Onshore Unconventional Resources Field Work Proposal

Research performed through NETL's Research and Innovation Center to support the Oil and Gas Unconventional Resources and Environmentally Prudent Development Programs

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National Energy Technology Laboratory

Mastering the Subsurface Through Technology Innovation, Partnerships and Collaboration: Carbon Storage and Oil and Natural Gas Technologies Review Meeting

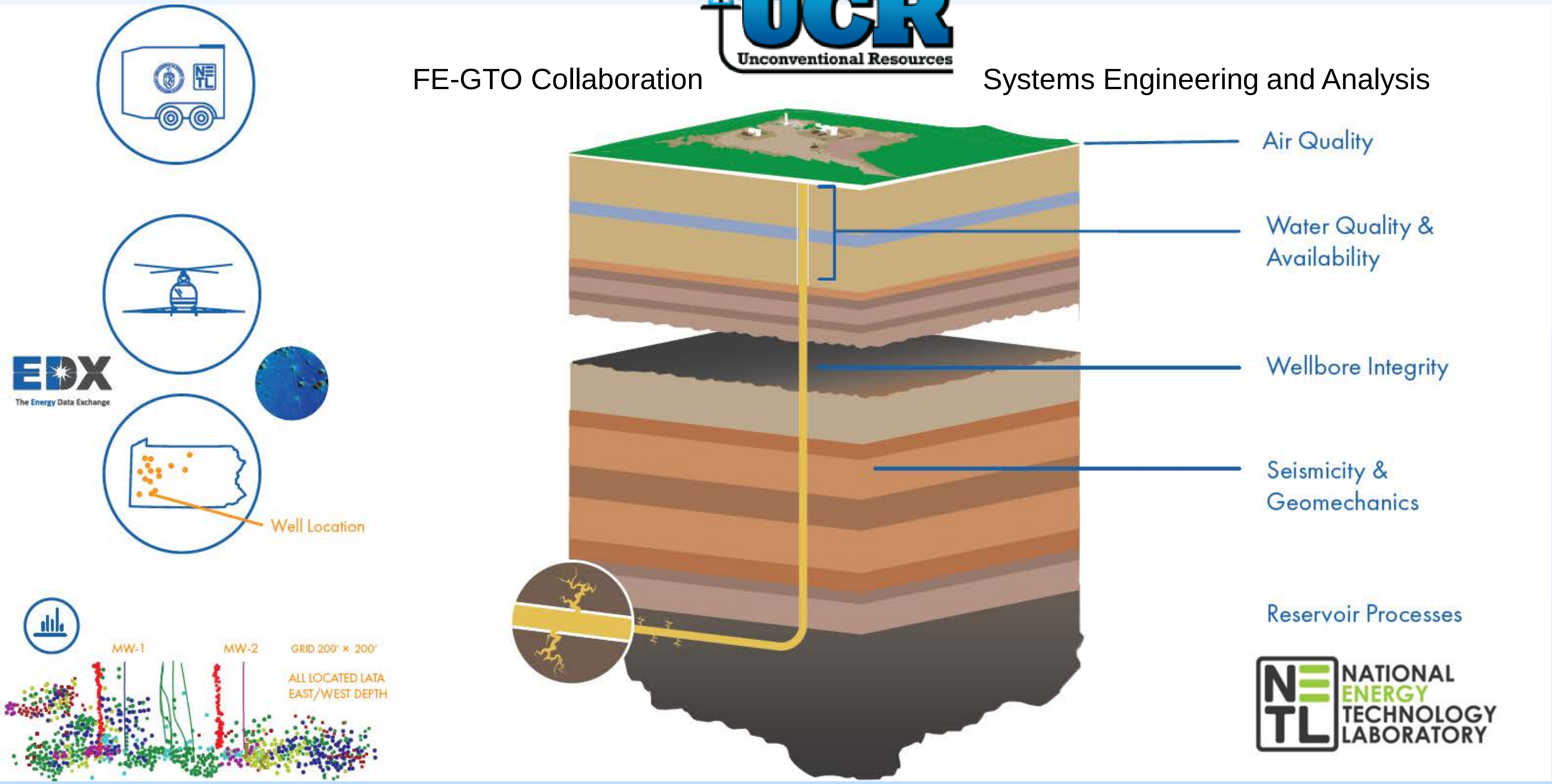
August 1-3, 2017

Presentation Outline

- **Overview** of the 2017 Onshore Unconventional Resources Portfolio
- **Technical Highlight** on Task 2: Reservoir Processes
- **Technical Detail** on Task 2 Project: Geochemistry of Pore-to-Core Processes
- **Discussion** of Results to Date and Synergies

2017 Onshore Unconventional Resources Portfolio Objectives

- Promote efficient resource development and associated footprint reduction
- Improve subsurface science in the context of improved reservoir understanding
- Address issues associated with water quality and availability, and well integrity
- Evaluate air quality changes during UOG development
- Define program metrics and evaluate oil and gas infrastructure maturity for future resource development



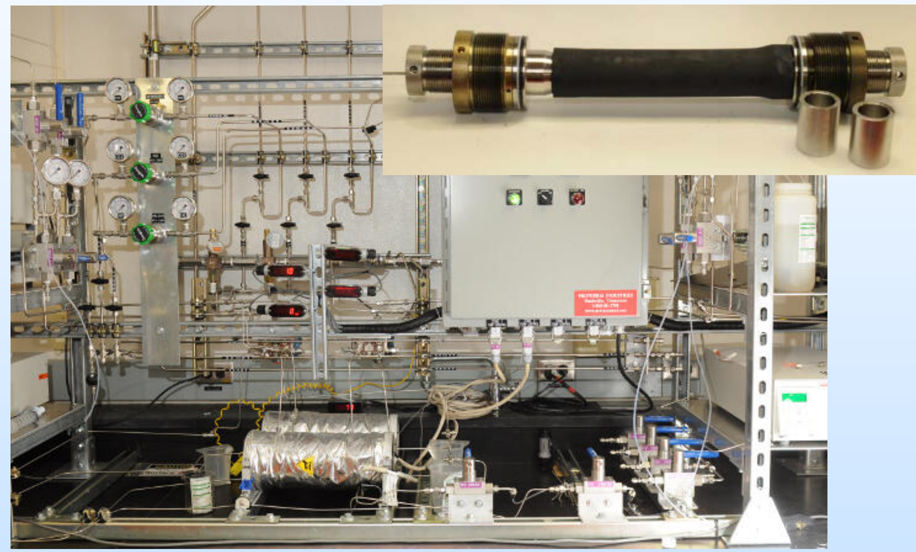
Task 2: Reservoir Processes

Team Technical Coordinator: Dustin Crandall

- **Geomechanics of pore-to-core scale processes**
  - PI: Dustin Crandall
- **Geochemistry of pore-to-core scale processes**
  - PI: Alexandra Hakala
- **Field site core analysis**
  - PI: Dustin Crandall
- **Microbiological processes in unconventional reservoirs**
  - PI: Djuna Gulliver

Application of NETL R&IC's experimental and analytical geochemistry capabilities to evaluate frac chemical-shale reactions

High-pressure, high-temperature Static and Flow-through reactor systems (Geological and Environmental Systems Directorate, GES)



Analytical geochemistry & geochemical modeling (GES) and characterization (Materials Engineering and Manufacturing Directorate, MEMD)

- Metal isotopes: Multicollector ICP-MS
- Organic geochemistry: LC-QTOF-MS, IC, GC-MS
- Visualization: environmental SEM, CT scanning

Geochemistry of Pore-to-Core:
Understanding Reactions between Fracturing Fluids and Shale

- **pH-driven dissolution of carbonate-bearing minerals**
- **Redox reactions involving pyrite, effects on iron mineral stability**
- **Secondary precipitation of sulfate minerals and clay (smectite), and carbonates (depending on pH buffering)**

How do these geochemical processes affect fluid and gas flow pathways in fractured shale?

&

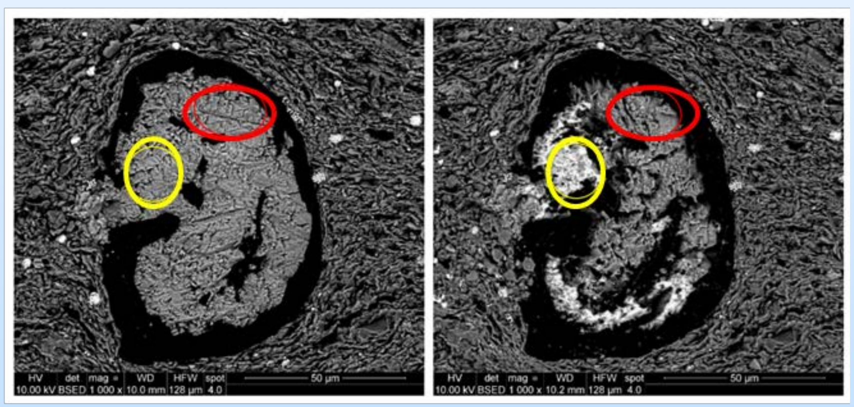
How can we monitor these reactions?

