Presentation Outline

• MSEEL Background
• Brief Review of Active Technical Areas
• Focus on Understanding the Reservoir MSEEL 2
  – Hypothesis Driven Field Test
    • Test Importance of Preexisting Fractures
    • Provide Data to Improve Completion Design
    • Develop Machine Learning Algorithms to Efficiently Use Thin (Low Cost) Data
• Summary, Synergies and Future Opportunities
Project Objectives

MARCELLUS SHALE ENERGY AND ENVIRONMENT LABORATORY
MSEEL

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

• October 2014 – September 2021

• Continued Work on MIP
  – Vertical Pilot Hole
  – Two + Two Laterals
  – Continued Monitoring

• MSEEL 2 – Boggess
  – Vertical Pilot Hole
  – 6 Laterals

• Work with LANL
  – ML/AI Research
Active Technical Areas

• Deep Subsurface Rock, Fluids, & Gas
  – Shikha Sharma with Paula Mouser and Dave Cole

• Produced Water and Solid Waste Monitoring
  – Paul Ziemkiewicz

• Environmental Monitoring: Air & Vehicular
  – Derek Johnson

• Database Development
  – Maneesh Sharma, Tim Carr

• Geologic Engineering
  – Ebrahim Fahti

• Geophysical and Geomechanical
  – Brian Panetta, Omid Dehangzi, Silixa, Tim Carr
Deep Subsurface Rock, Fluids, & Gas

• Characterization of organic matter - kerogen extraction and characterization at MIP and Boggess
  – Similar aliphatic and aromatic structural parameters
    Similar deposition environment, sources of organic matter, and thermal history

• High-pressure and temperature fracture fluid/shale interaction experiments
  – Carbonate dissolution effects
  – Three synthetic HFF solutions with oxidative breakers were reacted with kerogen concentrate for a 14-day period (to mimic the shut-in period).
    Oxidative breakers can significantly degrade shale organic matter (OM) and improve shale permeability
Produced Water and Solid Waste Monitoring

• Drilling and Completion Monitoring at MIP (3H, 4H, 5H, 6H) and Boggess (9H-17H) Pads
  – Hydraulic fracturing fluid, flowback, produced water, drilling muds and drill cuttings were characterized according to their inorganic, organic and radiochemistry.
  – Over 5 years of post-completion sampling of produced water and surface water.
    • Make-up water low TDS dominated by calcium and sulfate ions
    • Produced water high TDS sodium/calcium chloride water
  – TDS increases rapidly over the initial 90 days post-completion, and stabilized between 100,000 and 215,000 mg/L around 1200 days.
    • Shut-ins and subsequent return to product at MIP pad result in a decrease in TDS
  – Organic components (e.g., benzene, toluene) very low (<3μg/l to ND)
Environmental Monitoring: Air & Vehicular

- Seventeen (17) methane audits at MSEEL.
  - Full flow sampler (FFS) to quantify methane emissions detected using a handheld methane detector
  - Development and calibration of a Mobile Eddy Covariance Tower (MECT) for continuous monitoring
    - Geometric mean 0.82 kg/hr.
  - Completed energy audit during the drilling focused on engine activity for modeling of drill rig hybridization to reduce fuel consumption, reduce emissions, and improve efficiency

- Methane Mitigator – Reducing Methane Emissions at Well Sites (FE0031865) Derek Johnson and Robert Heltzel at Tuesday 1:05PM
Database Development

- Data available at MSEEL.ORG and FTP
  - Data sets from megabytes to terabytes
  - Transfer - Online to shipping of external drives
    - MIP – 5 Terabytes
    - Boggess – 108 Terabytes – Raid Storage
- Need to work with EDX for long-term storage and improved transfers
Database Development

• Data available at MSEEL.ORG and FTP
  – Data sets from megabytes to terabytes
  – Transfer - Online to shipping of external drives

• Need to work with EDX for long-term storage and improved transfers
Geologic Engineering, Geophysical and Geomechanical

- Numerous Fractures Along the Lateral
  - Occur as Swarms
  - Calcite Cemented during Catagenesis
  - Orientation NNE Different from Present-day NE-SW Stress

- Cross-Stage Communication Detected with DAS and DTS
  - Microseismic Shows Present Day Stress Directions NE-SW
  - Communication Through the Near-Wellbore
  - Communication Through the Formation
  - Microseismic Shows Present Day Stress Directions NE-SW

- Modify Cluster and Stage Placement to Avoid Fracture Swarms in 2 Wells (1H and 3H)
  - Improved Completion and Production Efficiencies

- Recognition of Fracture Intensity with Drilling Data
  - Machine Learning
MIP Pad Hypothesis

Significance of Preexisting Fractures

Stages 1-6
A
12,451’ – 13,809’

Stages 7-12
B
11,092’ – 12,451’

Stages 13-19
C
9,731’ – 11,092’

Stages 20-21
D
9,271’ – 9,731’

Stages 22-28
E
7,753’ – 9,271’

Not critically oriented in stress field, results in “slow” slip with low frequency seismic expression typically missed during microseismic monitoring

Optimally, critically oriented in stress field, results in “fast” slip with high frequency microseismic expression

