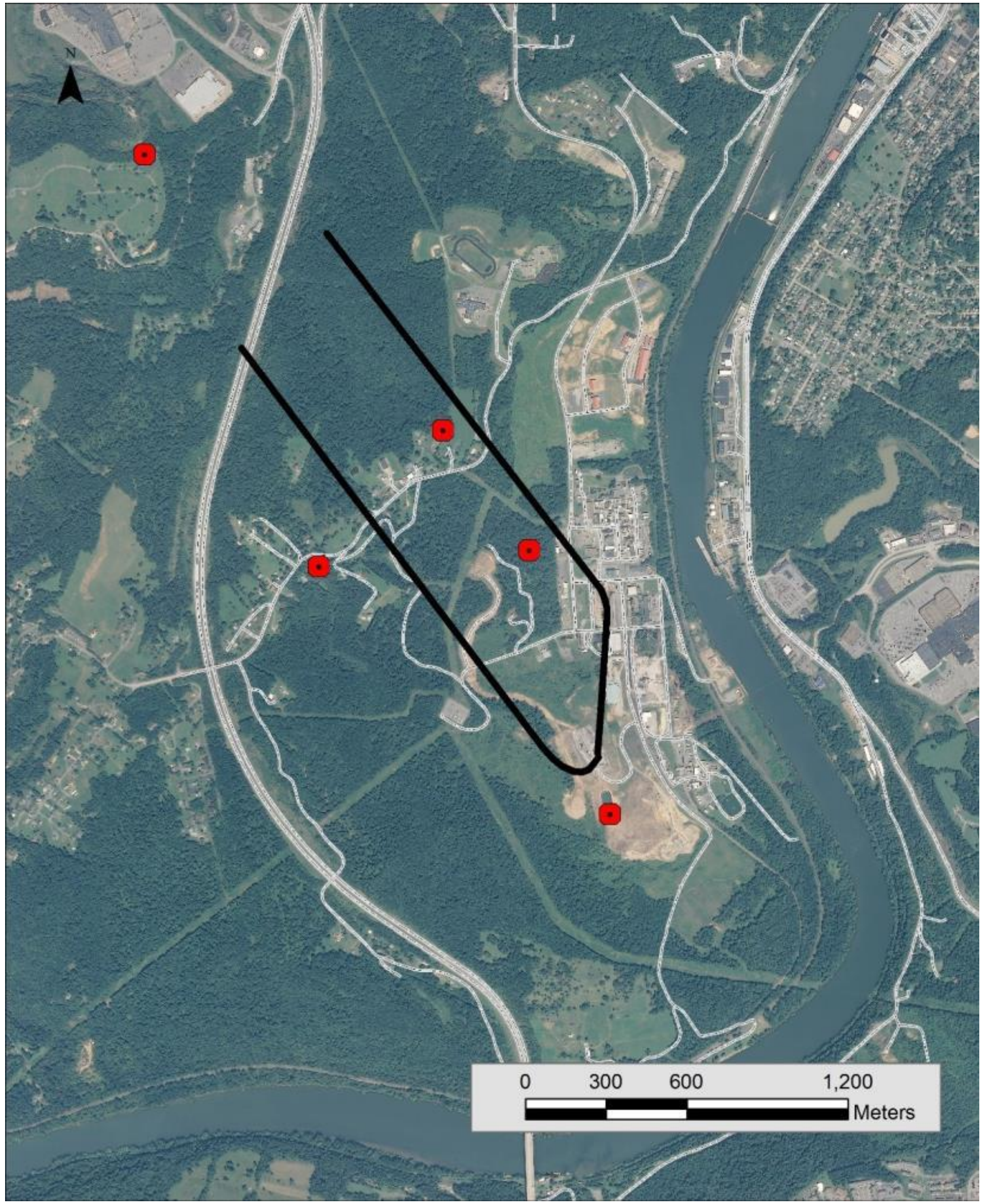
Surface seismic monitoring at MSEEL: Slow shear-slip deformation