Gypsum precipitation, calcite dissolution, and fracture growth after Marcellus Shale exposure to high-TDS fluid simulating recycled produced water

Static autoclave, polished Marcellus Shale before and after exposure to synthetic high-TDS fluid. Reacted at 77°C and 4000 psi for 6 days.

Post-exposure gypsum precipitation, calcite dissolution

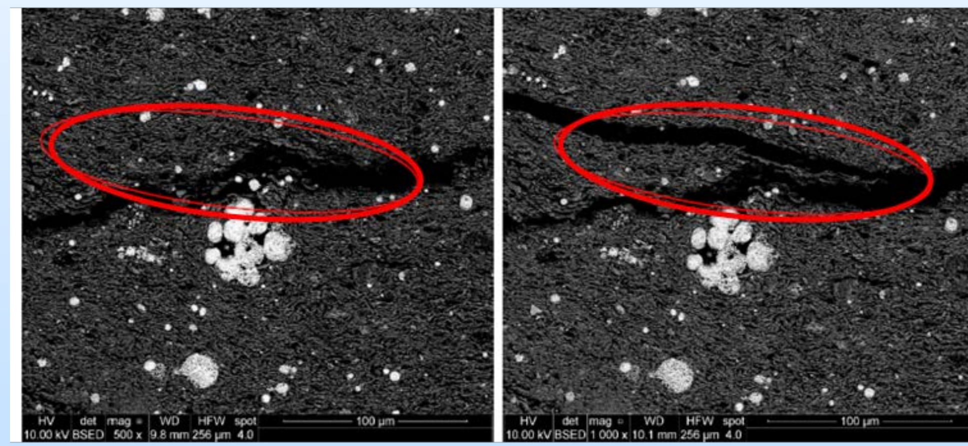
Pre-exposure | Post-exposure



1000x magnification

Post-exposure fracture growth

Pre-exposure | Post-exposure

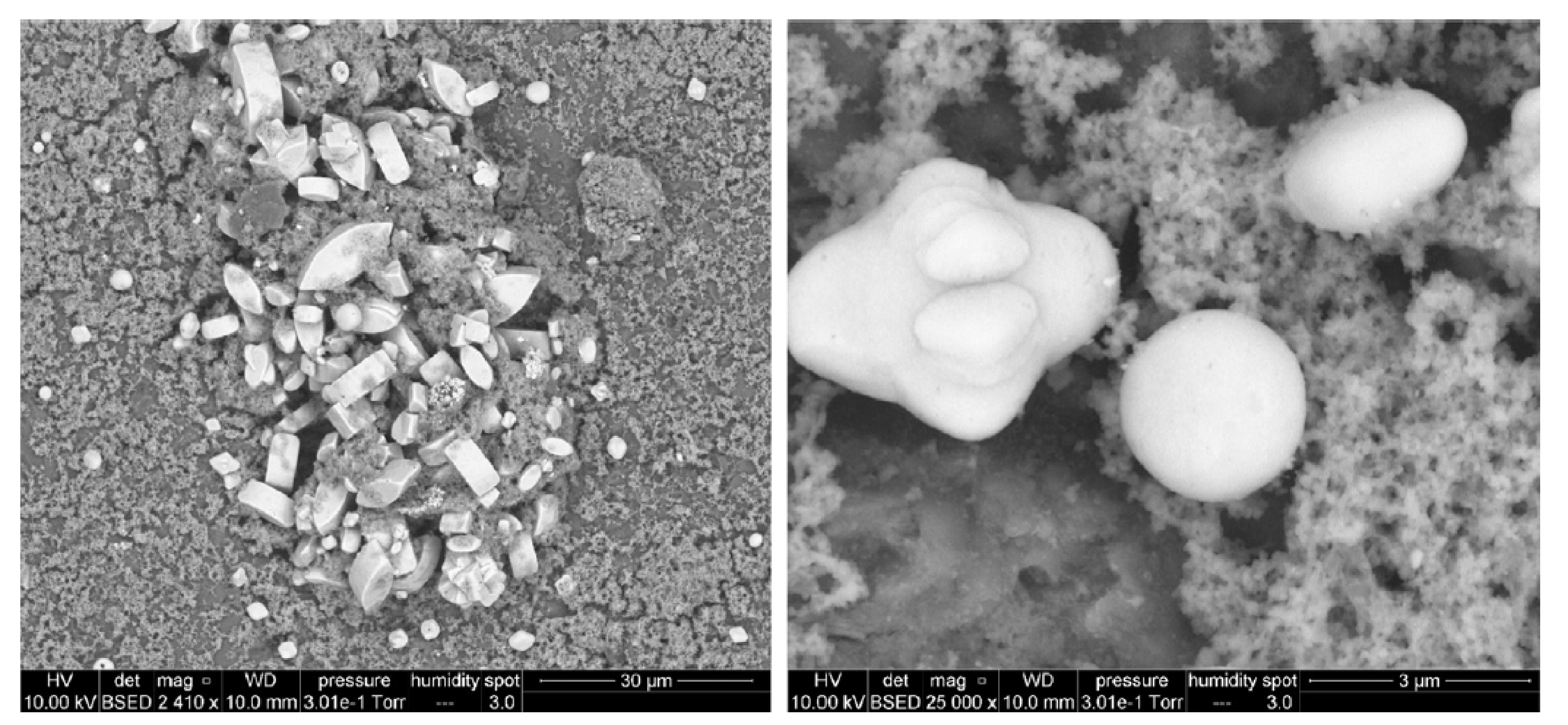


500x magnification

Dieterich, Kutchko, and Goodman (2016) *Fuel*

Barite precipitation, apatite, strontianite, and celestine precipitation on Huntersville Chert after exposure to produced water from Greene County, PA

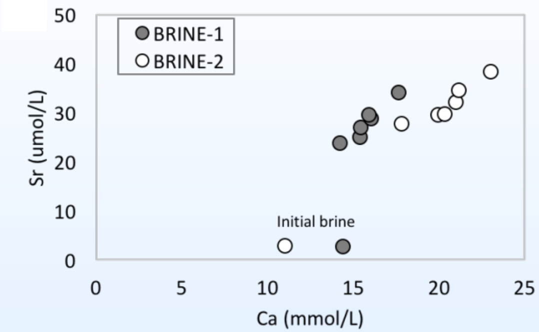
Static autoclave, polished Huntersville Chert before and after exposure to produced water from Greene County. Reacted at 50°C and 1500 psi for 89 days.

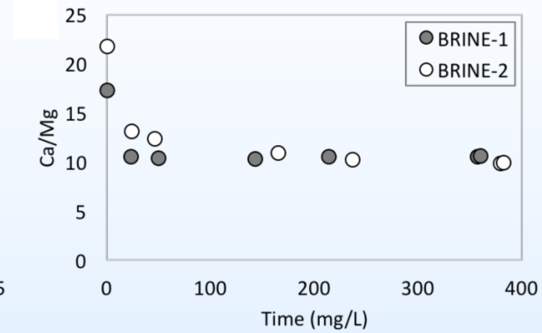


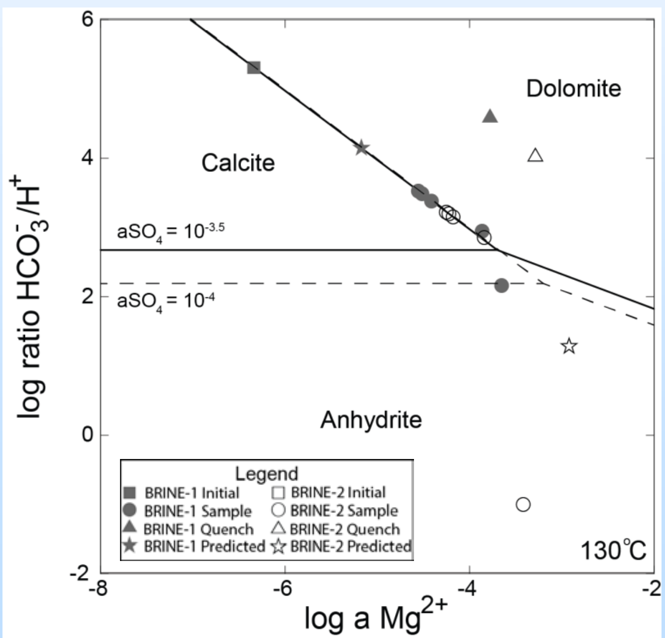
Dieterich, Kutchko, and Goodman (2016) *Fuel*