Temperature increase in previous stage(s)
A total of 6,363 fractures and faults were identified from Boggess 5H.
Fracture Characterization

Acoustic Waterfall 0-7500Hz

Stage 5
Fracture Characterization

Acoustic Waterfall 0-7500Hz

Stage 10
Modified Completion Design

Original Completion Design for Boggess 3H

New Completion Design
Boggess Pad Production (Actual)
Cumulative gas production forecasts of Boggess Pad and MIP3H
Boggess Pad Production (Forecast)

Cumulative gas production forecasts of Boggess Pad and MIP3H in BCF/1000 ft of lateral
WVU Characterization ML Tools

Drill String Acceleration Data Analysis

Low Fidelity Approaches Integrated with High Fidelity Approaches to make Smart Decisions

Drill string borehole imager and vibration sensor.
Drill String Acceleration Data Analysis

Low Fidelity Approaches Integrated with High Fidelity Approaches to make Smart Decisions

<table>
<thead>
<tr>
<th>Data warehouse</th>
<th>Data category</th>
<th>Sampling speed</th>
<th>Purpose for machine leaning</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pason</td>
<td>Drilling data</td>
<td>1 record per second</td>
<td>Input</td>
</tr>
<tr>
<td>FracView</td>
<td>Accelerometer data</td>
<td>1 record per 5.1 microsecond</td>
<td>Input</td>
</tr>
</tbody>
</table>
METHODOLOGY OF THE ML WORKFLOW

- **Auto-ML by Tree-based Pipeline Optimization Tool (TPOT)**
  - Genetic Programming (GP)
  - Complete ML pipeline

- **Sequential Based Model Optimization (SMBO)**
  - Bayesian Optimization Loop

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**TPOT +SMBO**

**GP**

**SMBO**
The Regression Model

- **Modelled features:**
  - RPM, GR data
  - 3D vibration and shock data
- **Output feature:**
  - Fracture intensity
- **Optimized model:**
  - K-Nearest Neighbor Regressor
  - Hyperparameters:
    - Number of leaf size: 30
    - Number of neighbors: 2
    - Distance p value: 2
      (i.e. Mincowski distance)
- **Error analysis:**
  - Final average Mean Squared Error for validation: 0.0085
  - Error values center around 0
  - Normally-distributed behavior
The Classification Model

- **Modelled features:**
  - RPM, GR data
  - 3D vibration and shock data

- **Output feature:**
  - 2-class fracture intensity data (0-0.5 and >0.5)

- **Optimized model:**
  - K-Nearest Neighbor Classifier
  - Hyperparameters:
    - Number of leaf size: 30
    - Number of neighbors: 9
    - Distance p value: 2 (i.e. Mincowski distance)

- **Error analysis:**
  - Final average accuracy (i.e. R2) for validation: 0.94
  - >=0.9 accuracy for TP and FN scores
LANL ML-based platform uses a “Behavior Library” that allows operators to tailor pressure drawdown for optimum recovery.

Developing & calibrating a site model for MSEEL–I for using in predicting the pressure dependent behavior relative to recovery efficiency.

Natural fractures around a single stage in MIP-3H

Fracture network along entirety of MIP-3H

Initial simulation of drainage along fracture network.

SMART Task – Real-Time Forecasting: Pressure Management at Marcellus Shale Energy and Environment Laboratory (MSEEL) Hari Viswanathan, Los Alamos National Laboratory (LANL) 4:20 PM Monday
Accomplishments to Date

• Documentation of Changes Rock, Fluids, & Gas Through Time (Completion and Production)
• Environmental Monitoring Through Time
  – Methane Leakage
• Development of New Tools for Analysis/Integration
• Improved Understanding of Unconventional Reservoirs Along Laterals
  – Changes Through Time (Geologic and Operational)
  – Use of Low Cost (Thin, Low Fidelity) Data Along Lateral
  – Improved Completion and Production Efficiency
Lessons Learned

• Data Management is Critical
• Research Productivity Beyond the Research Team
  – Multidisciplinary Multi-Organization Teams
  – Over 200 papers/presentations/theses/dissertations/etc.
• Need for Hypothesis Driven Field Tests
  – Expect Modification Additional Hypotheses Through Time (Iteration Critical)
• Reservoirs are Anisotropic
  – Demonstrated by Horizontal Wells
  – Can have Negative/Positive Impact on Performance
  – Can be Better Understood
Synergy Opportunities

- Cost-efficient machine learning approaches to reservoir imaging and design
  - “Almost All” Reservoirs are Anisotropic
  - Seal and Reservoir Compartment Evaluation
- Horizontal Wells in Carbon and H$_2$ Storage
  - Challenges of Data Acquisition and Analysis
  - Risk
    - Leakage and Pressure Management
  - Efficiency
- Use of Horizontal Wells in Geothermal
Project Summary

- Time Frame – October 1, 2014 to September 20, 2021
- Over 180 terabytes of Accessible Surface and Subsurface Data
- Over 200 Papers and Presentations
- Support of Numerous Post-Docs and Graduate Students across Multiple Institutions
- Better Understanding and New Tools