Field Laboratory for Emerging Stacked Unconventional Plays (ESUP)

Project No. DE-FE0031576

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CO-PIS: MICHAEL KARMIS, CHENG CHEN, ELLEN GILLILAND, BAHAREH NOJABAEI

VIRGINIA TECH™

Acknowledgments

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- Acknowledgments
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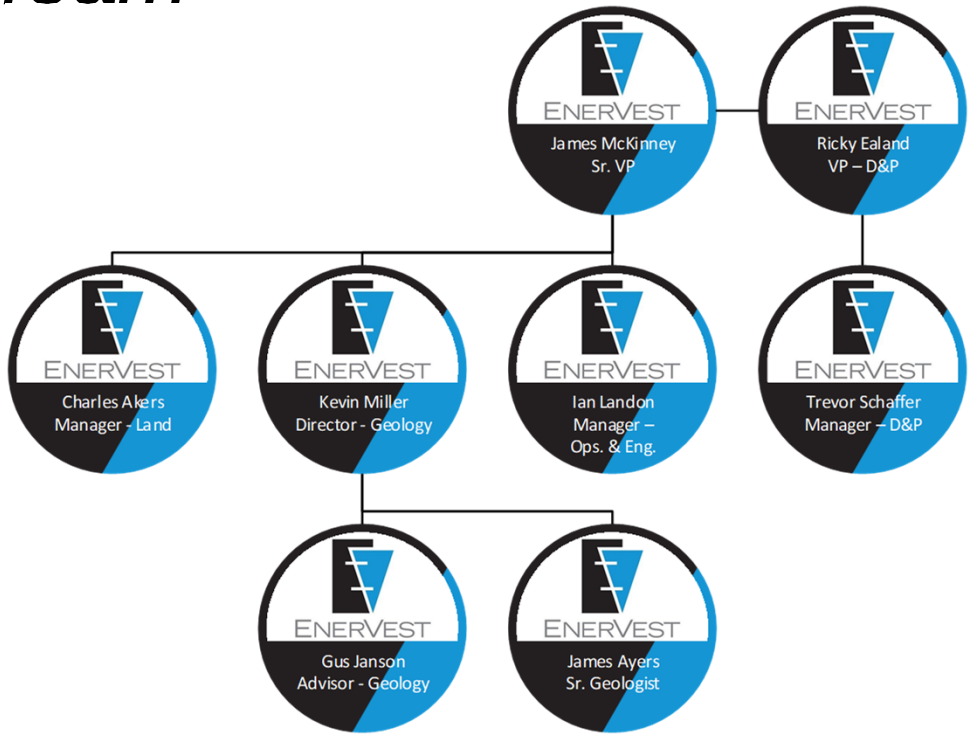
Objective, Project Team and Duration

- Objective:
  - Investigate and characterize the resource potential for multi-play production of emerging unconventional reservoirs in Central Appalachia.
- Project Team
  - Virginia Tech
  - Virginia Center for Coal & Energy Research
  - EnerVest Operating, LLC
  - Pashin Geoscience, LLC
  - Gerald R. Hill, PhD, Inc.
- Duration
  - April 1, 2018 – March 31, 2023 (5 years)