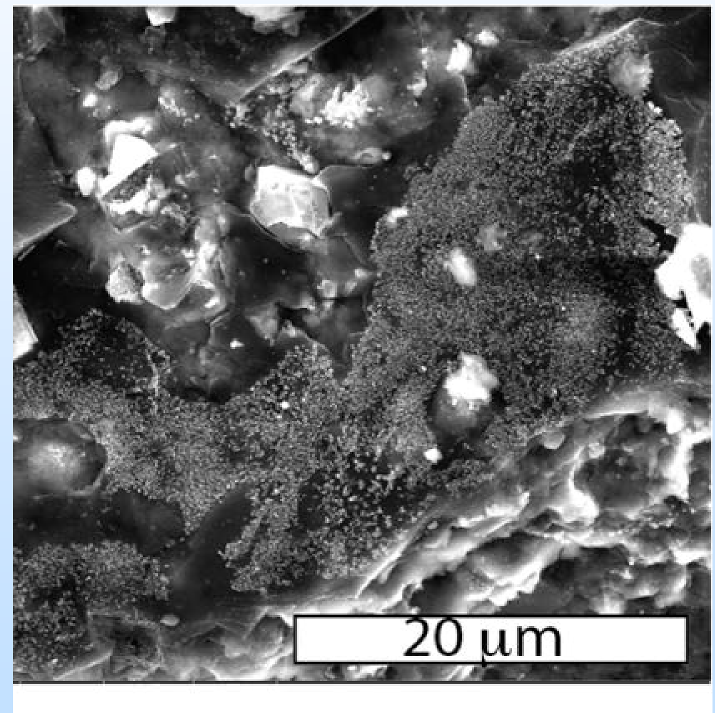
Evidence for secondary precipitation of carbonates and anhydrite in rocking autoclave experiments performed with fracturing chemicals and Marcellus Shale

Experimental conditions: 15 d, 130°C, 4000 psi





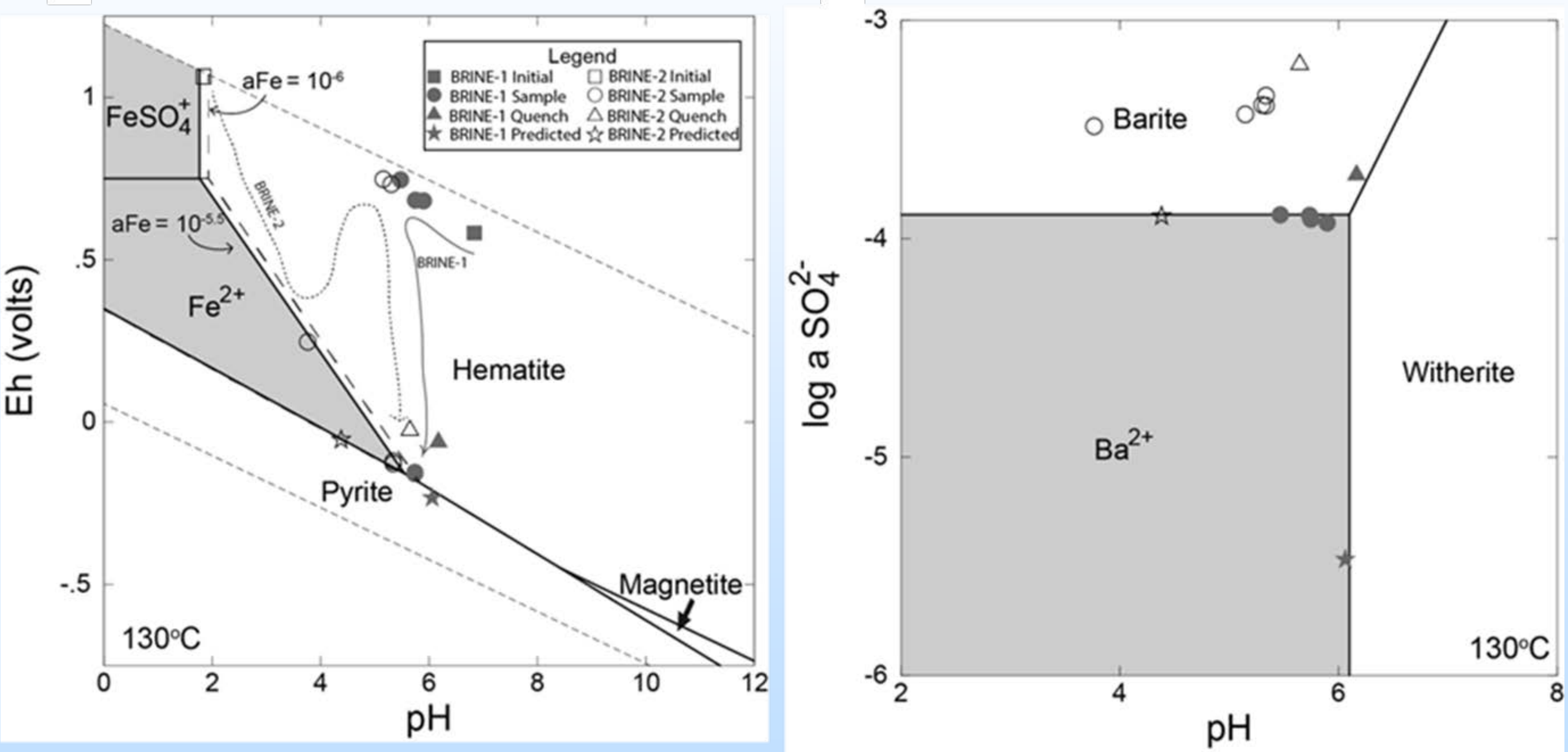




Marcon, Joseph, Carter, Hedges, Lopano, Guthrie, Hakala (2017) *Applied Geochemistry*

Redox changes during the fracturing fluid-shale experiments; may influence barite stability as observed by modeling fluid chemistry