Deformation mechanism
Brittle
(>100 Hz)
Non-brittle
(1-30 Hz)
Relative contributio
Two-year cumulative gas production (P) (MCF)
1200000
1000000
800000
600000
400000
200000
0
MH1
MH2
MH3
MH4
MH5
P = 5.3464E + 245900
R^2 = 0.9848
150000
200000
nergy (E) (J)
1.00E+08
1.50E+08
Stimulat
Meq (Mw ~ −1)
2 s
LPLD event
200 s
Displacement spectrum
LPLD event
Meq Mw ~ −1
Frequency (Hz)



Comparison of power spectra


10
0
10
Time (hour)
100
75
50
25
0
PSD (pdb(nm**2/s**4/hz))
10^0
10^1
Frequency (Hz)



Surface network and well location

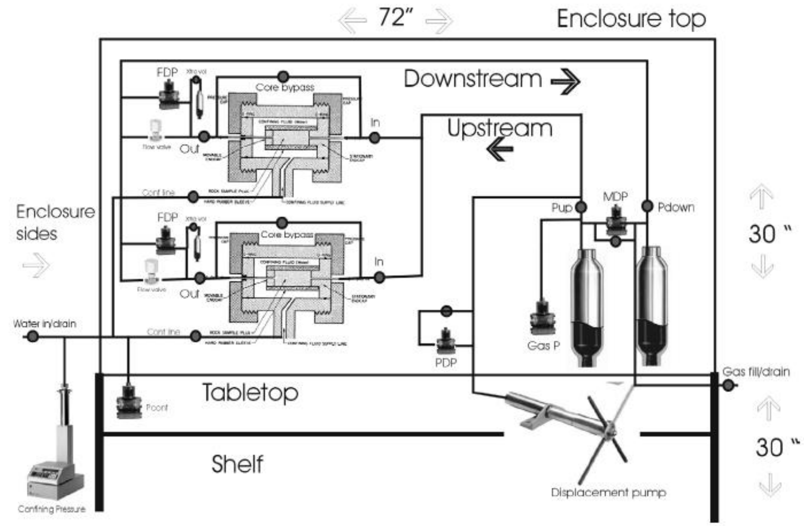
Measurement of Key Shale Petrophysical Properties

- **Porosity**
- **Permeability**
- **Compressibility**
- **Stress Effects**
- **Adsorption**

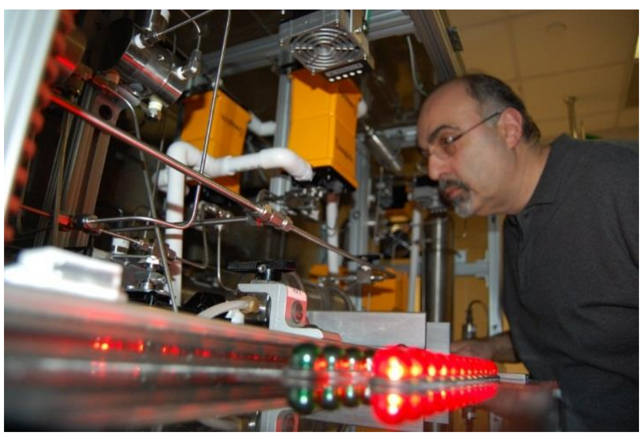
Precision Petrophysical Analysis Laboratory (PPAL)

- **Steady State Permeability Measurement**
  - **Impact of stress on permeability**
  - **Modified Klinkenburg (Double Slippage) Correction**
  - **Fracture Closure Pressure**

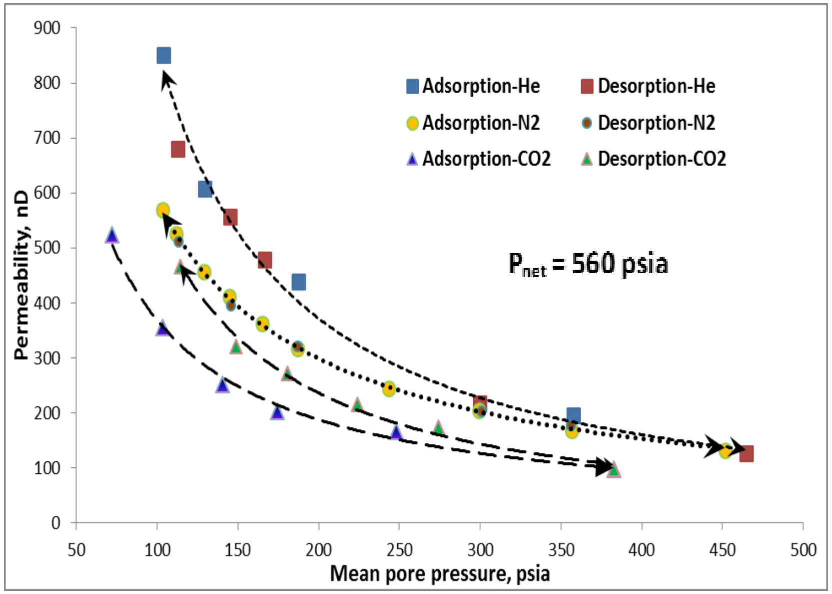
Precision Petrophysical Analysis Laboratory (PPAL)