Project Team



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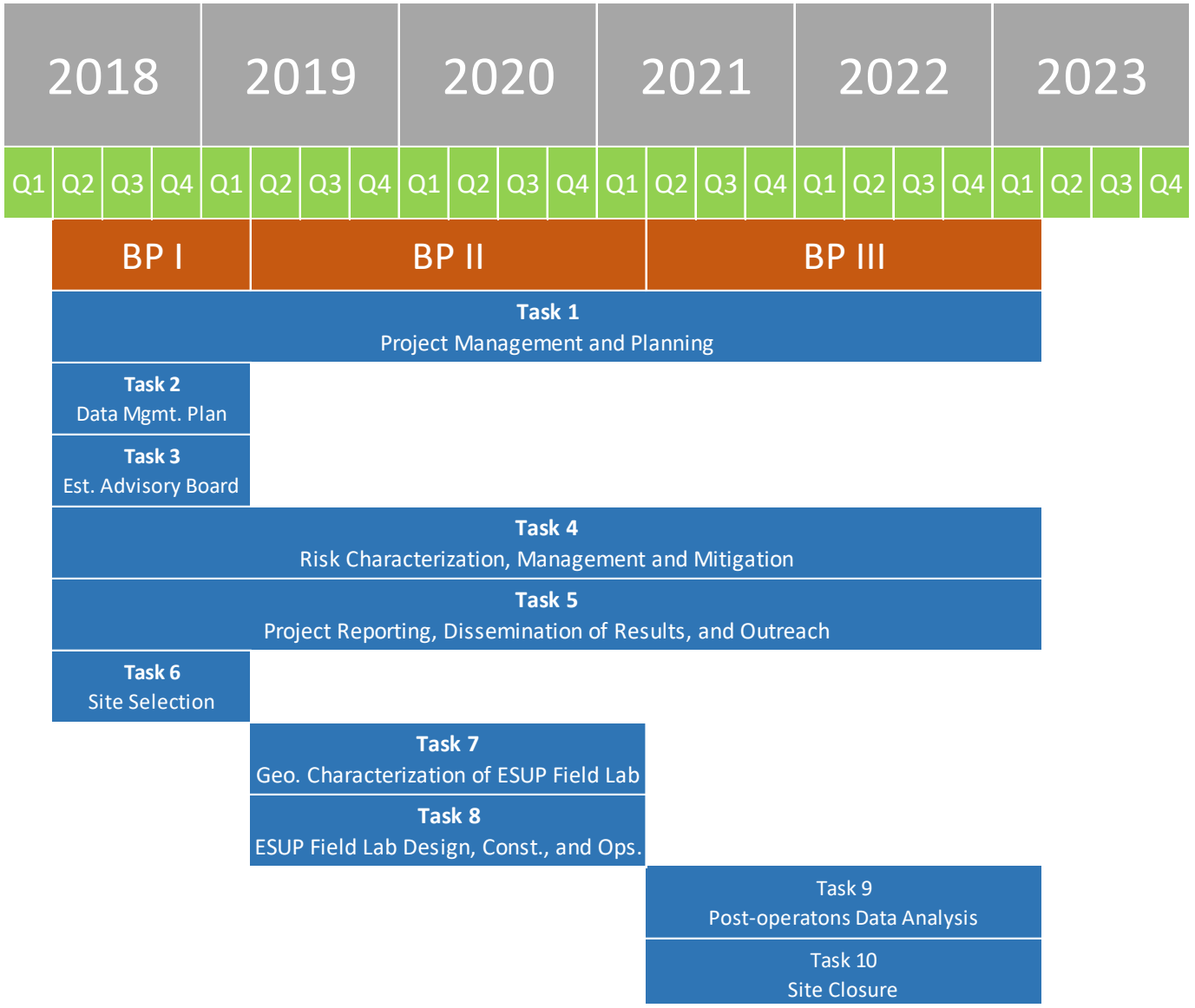
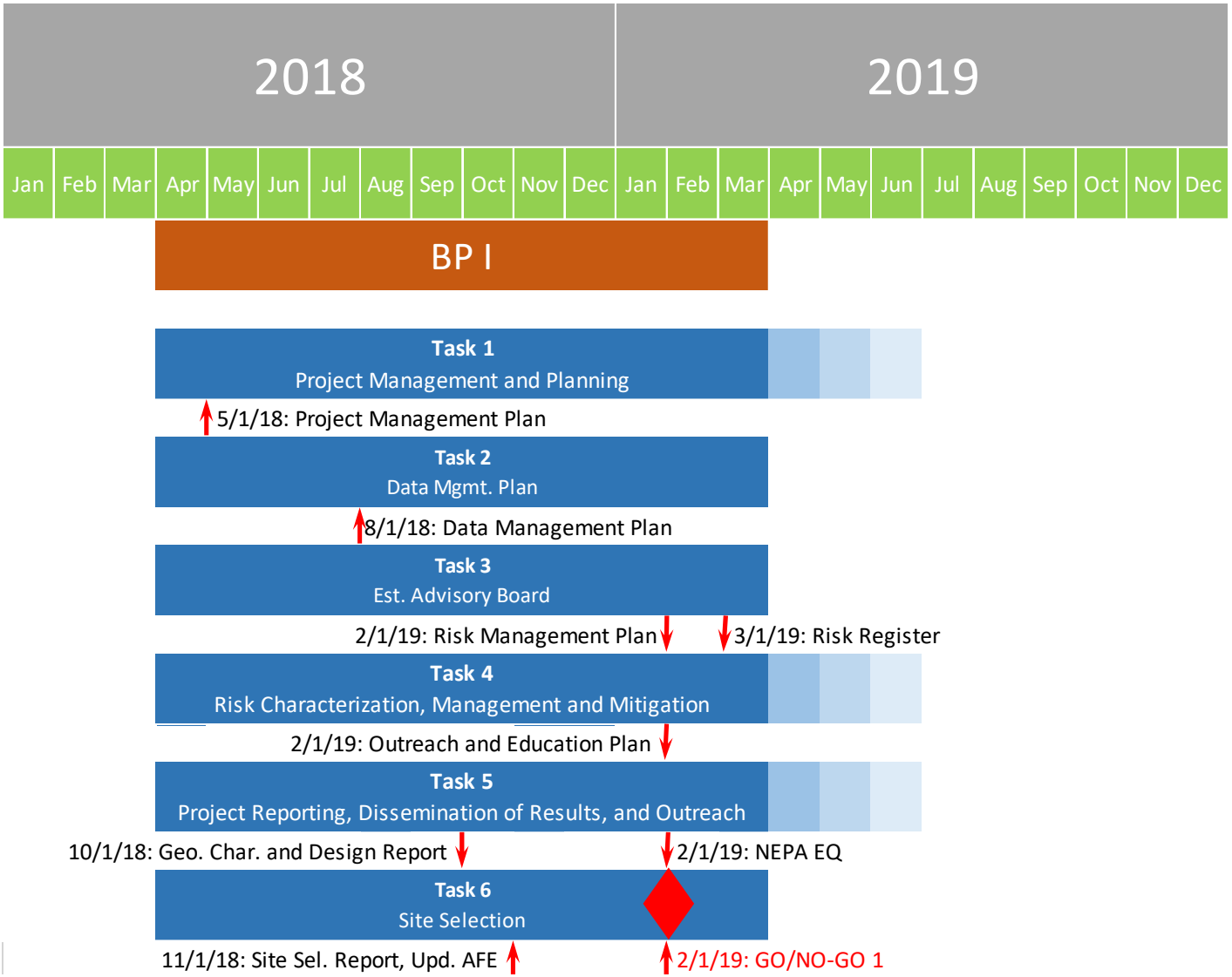