Experimental conditions: 15 d, 130°C, 4000 psi

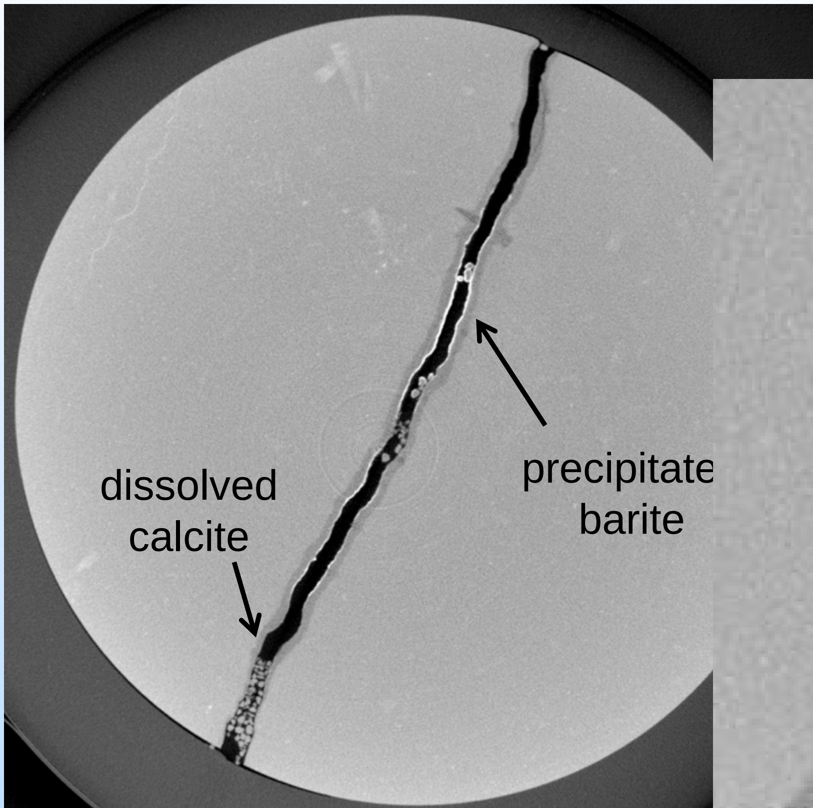


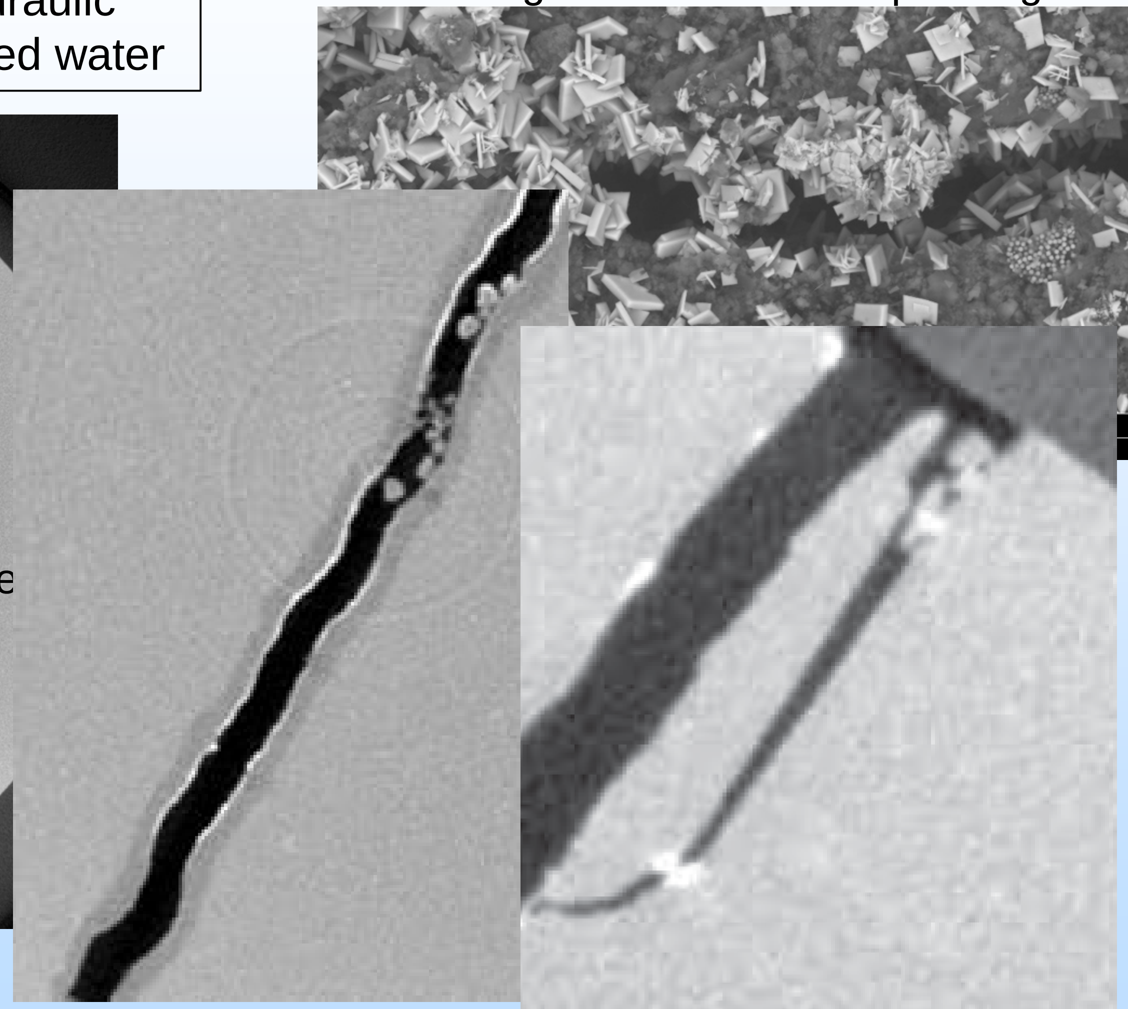
Marcon, Joseph, Carter, Hedges, Lopano, Guthrie, Hakala (2017) *Applied Geochemistry*

Barite precipitation and calcite dissolution observed in core flood experiment containing reused produced water + frac chemicals; ammonium persulfate breaker identified as significant reactant

Marcellus shale reacted with hydraulic fracturing fluid from reused produced water

Scanning electron microscope image





X-ray computed tomography image

Vankeuren, Hakala, Jarvis, Moore (2017) ***Environmental Science & Technology***

Fluid-based tracers – monitoring produced water to characterize reservoir processes

- **Isotope tracers**
  - Metal isotopes – $^{87/86}Sr$ and $\delta^{7}Li$ monitoring during core flood experiments showed that fluid TDS affected ability to monitor frac fluid-shale reactions *(Phan et al, in preparation)*
  - Stable isotopes – Collaboration with Shikha Sharma group from West Virginia University
- **Rare Earth Elements**
  - Laboratory-based experiments showed that REEs may not be good indicators for monitoring fracturing fluid-shale reactions in the reservoir, due to low concentration and sorption *(Yang et al., under review)*
- **Organic compounds and redox-active species**
  - Potential exists for identifying reaction-specific components, however requires better understanding of the system

2017 Onshore Portfolio Research on Geochemistry of Pore-to-Core Scale Processes

- **Reactive Fracture Flow Tests** (Lead: Alexandra Hakala)
  - Perform core flood experiments coupled with computed tomography imaging to characterize extent of mineral scale formation along primary fracture flow pathways due to interactions between fracturing fluids and shale
  - Team: Alexandra Hakala, Johnathan Moore, Christina Lopano, Thai Phan, Brittany McManus, Sarah Brown, Karl Jarvis, Bryan Tennant, Brandon McAdams, Dustin Crandall, Pittsburgh Analytical Laboratory
- **Precipitation Controls** (Lead: Christina Lopano)
  - Evaluate mechanisms and kinetics of mineral scaling in a shale fracture system under a variety of laboratory conditions, with a focus on Ba, Ca, Al, and Fe associated scaling minerals
  - Team: Christina Lopano, Harry Edenborn, Brandon McAdams, Alexandra Hakala

Reactive Fracture Flow Tests

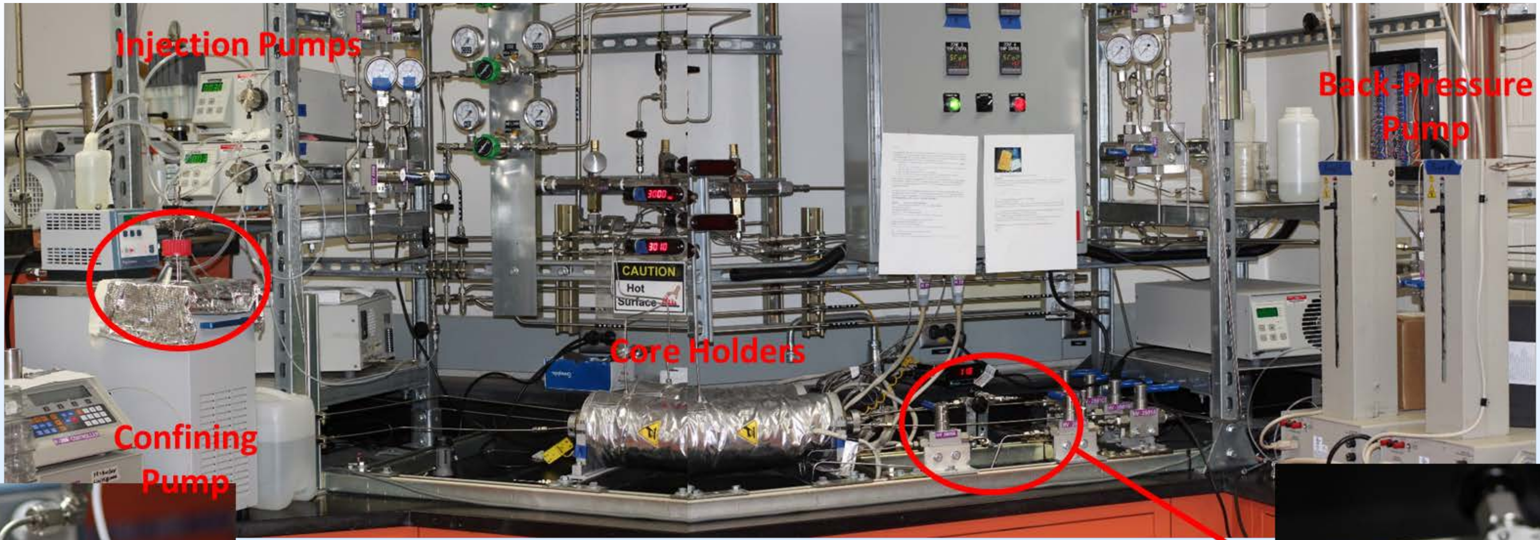
- **Comparison of make-up water compositional effects on fluid-rock reactions** **(Vankeuren et al., ES&T, 2017)**

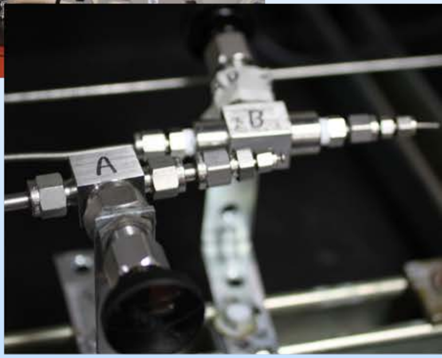
- **Evaluate extremes in make-up water composition and verify prior experimental results** **(Moore et al., Northeast GSA 2017)**

