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 Vision

- Demonstrate the Best Practices to Drill, Complete and Produce a New Horizontal Well That Minimizes Any Environmental/Societal Costs While Maximizing Economic Productivity
- Monitor and Document Impacts in a Controlled Environment
  - Greenhouse Gas Emissions
  - Local Air Pollution
  - Water Supply and Quality
  - Noise and Activity
  - Societal Impacts
- Develop New Technologies to Maximize Production
  - Microseismic Monitoring
  - Production Monitoring
  - Advanced Logging
  - Simulation
- Develop New Scientific and Engineering Approaches to Apply to Multi-disciplinary and Multi-institutional Natural Resource Studies
MSEEL Site

2.5 miles

WVU

MSEEL
Marcellus Shale Energy and Environment Laboratory

The objective of the Marcellus Shale Energy and Environment Laboratory (MSEEL) is to develop and validate new knowledge and technology to improve recovery efficiency and unconventional resource development.

MSEEL Data Portal

Organizations

- WVU
- NETL
- northeast natural energy

10 organizations found

- Background Datasets
- Database Dev & Maintenance
- Deep Subsurface Geochemistry

Maneesh Sharma – WVU
Frank Lafone – WVU
MSEEL Environmental Monitoring
Air Emissions

Michael McCawley – WVU
Derek Johnson – WVU
MSEEL Environmental Monitoring
Air Emissions

MSEEL Passive Sampling Setup

<table>
<thead>
<tr>
<th>Analyte</th>
<th>Samples collected (#)</th>
<th>Samples analyzed for concentration (#)</th>
<th>Samples analyzed for isotopes (#)</th>
<th>Concentration completion (%)</th>
<th>Isotope completion (%)</th>
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</thead>
<tbody>
<tr>
<td>NO₃</td>
<td>572</td>
<td>354</td>
<td>10</td>
<td>61.9</td>
<td>1.7</td>
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<tr>
<td>HNO₃</td>
<td>296</td>
<td>219</td>
<td>118</td>
<td>74.0</td>
<td>39.9</td>
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<td>NH₃</td>
<td>572</td>
<td>0</td>
<td>0</td>
<td>0.0</td>
<td>0.0</td>
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<tr>
<td>O₃</td>
<td>296</td>
<td>80</td>
<td>N/A</td>
<td>27.0</td>
<td>N/A</td>
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</tbody>
</table>

Legend

- Met Station
- Sampling Points

Emily Elliot – PITT
Department of Geology and Geography
MSEEL
Drilling MIPU 3H and 5H
Geosteering MIP-3H
Geosteering MIP-3H
Using ‘Green’ Drilling Mud

NO Parameters Exceeded TCLP

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

TCLP - Toxicity Characteristic Leaching Procedure

Better Drilling Performance with Steerable Bit
2011 – 3,000 feet curve & lateral in 30 days
2015 – 6,500 feet curve & lateral in 5 days
Brazil nuts are about 12 pCi/g

Radionuclides (pCi/g)
Subsurface Sampling

Retrieved 111’ of a targeted 120’ whole core
Collected 197 sidewall cores from the SW and 3H well
Sidewall Cores Geochemistry

At Each Transect

1. Ground
   - Planned Analyses:
     - Mouser (OSU): Biomass estimates and microbial lipid analysis
     - Wrighton (OSU): Metagenomic analysis
     - Sharma (WVU): TOC, %N, bulk C/N/S isotope composition, biomarkers, DGFA

2. Split
   - Wilkins (OSU): high pressure/temperature isolations and enrichments of indigenous microbes
   - Cole (OSU): pore structure, porosity, mineralogy, and geochemical analysis
   - Darrah (OSU): cryogenic laser ablation ICP-MS
     - Laser ablation GC-MS-FID, noble gas
High Resolution CT Scanning
Multi-Sensor Core Logging
CRUSHED SAMPLE PERMEABILITY

DEVELOPED BY GAS RESEARCH INSTITUTE AND IS REFERRED TO AS "GRI" METHOD.

Particles in the 20-35 US mesh size range (0.85 to 0.5mm)

- No Standard Protocol
- Inconsistent Results

Kashy Aminian - WVU
PRECISION PETROPHYSICAL ANALYSIS LABORATORY (PPAL) AT WVU

MEASUREMENT CAPABILITIES

- **Permeability** (Nano-Darcy range).
- **Pore Volume** (0.1% accuracy).
- **Absolute Permeability** (Gas Pressure Correction).
- **Impact of Stress** (Reservoir Conditions).
- **Impact of Adsorption**
- **Pore Structure Characterization**

**Accurate, Consistent, and Repeatable Results**

Kashy Aminian - WVU
ABSOLUTE PERMEABILITY

SAMPLE #2

\[ y = 1 \times 10^7 x + 124.27 \]
\[ R^2 = 0.9932 \]

\[ y = 1 \times 10^7 x + 113.67 \]
\[ R^2 = 0.9942 \]

\[ y = 1 \times 10^7 x + 115.44 \]
\[ R^2 = 0.9963 \]