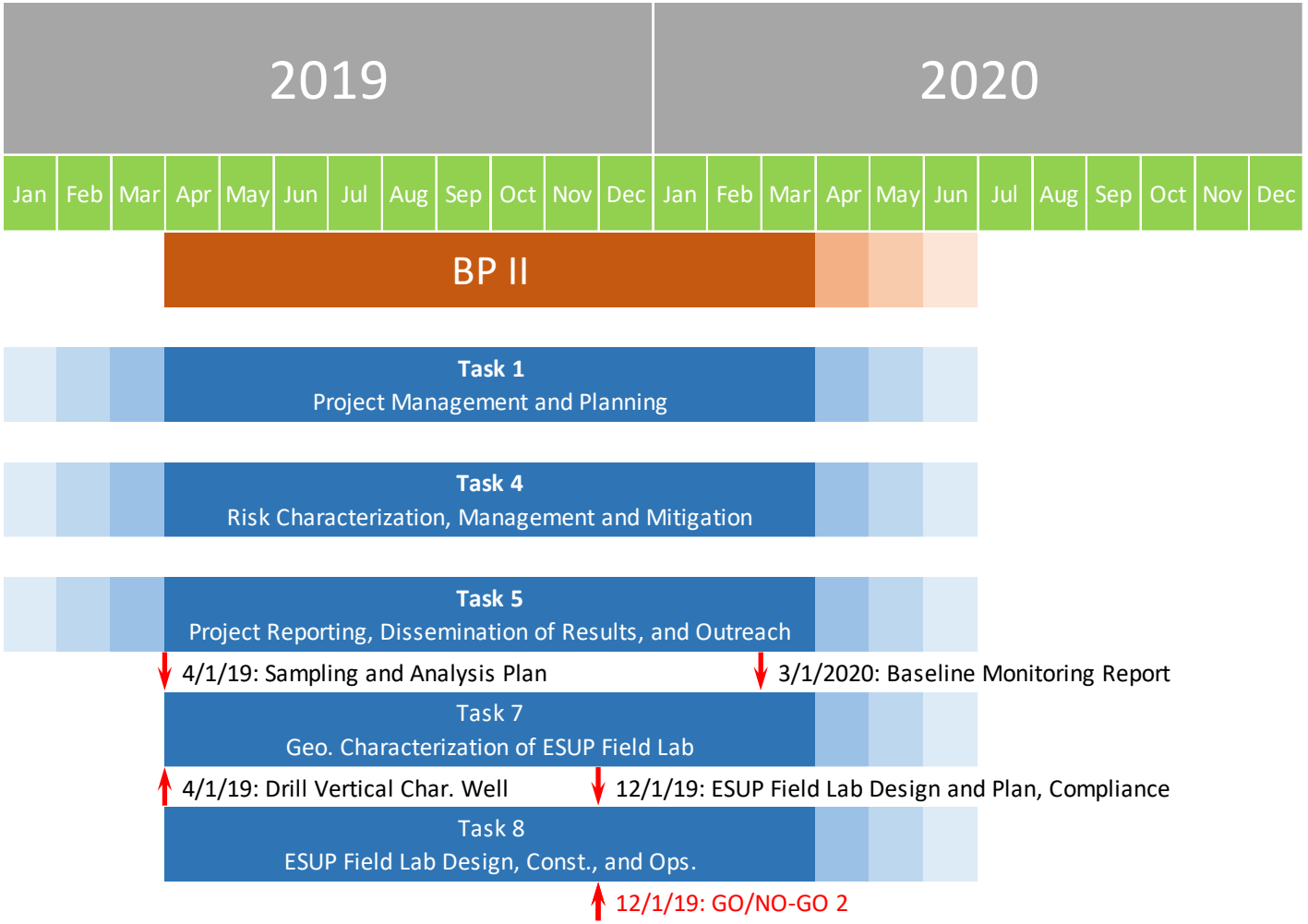
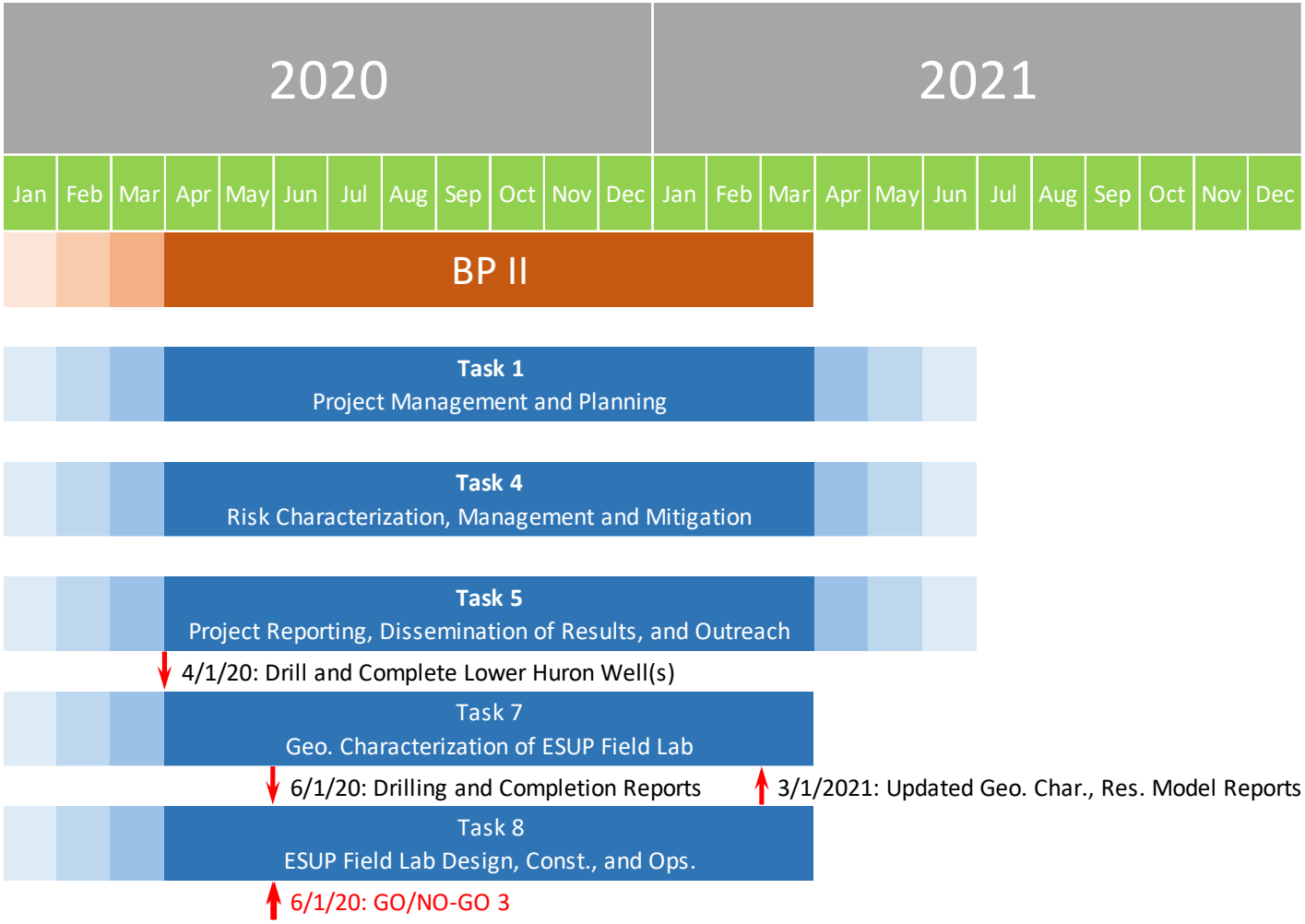
Goals