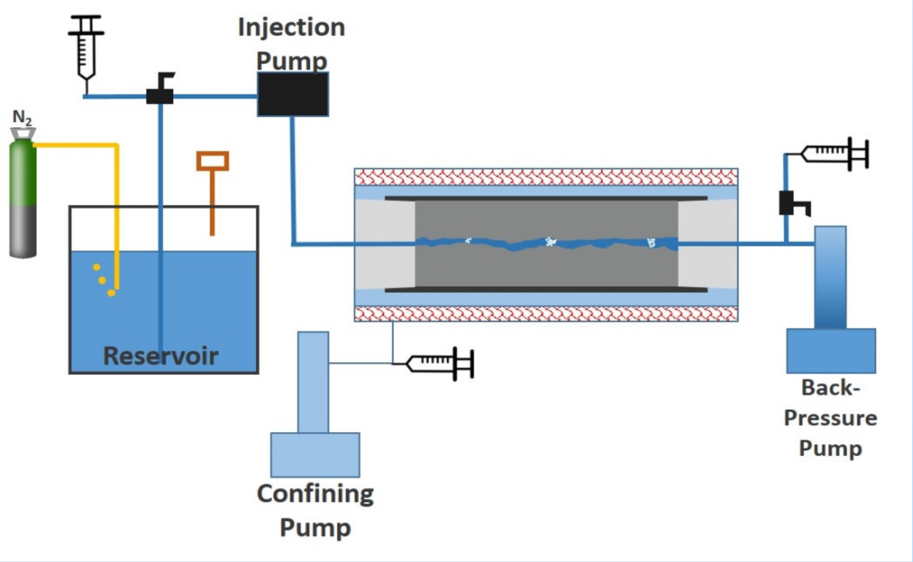
- **Evaluate possible fluid-rock reactions at the Marcellus Shale Energy and Environmental Laboratory (MSEEL)** **(Hakala et al., URTeC 2017)**

- **Evaluate effects of fracturing chemical composition on fluid-rock reactions (temporal; with and without breaker)** **(Moore and McManus, in progress)**

Core flood apparatus operated to mimic a 4-day shut in period: 150°F, 3000 psi confining pressure, 2800 psi pore pressure, Fluid flow rate 0.03 mL/min







Monitoring changes to fluid chemistry and mineral dissolution/precipitation

Fluid Chemistry

Bulk Elemental Concentrations

- ICP-OES and IC performed by Pittsburgh Analytical Laboratory
- ICP-MS and IC on sample splits for verification and Sr isotope preparation

Strontium Isotopes

- Method by Wall et al.(2014)

Carbon and Oxygen Isotopes

- Performed by Shikha Sharma Group, WVU

pH monitored in experimental effluent at regular intervals

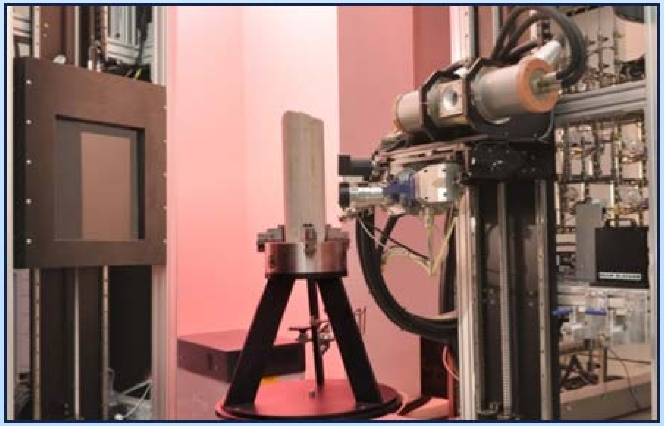
Changes in Shale

CT Scanning + Image Processing

- Scanned before and after exposure with North-Star Imaging M-5000 Industrial CT
- ImageJ© and ilastik® for image processing
- Pixel classification used to segment system components

Scanning Electron Microscopy -EDS

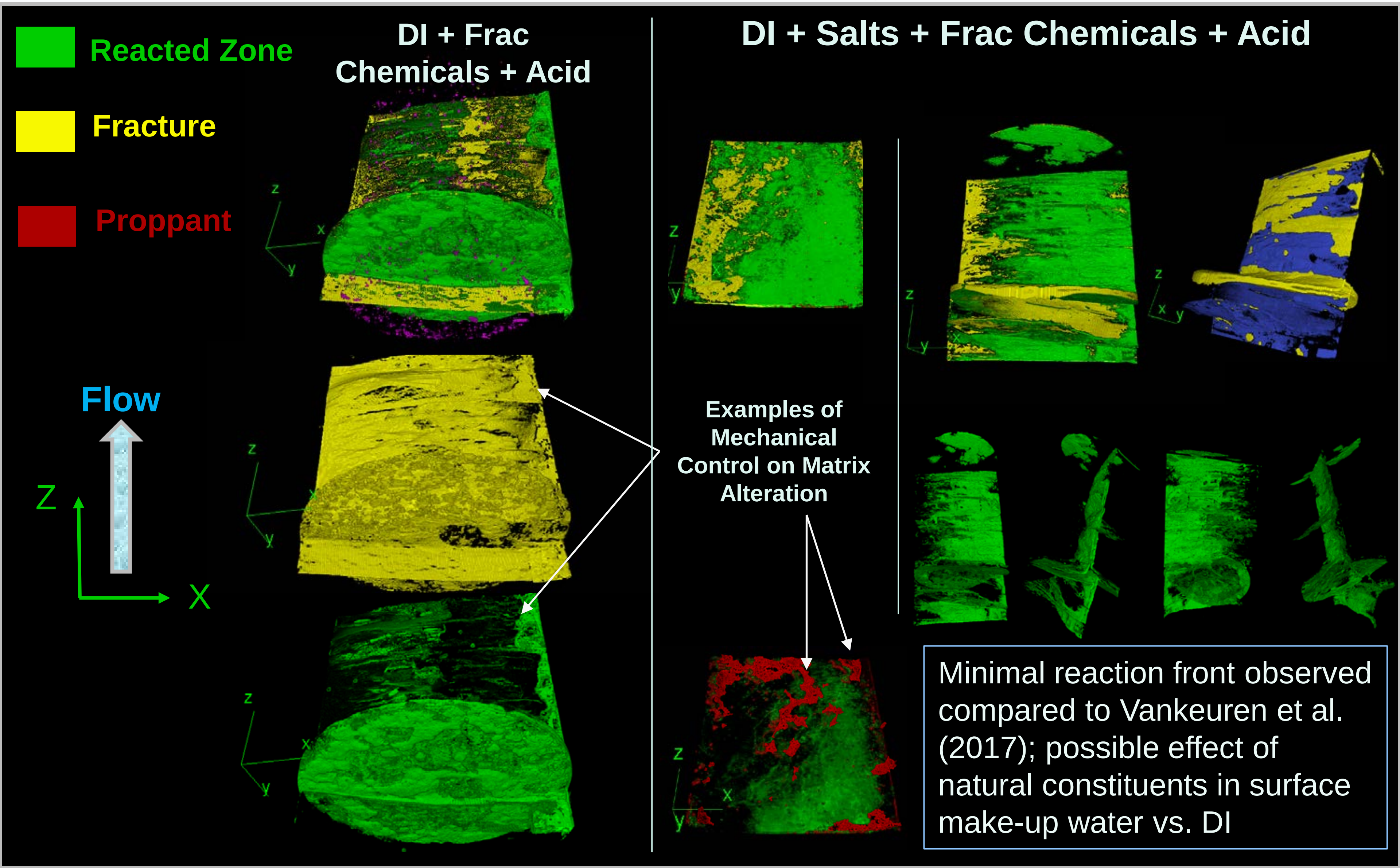
- E-SEM



Industrial CT scanner

Experiments Evaluating Geochemical Alteration of Matrix Minerals Adjacent to Simulated Hydraulic Fractures

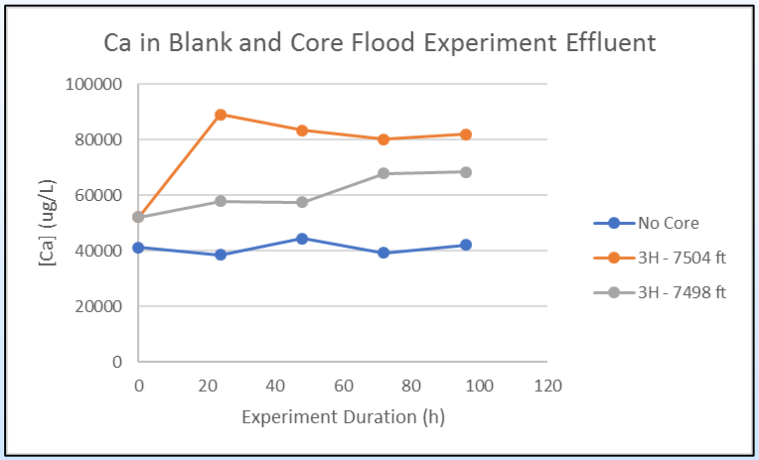
Moore et al., Northeast GSA Meeting, March 2017