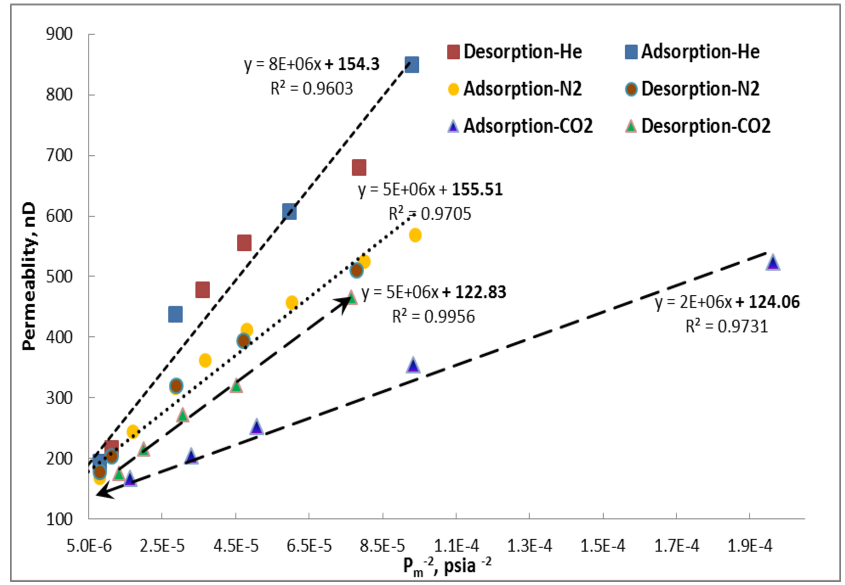


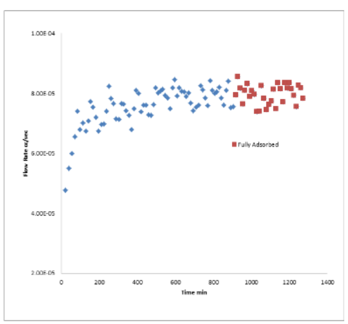
Layout of the PPAL components and plumbing