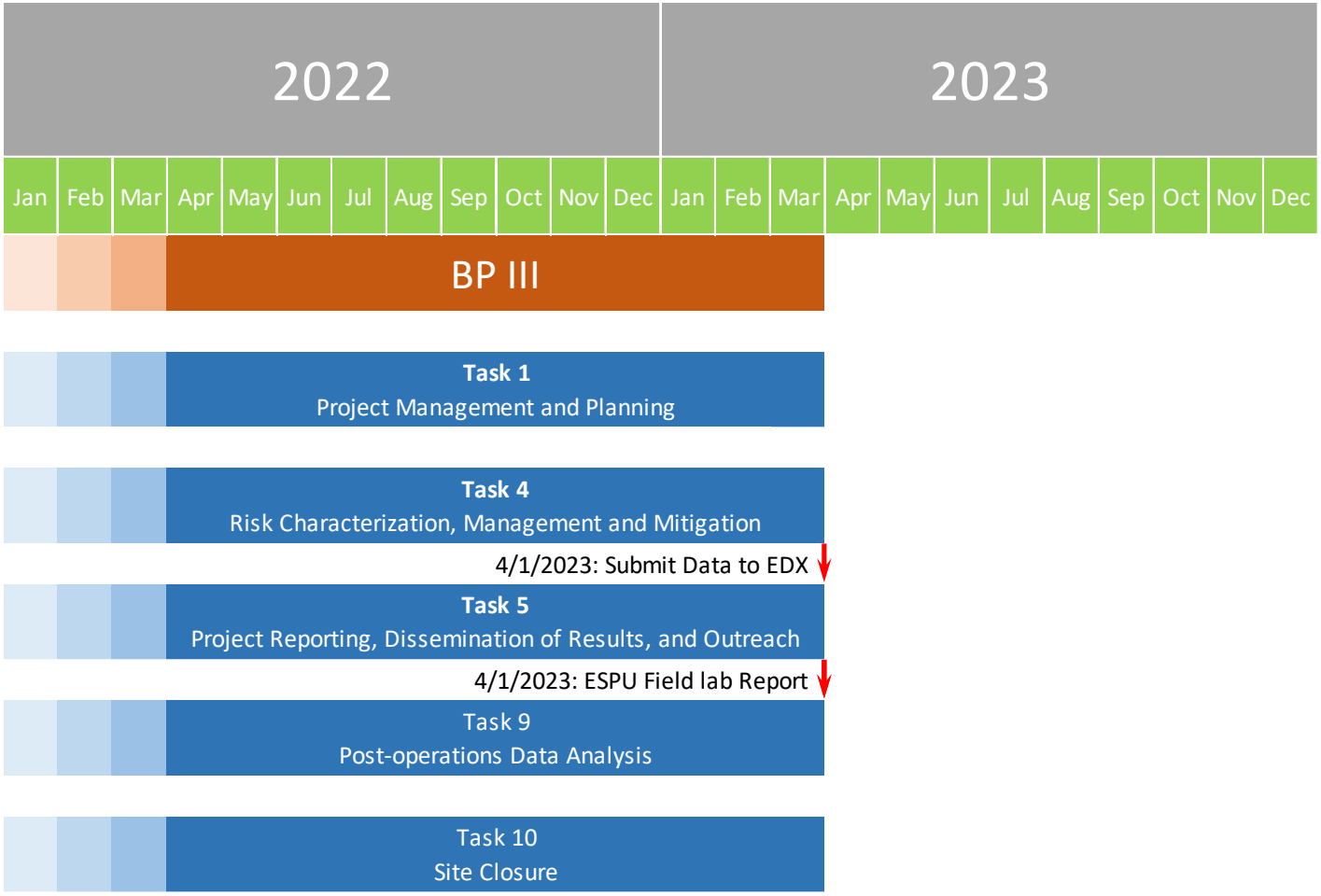
- Investigate and characterize the resource potential for multi-play production of emerging unconventional reservoirs in Central Appalachia.
- **Goal 1:** Drill and selectively core a deep vertical stratigraphic test well up to 15,000 feet to basement through the Conasauga-Rome Petroleum System
- **Goal 2:** Drill at least one multi-stage lateral well in the Lower Huron Shale for completion using non-aqueous fracturing techniques, such as CO_2 or high rate N_2 with proppant
- Laboratory analysis, reservoir simulation, and monitoring observations will be integrated.
- An assessment will be made of the multi-play resource potential and a recommended strategy advanced for prudent development that considers regional **environmental** and **socioeconomic impacts**.