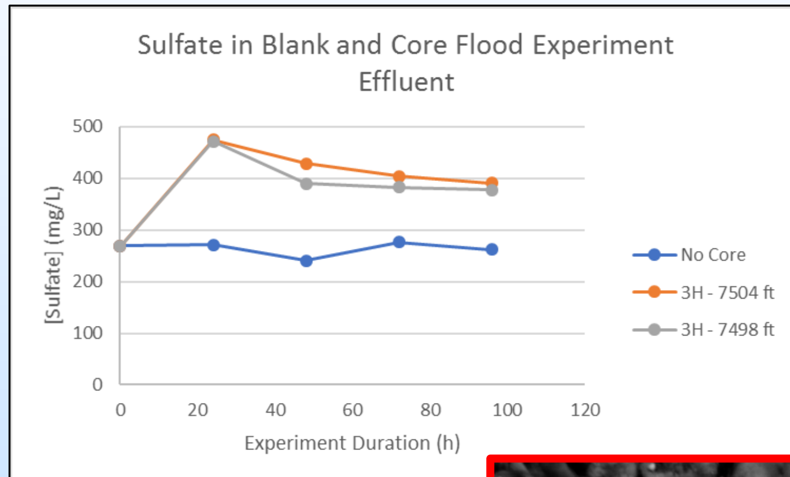


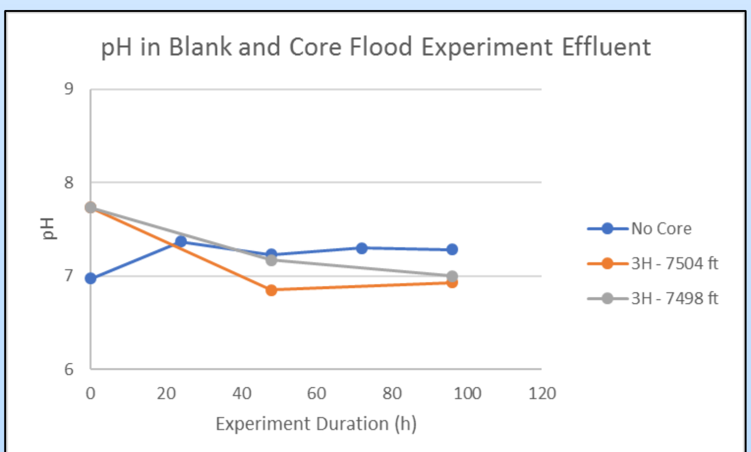
Laboratory-Scale Studies on Chemical Reactions Between Fracturing Fluid and Shale Core from the Marcellus Shale Energy and Environmental Laboratory (MSEEL) Site

Hakala et al., URTeC, 2017

Evidence for sulfate and Ca^{2+} production, pH drop, pyrite oxidation and local barite precipitation. No change in CT pre- and post-reaction (effect of aged frac fluid?).







Coming in 2018: Detailing chemical changes in fracturing fluids and their effect on shale

- **Characterize changes in fracturing fluid formulations**
  – pH, redox potential, changes in organic structure, and other parameters
- **Barite nucleation and precipitation/dissolution kinetics**
  – Relationship to changing fluid chemistry conditions
- **Surface phenomena that promote secondary precipitation**
  – Further investigate role of proppant and fracture surfaces
- **Core flood experiments to "pull it all together"**
  – Apply insights from fluid and mineral studies towards core flood scale experiments

Synergy Opportunities

Collaborate with oil and gas fundamentals research teams to design NETL-R&IC experiments geared towards addressing geochemical processes that affect long-term gas production from shales.

Apply results to develop: 1) inputs for modeling across physical scales, and 2) reservoir performance monitoring strategies.

- **Characterize changes in fracturing fluid formulations**
  - pH, redox potential, changes in organic structure, and other parameters
- **Barite nucleation and precipitation/dissolution kinetics**
  - Relationship to changing fluid chemistry conditions
- **Surface phenomena that promote secondary precipitation**
  - Further investigate role of proppant and fracture surfaces
- **Core flood experiments to "pull it all together"**
  - Apply insights from fluid and mineral studies towards core flood scale experiments

Accomplishments to Date (2017)

Reactive Fracture Flow Tests

- Multiple core flood experiments performed to evaluate how fracturing fluid composition affects shale fracture alteration due to fluid-mineral reactions
- Journal Publications
  - Vankeuren, A.N.P.; Hakala, J.A.; Jarvis, K.; Moore, J.E. "Mineral Reactions in Shale Gas Reservoirs: Barite scale formation from reusing produced water as hydraulic fracturing fluid." Environmental Science and Technology, Publication Date (Web): July 19, 2017, DOI: 10.1021/acs.est.7b01979
- Technical Presentations
  - Moore, J.; Hakala, A.; Vankeuren, A.; Phan, T.; Crandall, D. "Experiments Evaluating Geochemical Alteration of Matrix Minerals Adjacent to Simulated Hydraulic Fractures." Northeast Regional Meeting, Geological Society of America, Pittsburgh, PA, March 19, 2016
  - Hakala, J.A.; Crandall, D.; Moore, J.; Phan, T.; Sharma, S.; Lopano, C. "Laboratory-Scale Studies on Chemical Reactions Between Fracturing Fluid and Shale Core from the Marcellus Shale Energy and Environmental Laboratory (MSEEL) Site." Unconventional Resources Technology Conference, Austin, TX, July 24, 2017
  - Hakala, J.A.; Phan, T.; Stuckman, M.; Edenborn, H.M.; Lopano, C.L. "Role of Organic Acids in Controlling Mineral Scale Formation During Hydraulic Fracturing at the Marcellus Shale Energy and Environmental Laboratory (MSEEL) Site." Unconventional Resources Technology Conference, Austin, TX, July 24, 2017

Lessons Learned

Reactive Fracture Flow Tests

- Challenges
  - **Fluid/rock ratio effects** in lab experiments versus what happens in the field (need to continue coordination with field projects)
  - **Ability to characterize influences of variable fluid chemistry** on mineral reactions (variety of fluid formulations and reservoir treatment strategies)
  - **Coordinating multiple chemical analyses on limited amount of sample** – continuous need for multiple lines of evidence and re-working of experimental design

Project Summary

Reactive Fracture Flow Tests

- **Key Findings**
  - pH-driven dissolution of carbonate-bearing minerals (buffering observed), coupled with sulfate mineral precipitation
  - Redox reactions involving pyrite, effects on iron mineral stability
  - Secondary precipitation of sulfate minerals and clay (smectite), and carbonates (depending on pH buffering); minor fractures showed both dissolution and precipitation
  - Proppants affect distribution of reacted zones and precipitates
- **Next Steps**
  - Continue collaborative discussions with Oil and Gas Fundamental Science team (SLAC, LANL)
  - Complete core flood experiments with fresh frac fluid (including breaker) and MSEEL core
  - Explore opportunities with USEEL team at Ohio State, and other field laboratory sites when available
  - Explore changes in fracturing fluid over time and with different formulations; focus on surface sites that promote mineral precipitation

Appendix

The following slides contain information for the entire 2017 NETL Research and Innovation Center Onshore Unconventional Resources Portfolio. Details at the project level can be requested through the Technical Portfolio Lead (Alexandra Hakala) or the Team Technical Coordinator for the task (listed in the "Organization Chart" slides below).

Benefit to the Program

- Program Goals Addressed:
  - Safe and environmentally sustainable supply of natural gas
  - Environmental footprint reduction through efficient resource development
  - Subsurface science in the context of understanding the reservoir
- Project Benefits Statement:

The Onshore Unconventional Resources portfolio addresses upstream-related topical areas as outlined for unconventional oil and natural gas research within the Department of Energy's (DOE's) Office of Fossil Energy (FE), Oil and Gas, with a primary focus on research that facilitates a safe and environmentally sustainable supply of natural gas. Environmental footprint reduction through efficient resource development is being addressed through research across the portfolio, with projects focused on the reservoir, wellbores, seismicity, water issues, air quality, and systems planning including potential applications of UOG infrastructure towards geothermal energy in future hybrid energy systems. Subsurface science in the context of understanding the reservoir is being studied through projects focused on geomechanical, geochemical, and microbiological processes that occur in hydraulically-fractured shales, along with the seismicity-related phenomena that can provide greater insight into reservoir behavior over time. Improved understanding of subsurface science leads to improved predictability of reservoir behavior and associated increase in the ability to prevent reservoir or well failures. Water quality and availability, and associated wellbore integrity issues, are being evaluated through field, laboratory, and modeling efforts. Air quality changes during the course of UOG development at specific sites will be evaluated to identify non-greenhouse gas related emissions associated with UOG activities.

Project Overview, 1 of 8

Goals and Objectives

Statement of Onshore Unconventional Resources Project Objectives

- The Onshore Unconventional Resources portfolio research addresses institutional priorities focused on the following aspects of onshore UOG production: promoting efficient resource development and associated footprint reduction; improving subsurface science in the context of improved reservoir understanding; addressing issues associated with water quality and availability, and associated well integrity issues; evaluating air quality changes during the course of UOG development, and; defining UCR program metrics and evaluating the state of oil and gas infrastructure maturity for future resource development.

Project Overview, 2 of 8

Goals and Objectives

Task 2: Reservoir Processes

- The primary objective of the Reservoir Processes research is to examine fundamentals of shale/fluid interaction that influence reservoir production, such as fracture dynamics, imbibition into the matrix, and geochemical alterations.
- The primary impact of this research is better definition on how reservoir geomechanical, geochemical, and microbiological processes contribute towards the potential for long-term gas production from shale. Results from this research will inform whether increased production efficiency is possible through improved design of reservoir processes, which can lead to reduced geologic and environmental footprints associated with UOG production.