Permeability, nD

\( \frac{1}{P^2}, \text{psia}^{-2} \)

N2 Desorption
N2 Adsorption
Helium
IMPACT OF STRESS

**Porosity vs. Net Stress**

- **Increasing Net Stress**
- **Decreasing Net Stress**

**Permeability vs. Net Stress**

SAMPLE 7547.03
IMPACT OF STRESS

Fracture Closure Stress = 4770 psi

Sample 7547.03
Brunauer–Emmett–Teller (BET) theory

- The Type H4 loop, which does not exhibit any limiting adsorption at high \( p/p_0 \), is observed as aggregates of plate-like particles and slit-shaped pores, often associated with microporosity (IUPAC Recommendation 1984).

Pores of diameters less than 5 nm make the greatest contribution to SSA, whereas pore volumes are affected by larger pores. Samples with higher thermal maturity have less smaller pores (pore diameter less than 5 nm).
This is an SE2-SEM image provided by Ingrain, and the scale of this image is 20 by 30 microns
SEM Core Analysis

Porosity

Organic Matter
SEM Core Analysis

After Gaussian Blur

Organic Matter

After Binary

Organic Matter

Liaosha Song - WVU
Subtract organic matter from porosity to get the inorganic porosity.

Inorganic porosity
Subtract inorganic porosity from porosity to get the organic matter porosity

**Organic porosity**
SEM Core Analysis

Organic Matter Porosity

©2014 Ingrain Inc.
MSEEL
Completion MIPU 3H and 5H
Sonic Scanner 3H Pilot Hole

<table>
<thead>
<tr>
<th>Depth (ft subsea)</th>
<th>Depth (m)</th>
<th>γ ray</th>
<th>Density</th>
<th>Stress Gradient</th>
<th>Young’s Modulus</th>
<th>Sonic</th>
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<tbody>
<tr>
<td>6100 ft</td>
<td>1860 m</td>
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<td>6200 ft</td>
<td>1890 m</td>
<td></td>
<td></td>
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<tr>
<td>6300 ft</td>
<td>1920 m</td>
<td></td>
<td></td>
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<td>6400 ft</td>
<td>1950 m</td>
<td></td>
<td></td>
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<tr>
<td>6500 ft</td>
<td>1980 m</td>
<td></td>
<td></td>
<td></td>
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</table>

- Mahantango Formation
- Marcellus Shale

Tom Wilson

Department of Geology and Geography
MSEEL - LOGGING LATERAL

High Definition open hole logs in lateral with synthetic mud
MIP 3H Completion Design

### MIP 3H Stimulation Summary

<table>
<thead>
<tr>
<th>Sect.</th>
<th>Stages</th>
<th>Description</th>
<th>Cluster</th>
<th>Perf Size</th>
<th>Sand (lbs/ft)</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>1-6</td>
<td>40/70 Design – Testing</td>
<td>5</td>
<td>0.42 5&quot;</td>
<td>400k Standard</td>
</tr>
<tr>
<td>B</td>
<td>7-12</td>
<td>100 Mesh</td>
<td>5</td>
<td>0.42 5&quot;</td>
<td>400k 100 Mesh</td>
</tr>
<tr>
<td>C</td>
<td>13-18</td>
<td>Engineered Design</td>
<td>Varied</td>
<td>Variable</td>
<td>400k Standard</td>
</tr>
<tr>
<td>D</td>
<td>19-24</td>
<td>Fluid/Diverter</td>
<td>5</td>
<td>0.42 5&quot;</td>
<td>400k Standard</td>
</tr>
<tr>
<td>E</td>
<td>25-30</td>
<td>Best practice</td>
<td>Varied</td>
<td>Variable</td>
<td>Variable</td>
</tr>
</tbody>
</table>

- Split into five segments: 2,000 lb/ft 40/70 design, 2,000 lb/ft 100 mesh design, engineered design, fluids/diverter test, real time adjustment
- Test single vs double acid drop as well as ball-in-place and ball drop plugs in segment A/breakdown toe cluster during wireline ops, Apply findings in segments B through E
- Engineered design based on rock stress/strategic perf placement. Test cluster count and perf size
- Segment D — Split into two portions
  - 2-3 Stages: Test potentially shooting 5 clusters, pump certain percentage of job and watch fiber to see what clusters are taking then pump diverter based on feedback to initiate closed clusters. Temperature resolution is every 15 ft with fiber.
  - 2-3 Stages: Test different fluid system
- Perform step-down test on all five sections, second stage on each
MSEEL - LOGGING LATERAL

High Definition open hole logs in lateral with synthetic mud
MSEEL - Microseismic
SURFACE MONITORING OF SLOW SLIP (LPLD)

- Proposed Monitor Sites
  - (Coordinates XY UTM NAD83 Zone 17N)
  - FRAC5
  - FRAC4
  - FRAC3
  - FRAC2
  - FRAC1

Meters
0  250  500  1,000
Energy deficit \( \approx 77.5\% \)

Mechanical losses and/or Slow Slip deformation?