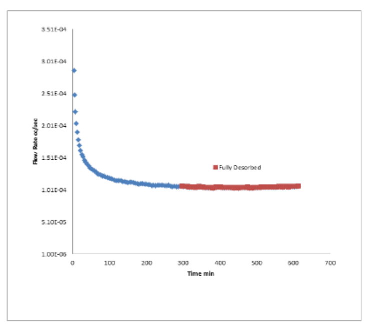


Double Slippage Correction



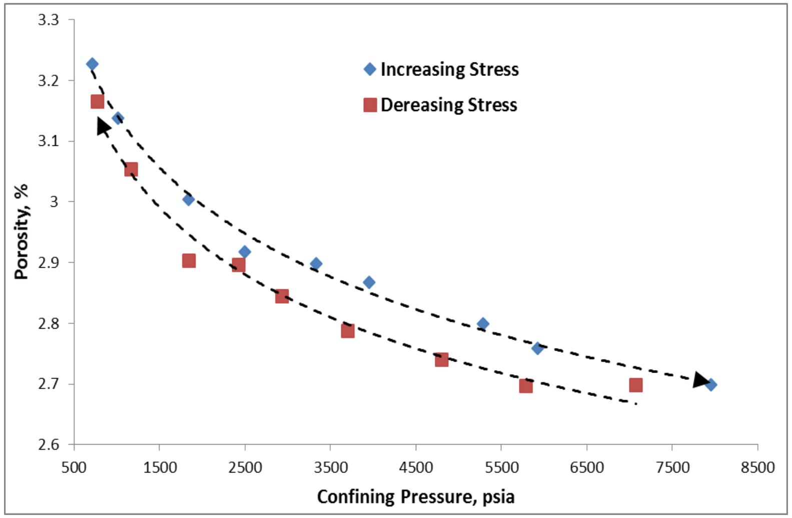


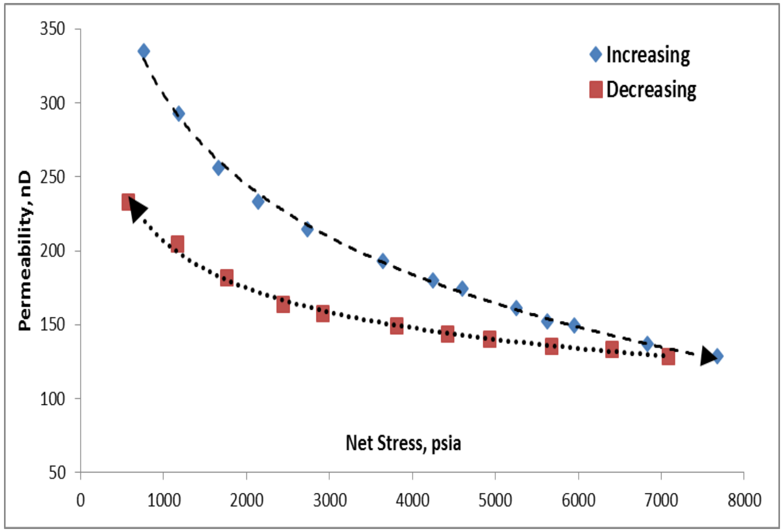


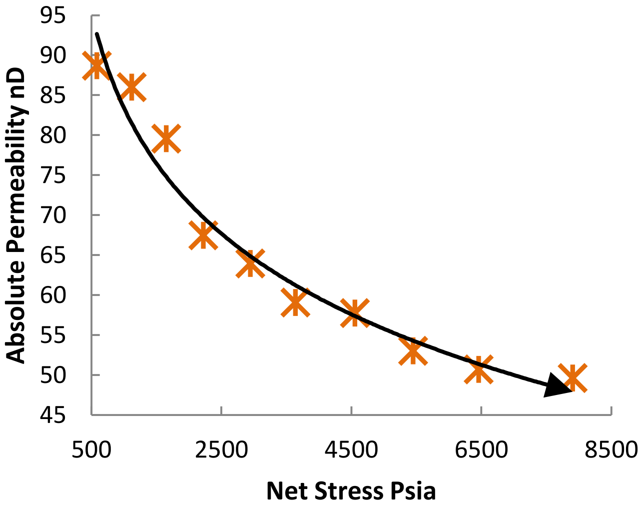


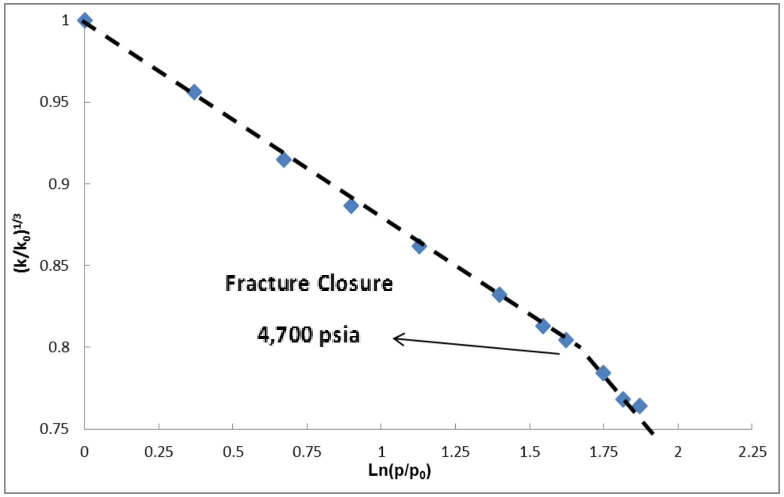
$$K_a = K\left[1+\left(\frac{b^2 L_{Ke}}{\lambda}\right)\frac{1}{p^2}\right]$$