Project Overview, 3 of 8

Goals and Objectives

Task 3: Wellbore Integrity

- The primary objectives of the Wellbore Integrity research are to: (1) develop approaches to remotely sense legacy wells that may serve as conduits for fluid and gas migration into shallow groundwater, and; (2) understand effects to wellbore integrity due to interactions with subsurface fluids.
- The primary impact of this research will be an ability to evaluate how various pre-existing geologic conditions and materials integrity affect the ability for onshore unconventional wells to maintain zonal integrity, thus preventing fluid and gas migration and potential contamination of underground sources of drinking water.

Project Overview, 4 of 8

Goals and Objectives

Task 4: Relationships between Seismicity and Geomechanics

- The primary objectives of the Relationships between Seismicity and Geomechanics research are to: (1) understand inter-relationships between microseismicity and geomechanics, and; (2) evaluate tremors associated with hydraulic fracturing events.
- The primary impacts of this research are developing a means to identify how geomechanical events during hydraulic fracturing are related to observed seismicity, which can be used to better understand reservoir processes during and after hydraulic fracturing.

Project Overview, 5 of 8
Goals and Objectives

Task 5: Water Quality and Availability

- The primary objectives of the Water Quality and Availability research are to understand the surface environmental behavior of drill cuttings under different disposal conditions to inform improved waste management strategies, and to apply geochemical monitoring tools towards identifying UOG versus non-UOG related impacts to water resources.
- The primary impacts of this research are to develop best practices recommendations for monitoring and management of UOG wastes and fluids to prevent unintentional surface and groundwater contamination, and to properly attribute causes for water resource impacts in areas with heavy UOG development.

Project Overview, 6 of 8

Goals and Objectives

Task 6: Air Quality Issues

- The primary objectives of the Air Quality Issues research are to: (1) process data from prior-year monitoring, and continue with new ambient air monitoring opportunities for non-greenhouse gas (GHG) emissions at UOG field sites, and; (2) evaluate emissions tradeoffs associated with natural gas-enhanced oil recovery.
- The primary impacts of this research are to establish baseline measurements for non-GHG air pollutants that may change during the course of UOG development, and to identify potential use scenarios for application of excess methane for enhanced oil recovery operations as opposed to flaring.

Project Overview, 7 of 8

Goals and Objectives

Task 7: Hybrid Energy Systems

- The primary objective of the Hybrid Energy Systems research is to evaluate the feasibility and economics of applying developed UOG wells towards hybrid natural gas-geothermal energy system development in the eastern United States.
- The primary impact of this research will be an analysis of how existing oil and gas infrastructure may be applied to future geothermal energy systems.

Project Overview, 8 of 8

Goals and Objectives

Task 8: Systems Engineering & Analysis (SE&A)

- The primary objectives of the SE&A research are to develop metrics for future Research and Development (R&D) targets associated with onshore UOG, and to quantitatively predict oil and gas infrastructure evolution over the lifespan of development.
- The primary impact of this research is to define metrics to inform future research needs for environmentally prudent onshore UOG development, and to provide predictive tools for evaluating future UOG infrastructure type, amount, and approximate investment costs.

Organization Chart, 1 of 2

Additional detail on team members can be obtained from the TTC and/or PI

- Task 2 – Reservoir Processes
  - Team Technical Coordinator: Dustin Crandall
  - Geomechanics of pore-to-core (PI: Dustin Crandall)
  - Geochemistry of pore-to-core (PI: Alexandra Hakala)
  - Core Analysis (PI: Dustin Crandall)
  - Microbiology (PI: Djuna Gulliver)
- Task 3 – Wellbore Integrity
  - Team Technical Coordinator: Barbara Kutchko
  - Wellbore Detection through Remote Techniques (PI: Rick Hammack)
  - Cement Integrity (PI: Barbara Kutchko)
- Task 4 – Relationship between Seismicity and Geomechanics
  - Team Technical Coordinator: Rick Hammack
  - Microseismic Geomechanics Inter-relationships (PI: Rick Hammack)
  - Tremor Analysis (PI: Rick Hammack)

Organization Chart, 2 of 2

Additional detail on team members can be obtained from the TTC and/or PI

- Task 5 – Water Quality and Availability
  - Team Technical Coordinator: Alexandra Hakala
  - Environmental Behavior of UOG Fluids and Solids (PI: Christina Lopano)
- Task 6 – Air Quality
  - Team Technical Coordinator: Natalie Pekney
  - Ambient air monitoring (PI: Natalie Pekney)
  - Natural Gas EOR Evaluation (PI: Natalie Pekney)
- Task 7 – Hybrid Energy Systems (FE-GTO Collaboration)
  - Team Technical Coordinator: Mark McKoy
  - Modeling geothermal reservoirs in sedimentary rock (PI: Mark McKoy)
- Task 8 – Systems Engineering and Analysis
  - Team Technical Coordinator: Donald Remson
  - Natural Gas Upstream Metrics and Targets (PI: Donald Remson)
  - Unconventional Resource Development and Associated Infrastructure (PI: Justin Adder)

Gantt Chart, 1 of 9

Table 3: Onshore Unconventional Resources Timeline

		BP1 (01/01/2017-12/31/2017)			
Task 1.0 Project Management and Planning					
1.1	Program Management				
1.2	Technical Resource Coordination				
1.3	Project Management Office Support				
1.4	Contractor Management Support				
Task 2.0 Reservoir Processes					
2.1	Geomechanics of Pore-to-Core				
	Work with other national laboratories (Los Alamos National Laboratory (LANL) and Lawrence Berkeley National Laboratory (LBNL)) to identify experimental parameters for laboratory scale tests to be performed in FY17.				
	Obtain shales for testing.				
	Perform laboratory tests, numerical simulations, and begin analysis of results.				
	Finalize computed tomography (CT) analysis and report out results to collaborators. Develop draft journal articles and conference presentations to disseminate results.				
	M1 Milestone (M1.17.2.B) – Characterize changes in permeability as a function of stress/clay content. Summary presentation of results.				

Gantt Chart, 2 of 9

		BP1 (01/01/2017-12/31/2017)			
2.2	Geochemistry of Pore-to-Core				
	Work with other national laboratories (LANL and LBNL) to identify experimental parameters for laboratory scale tests to be performed in FY17. Perform literature review of precipitation controls.				
	Perform laboratory tests and begin analysis of results.				
	Continue experiments and develop precipitation control experiments.				
	Perform first round of precipitation control experiments and develop draft journal articles and/or conference presentations to disseminate results from earlier fracture flow tests.				
	M1 Milestone (M1.17.2.A) – Characterize key elements for dissolution and precipitation in reacted fractured shale. Summary presentation of results.				
2.3	Core Analysis				
	Develop draft catalog/database for cores at NETL-MGN.				
	Assist in publication of MSEEL scanning data in finalized Technical Report Series (TRS) form and at conferences, as appropriate.				
	As core from new locations becomes available, obtain, catalog, store, and distribute.				

Gantt Chart, 3 of 9

		BP1 (01/01/2017-12/31/2017)			
	As/if USEEL core (or HFTS or other NETL sponsored sites) becomes available throughout the year make scanning of the core a priority.				
	Milestone – Co-author at minimum one peer-reviewed publication discussing MSEEL core scanning and incorporation with well scale measurements.				
2.4	Microbiological Impacts of Perturbed Subsurface Environments				
	Isolate and characterize draft genome of abundant microorganisms from CO_2 exposed fresh water aquifer.				
	Investigate future collaborations for microbial experiments with new CO_2 exposed system.				
	Present results from metagenomics analysis of CO_2 exposed systems at national conference.				
	Milestone – Conference presentation of metagenomics analysis of CO_2 exposed systems.				
Task 3.0 Wellbore Integrity					
3.1	Wellbore Detection through Remote Techniques				
	Design/cost analysis will be prepared for a leaf-off, drone, LiDAR survey to detect legacy wells with no casing or wooden casing.				
	Microfabricated Atomic Magnetometer (MFAM) will be integrated with drone aircraft and made airworthy.				
	Drone MFAM surveys will be performed in Hillman State Park where magnetic surveys were previously performed with a full-sized helicopter.				
	M1 Milestone (M1.17.3.A) – A comparison of drone magnetometer surveys and helicopter magnetometer surveys for the ability to survey large areas and locate legacy wells will be presented at relevant conference.				