---

Motivation

---


Kumar at al. NETL
Synopsis of slow-slip deformation

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

Not critically oriented in stress field, results in “slow” slip with low frequency (1-30 Hz) seismic expression typically missed during microseismic monitoring.

Adapted from Kumar et al. 2016 and Zoback et al., 2012
SURFACE MONITORING OF SLOW SLIP (LPLD)

Current study

Spectrogram: LPLD events

Das and Zoback, 2013

(a) Raw waveform

Marcellus Shale

(b) spectrogram

Kumar at al. NETL
SURFACE MONITORING OF SLOW SLIP (LPLD)

LPLD and injection parameters

Well 3H

Well 5H

Kumar at al. NETL
MIP3H - Stage 10: Uneven Distribution
MIP 3H - Stage 18 Even Distribution
MSEEL - LOGGING LATERAL

High Definition open hole logs in lateral with synthetic mud
Anisotropic Closure Pressure
Anisotropic Closure Pressure
Thin Data Prediction
MSEEL SUBSURFACE SCIENCE

MSEEL Project Team

Geochemistry (Sharma, Weislogel, Donovan - WVU; Cole, Darrah - OSU)
- Rock – Kerogen; TOC; C/N/S; XRD; FIB/SM; cryolaser ablation; Hg porosimetry
- Fluids/Gases – Continuous monitoring S/C/O/H isotopes, organics, DOC, NORM, noble gases

Microbiology (Mouser, Wrighton - OSU; Sharma - WVU)
- Biomass; microbial lipids, metagenomics

Petrophysics/Geomechanics (Aminian, Wang, Siriwardane – WVU)
- Steady-state permeability (in situ P/T); porosity; pore-size; adsorption → dynamic petrophysics f(P); vertical/lateral heterogeneity.
- Mechanical strength measurements
- FIB/SEM: pore and mineralogical structure
- Horizontal section: natural fracture imaging; geomechanics fibre-optics monitoring
- Log to core calibration; comparison to industry standard methods; refinement of prior basin-scale models.
- Real-time, actionable data for HF operations
- Advanced multi-scale reservoir modeling

Geophysics (Wilson – WVU)
- Borehole microseismic – SRV characterization in multi-well context

Complementary (enabled by NETL/MSEEL)

From NETL-ORD
- Crandall (NETL): multi-scale CT imaging/micro-scale structure; MSCL
- Hakala (NETL): Sr/Li isotopes; major cation/anion/trace elements
- Hammack (NETL): surface micro-science array; fracturing and relaxation
- Soeder (NETL): SRA/TOC
- Boyle (NETL): Fracture modeling (FMI)

From Existing National Laboratory Contributors*,#
- Xu (LANL): XRD, XRF, DSC/TG, SEM, TEM → characterization and LBM modeling; SANS → hydrocarbon phase and flow behavior
- Carey (LANL): tri-axial core-flood w/tracers & AE → in situ fracture formation and permeability; X-ray tomography → apertures and conductivity.
- Wang (SNL): thermodynamics of CH₄-CO₂-H₂O under nanopore confinement; Hi T/P sorption measurement methods.
- Moridis (LBNL): thermodynamic; X-Ray CT → production strategies

From Collaborating Federal Agencies
- Orem (USGS): contaminants in drill cuttings – wastewater evaluations

From Shale Gas Cooperative Agreement Contributors*,+
- Zhu (TAMU): fracture conductivity
- Daigle (UT-A): tri-axial compressive strength; ultrasonic velocity; NMR during fracture; SEM and FIB
- Jessen (USC): shale-rock interactions
- Puckett (Ok. St.): petrophysical protocols: shale-fluid interaction

Add’l supplement from SubTER participants?
- TBD via FY16 “Lab Call” to enable additional science as desired by SubTER management

Protocols developed during MSEEL reflect strong collaboration and project commitment from WVU and Northeast Natural Energy. NETL will strive to extend this approach to other Field Observatories as those projects progress.

Progression into Field Laboratories (downhole experimental science) faces numerous challenges related to costs and liabilities. Good promise for future tests of SRV diagnostic/imaging technologies; well-bore integrity.
## Contacts

<table>
<thead>
<tr>
<th>Program Management</th>
</tr>
</thead>
<tbody>
<tr>
<td>WVU-Principal investigator</td>
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<tr>
<td>WVU-Operations mgr.</td>
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<td>Northeast Natural Energy</td>
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<td>USDOE/NETL</td>
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<td>Surface Environmental</td>
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</table>
Building Partnerships for Research, Education, and Outreach

Industry

MSEEL

Community

Government

Academia

Tim Carr
Phone: 304.293.9660
Email: tim.carr@mail.wvu.edu