Impact of Stress

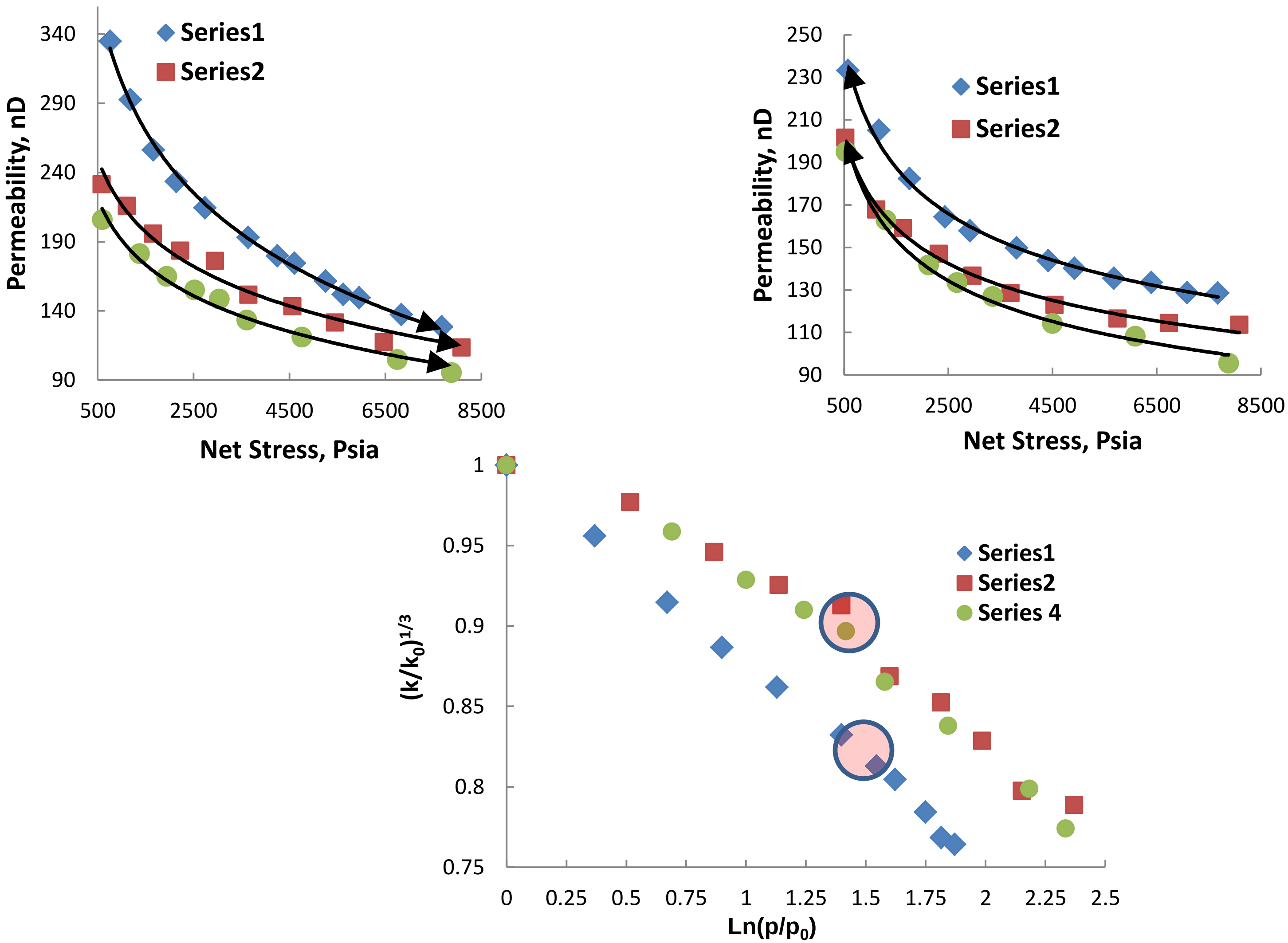








Sequential Stress

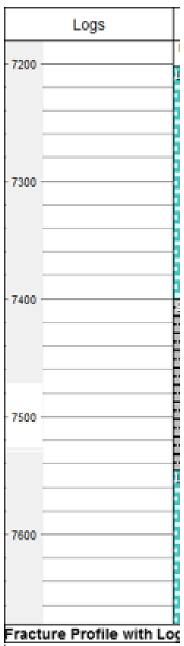


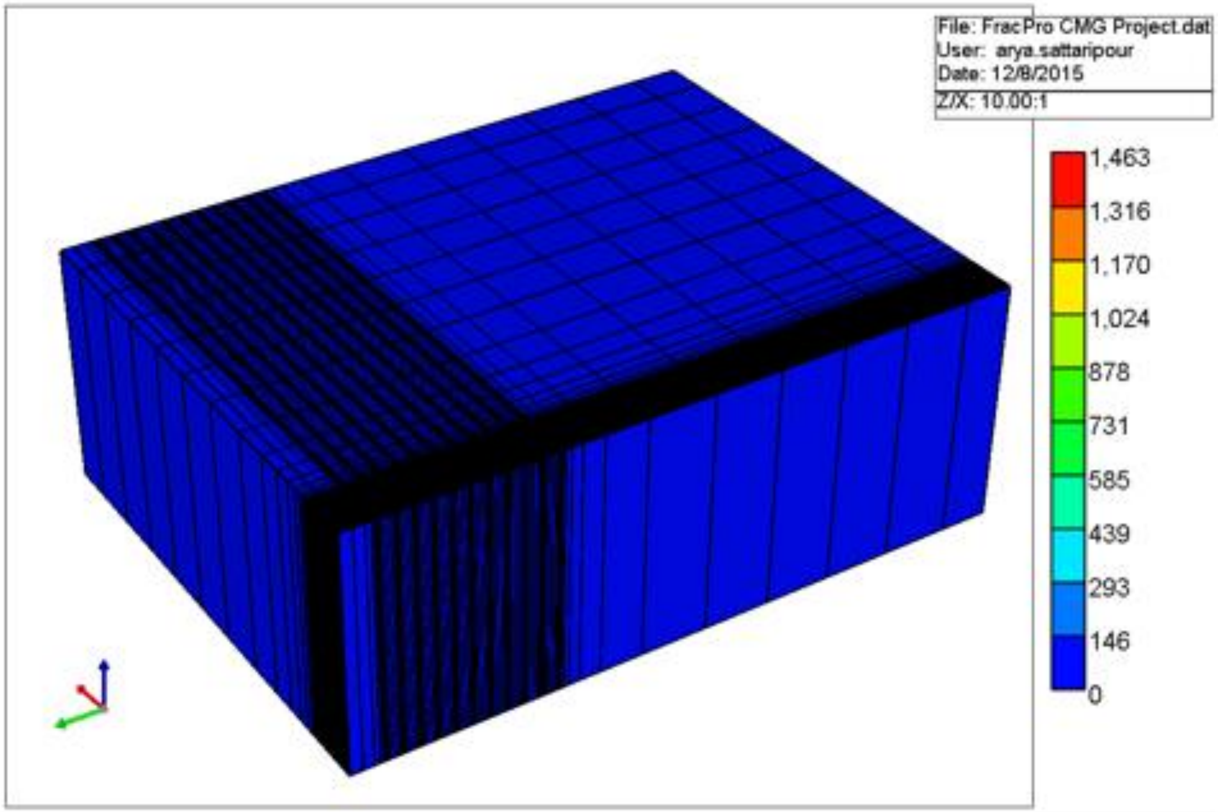
Research Overview

Ali Takbiri-Borujeni
WVU

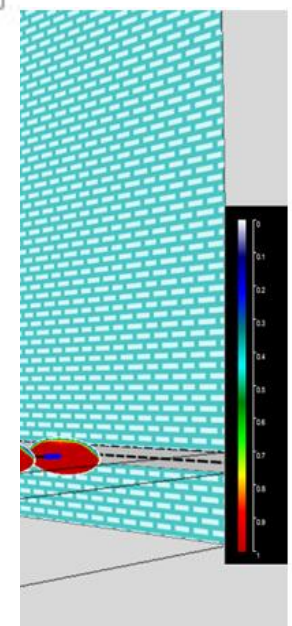
Simulation of hydraulic fracturing treatment (MIP-4H well)