Gantt Chart, 4 of 9

		BP1 (01/01/2017-12/31/2017)			
3.2	Cement Integrity				
	Compare field-collected and laboratory fluid exposure analysis of wellbore cements.				
	Identify whether laboratory-characterized reactions occurred in field settings.				
	Milestone – Determine mechanism of alteration in wellbore cements.				
Task 4.0 Relationships between Seismicity and Geomechanics					
4.1	Microseismic-Geomechanics Inter-Relationships				
	Observed relationships between microseismic attributes and geomechanical rock properties at one Marcellus well location will be submitted to a peer-reviewed journal.				
	An analysis of the interrelationships between microseismic attributes and geomechanical properties will be initiated for the HFTS and two additional Marcellus locations.				
	Continued analysis of microseismic and geomechanical data from HFTS and Marcellus well locations.				
	Prepare summary analysis of the interrelationships between microseismic attributes and geomechanical rock properties that includes the results from HFTS, MSEEL, and two other Marcellus locations.				

Gantt Chart, 5 of 9

		BP1 (01/01/2017-12/31/2017)			
4.2	Tremor Analysis				
	Data from surface 3-C geophone array at HFTS will be evaluated for low-frequency tremor (LPLD events).				
	Data from vertical array at MSEEL will be evaluated for low-frequency tremor (LPLD events).				
	LPLD events will be evaluated for a temporal relationship with hydraulic fracturing operations, local and distant earthquakes, and nearby, man-made seismicity (blasting etc.).				
	Summary analysis of the relationship between LPLD events and hydraulic fracturing will be prepared.				
	M1 Milestone (M1.17.4.B) – A manuscript that describes seismicity recorded by surface seismometers at Marcellus well locations during stimulation will be submitted to a refereed journal.				
Task 5.0 Water Quality and Availability					
5.1	Environmental Behavior of UOG Fluids and Solids				
	Synthesize results from multi-year study to prepare for completion of leaching experiments and modeling.				
	Design and begin leaching experiments on drill cutting materials under different environmentally relevant scenarios.				
	Define model parameters and approach for evaluating future leaching scenarios using TOUGH2 (Transport Of Unsaturated Groundwater and Heat).				
	Develop manuscript or conference presentation for experimental leaching results.				
	Milestone – Identify environmental conditions that can promote leaching from drill cuttings disposal sites and characterize potential implications for environmental systems.				

Gantt Chart, 6 of 9

		BP1 (01/01/2017-12/31/2017)			
Task 6.0 Air Quality Issues					
6.1	Ambient Air Monitoring[1]				
	Analyze data from the MSEEL site. Compare atmospheric concentrations of measured species with operator activity, meteorological conditions, and influence from off-site emission sources. Results will be reported in a manuscript to be submitted to a peer-reviewed publication.				
	Deploy mobile air monitoring laboratory to the USEEL site. Calibrate air monitoring instruments and begin data collection.				
	Collect data from the USEEL site. Conduct data analysis monthly.				
	M1 Milestone (M1.17.6.B) – Complete analysis of ambient air monitoring data for the MSEEL site.				
	Milestone – Manuscript describing results from air monitoring at the MSEEL site submitted to a peer-reviewed publication.				
	Milestone – Ambient air monitoring data collection at the USEEL site for pre-drilling, vertical drilling, horizontal drilling, hydraulic fracturing, flowback, and production phases of operation.				

Gantt Chart, 7 of 9

		BP1 (01/01/2017-12/31/2017)			
6.2	Natural Gas EOR Evaluation				
	Hire post-doctoral appointee for the project. Post-doc will work with EERC, Canmet, and other participants to develop a collaborative team.				
	Investigate available datasets and resources to conduct environmental assessment. Cost-benefit analysis will be conducted using available data.				
	Identify data gaps from the assessment. Determine feasibility of designing a field campaign to collect data that are uncertain or not available.				
	Milestone – Collaborative research team formed.				
	M1 Milestone (M1.17.6.A) – Initiate analysis for evaluating tradeoffs analysis for natural gas-EOR				
	Milestone – Feasibility assessment conducted that examines the extent to which re-injecting captured methane into the Bakken to enhance oil recovery reduces GHG and VOCs emissions associated with flaring.				

Gantt Chart, 8 of 9

		BP1 (01/01/2017-12/31/2017)			
Task 7.0 Hybrid Energy Systems					
7.1	Modeling Geothermal Reservoirs in Sedimentary Rock				
	Initiate work. Determine best approach to modification of NFFLOW for heat conduction and transport. Develop mathematical equations for heat transport and 3D heat conduction.				
	Modify 1D models for fluid flow in matrix to either 2D or 3D models of heat accumulation (from layers above and below) and heat conduction through matrix to fractures.				
	Modify computer code to model 3D heat conduction in layer above and below the layer(s) of fluid flow.				
	Modify code of heat transport as fluid flow through fractures. Modify the input files and output files. Debugging and testing of new code.				
	Milestone – Completion of modifications for heat conduction in matrix.				
	Milestone – Completion of modifications for heat conduction in layers above and below reservoir.				
	Milestone – Completion of alpha version of computer code.				

Gantt Chart, 9 of 9

		BP1 (01/01/2017-12/31/2017)			
Task 8.0 Systems Engineering & Analysis (SE&A)					
8.1	Metrics Development and Target Setting for the NETL Unconventional (EPD) Program				
	Prepare presentation and present results of initial metrics report. Obtain feedback from oil and gas program and plan efforts to perform more detailed analysis on specific metrics elements which can best define the unconventional onshore EPD program.				
	Acquire data gathering capabilities and perform necessary modeling to acquire selected metrics elements at level of detail necessary to measure NETL's Onshore Unconventional Resources Portfolio's progress towards its objectives.				
	Calculate up to date baseline values for all metrics elements.				
	Develop a set of future targets for baselined metrics elements that will drive and support the R&D objectives of the Onshore Unconventional Resources Portfolio.				
	Milestone – Develop a plan that identifies data sources and modeling necessary to develop those metrics elements approved by program personnel based on feedback acquired from initial metrics effort.				
	Milestone – Baseline values calculated.				
	M1 Milestone (M1.17.8.A) – Define metrics for onshore UOG with future R&D targets.				
8.2	Unconventional Resource Development and Associated Infrastructure				
	Overall approach to the analysis developed.				
	Data collected and prepared.				
	Model developed.				
	Draft final report and documentation.				
	Milestone – Briefing describing the scope, data, and analytical approach.				
	Milestone – Develop buildout model.				
	M1 Milestone (M1.17.8.B) – Complete documentation and draft final report for buildout model.				

Bibliography, 1 of 2

Recent Publications

Publications from prior-year Onshore Unconventional Resources research through the Energy Policy Act Section 999, Environmentally Prudent Development, and Unconventional Resources funding lines can be found at: https://edx.netl.doe.gov/ucr/

- Vankeuren, A.N.P.; Hakala, J.A.; Jarvis, K.; Moore, J.E. "Mineral Reactions in Shale Gas Reservoirs: Barite scale formation from reusing produced water as hydraulic fracturing fluid." Environmental Science and Technology, Publication Date (Web): July 19, 2017, DOI: 10.1021/acs.est.7b01979
- Moore, J., Crandall, D., Gill, M., Brown, S., and Tennant, B., (*submitted*) **Design and implementation of a shearing apparatus for the experimental study of shear displacements in rock** *to be submitted to Review of Scientific Instruments*
- Lipus D, Ross D, Bibby K, Gulliver D. **Draft Genome Sequence of *Pseudomonas* sp. BDAL1 Reconstructed from a Bakken Shale Hydraulic Fracturing-Produced Water Storage Tank Metagenome**. *Genome Announcements*. 2017;5(11):e00033-17. doi:10.1128/genomeA.00033-17.
- Daniel Lipus, Amit Vikram, Daniel Ross, Daniel Bain, Djuna Gulliver, Richard Hammack and Kyle Bibby, **Predominance and Metabolic Potential of Halanaerobium in Produced Water from Hydraulically Fractured Marcellus Shale Wells**, *Applied and Environmental Microbiology*, 3 February 2017

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Recent Publications

Publications from prior-year Onshore Unconventional Resources research through the Energy Policy Act Section 999, Environmentally Prudent Development, and Unconventional Resources funding lines can be found at: https://edx.netl.doe.gov/ucr/

- Crandall, D.; Moore, J.; Rodriguez, R.; Gill, M.; Soeder, D.; McIntyre, D.; Brown, S. (*2017*) **Characterization of Martinsburg Formation using Computed Tomography and Geophysical Logging Techniques**,NETL-TRS-4-2017; Technical Report Series; U.S. Department of Energy, National Energy Technology Laboratory: Morgantown, WV, 2017; p 68.
- Soeder, D. J.; Wonnell, C. S.; Cross-Najafi, I.; Marzolf, K.; Freye, A.; Sawyer, J. F. Assessment of Gas Potential in the Niobrara Formation, Rosebud Reservation, South Dakota; NETL-TRS-1-2017; NETL Technical Report Series; U.S. Department of Energy, National Energy Technology Laboratory: Morgantown, WV, 2017; p 152.
- Eastman, H. S.; Murin, T. Geologic Characterization of Johnson County, Texas; NETL-TRS-17-2016; NETL Technical Report Series; U.S. Department of Energy, National Energy Technology Laboratory: Morgantown, WV, 2016; p 68.