Data ga



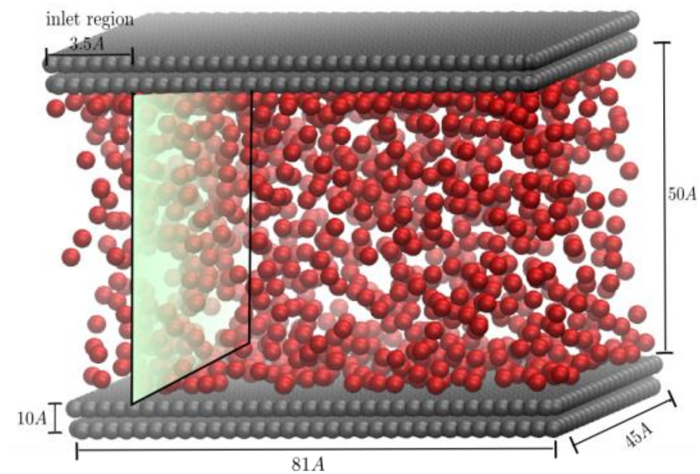


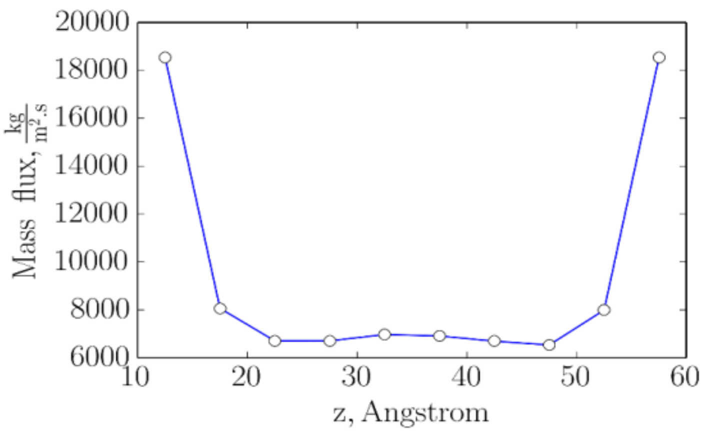
mulation



Multiscale modeling of gas flow in shale

Molecular Dynamics (MD) simulations

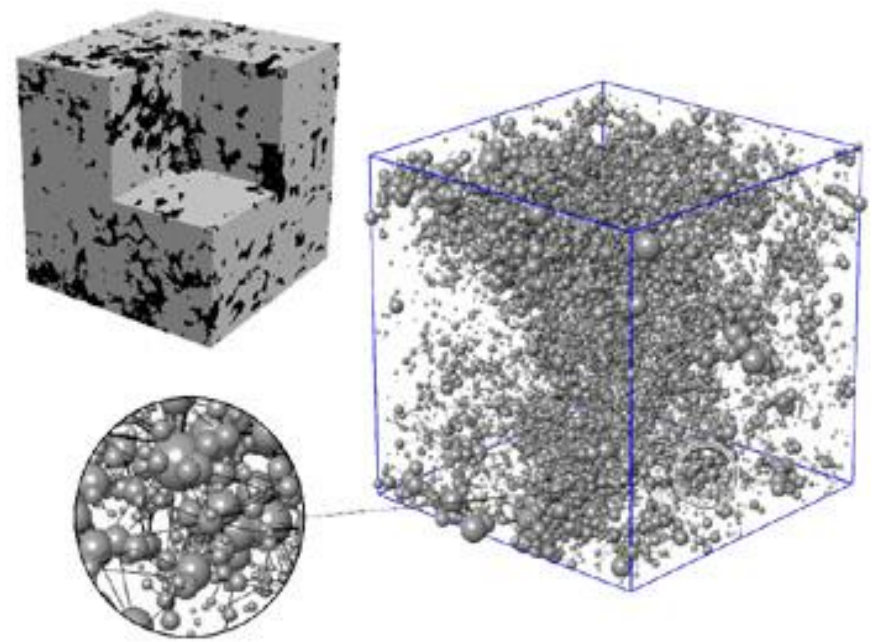




Mass flux of Methane across a 5-nm graphite channel

Kazemi, M and Takbiri-Borujeni, A, “Molecular Dynamics Simulation of Gas Flow in Shale Gas Reservoirs”, Submitted to Journal of Natural Gas Science and Engineering, 2016

Pore network modeling



http://www.poresim.org/NWM/nwm.htm

Using Predictive Modeling to Develop a Cost Efficient and Effective Completion Design

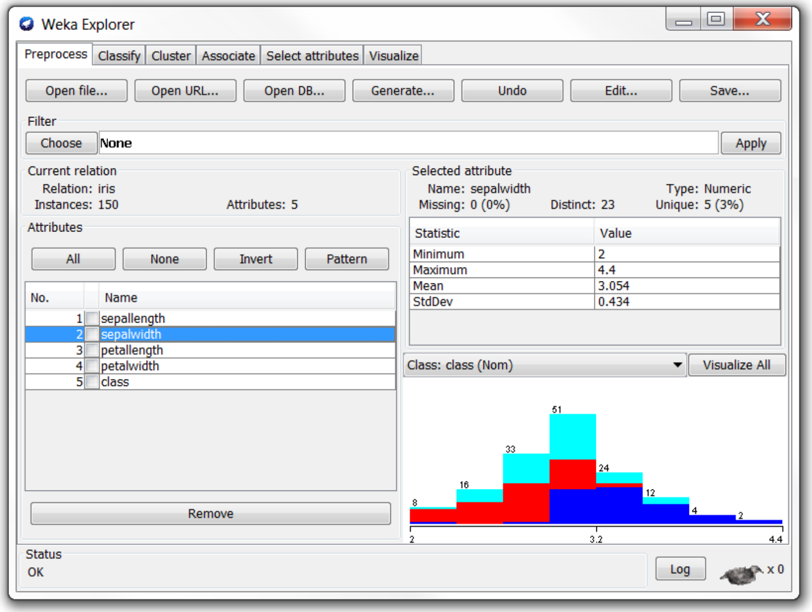
Variables of Interest

- To develop a predictive model for production per stage data gathered through the use of fiber optics, microseismic, and high imaging lateral logs will be used. The variables of interest at the start of this process include the following listed below:

  - Depth
  - Bond Index
  - CBL Amplitude
  - Gamma Ray
  - Gamma*ROP
  - Sonic Porosity
  - Shots
  - Clusters
  - Faults
  - Total Fractures
  - Wellbore Placement Above Onondaga
  - Target Top Above Onondaga
  - ROP/WOB
  - Background Gas
  - Rate of Penetration
  - ROP/WOB
  - Number of Microseismic Events
  - Fracture Height
  - Fracture Complexity
  - Fracture Width
  - Average Magnitude
  - Downward Growth
  - Average Stage Temperature
  - Cluster Efficiency
  - Frac Gradient
  - ISIP
  - Breakdown Pressure
  - Average Treating Pressure
  - Average Treating Rate
  - Pad Volume
  - Total Clean Fluid
  - Total Proppant
  - Total 100 Mesh
  - Total 40/70 Mesh
  - Flush Volume
  - LB/BBL
  - Flow Rate Per Perforation
  - Gel Per Stage
  - Percentage Coated Proppant

Weka

- Weka is a popular machine learning software developed by the University of Waikato in New Zealand.
- Weka is a collection of algorithms used for data mining, data analysis, and predictive modeling.
- For our project, Weka will mainly be utilized to run linear regressions and multiple linear regressions to find the best predictive model for production per stage.



MARCELLUS SHALE ENERGY AND ENVIRONMENT LABORATORY
MSEEL

- Integration of Research/Technical Results
  - Key Research Foci
  - Anticipated Results
  - Impact/Implications
  - Timeline - Acceleration
- Coordinated Publication/Presentations
  - National Meeting(s) Session(s)
  - Dedicated Journal/Memoir
  - Other Avenues of Dissemination
  - Timeline
- Results Supporting 2017-18 Decision Point
  - Extend Study – Drill Additional Wells
  - Remaining Questions for Marcellus

MSEEL
Marcellus Shale Energy & Environment Laboratory
Northeast Natural Energy
West Virginia University