2018
2019
2020
2021
2022
2023
Q1 Q2 Q3 Q4 Q1 Q2 Q3 Q4 Q1 Q2 Q3 Q4 Q1 Q2 Q3 Q4 Q1 Q2 Q3 Q4 Q1 Q2 Q3 Q4
BP I
BP II
BP III
Task 1
Project Management and Planning
Task 2
Data Mgmt. Plan
Task 3
Est. Advisory Board
Task 4
Risk Characterization, Management and Mitigation
Task 5
Project Reporting, Dissemination of Results, and Outreach
Task 6
Site Selection
Task 7
Geo. Characterization of ESUP Field Lab
Task 8
ESUP Field Lab Design, Const., and Ops.
Task 9
Post-operatons Data Analysis
Task 10
Site Closure


2018
2019
Jan Feb Mar Apr May Jun Jul Aug Sep Oct Nov Dec Jan Feb Mar Apr May Jun Jul Aug Sep Oct Nov Dec
BP I
Task 1
Project Management and Planning
5/1/18: Project Management Plan
Task 2
Data Mgmt. Plan
8/1/18: Data Management Plan
Task 3
Est. Advisory Board
2/1/19: Risk Management Plan
3/1/19: Risk Register
Task 4
Risk Characterization, Management and Mitigation
2/1/19: Outreach and Education Plan
Task 5
Project Reporting, Dissemination of Results, and Outreach
10/1/18: Geo. Char. and Design Report
2/1/19: NEPA EQ
Task 6
Site Selection
11/1/18: Site Sel. Report, Upd. AFE
2/1/19: GO/NO-GO 1


2019
2020
Jan Feb Mar Apr May Jun Jul Aug Sep Oct Nov Dec Jan Feb Mar Apr May Jun Jul Aug Sep Oct Nov Dec
BP II
Task 1
Project Management and Planning
Task 4
Risk Characterization, Management and Mitigation
Task 5
Project Reporting, Dissemination of Results, and Outreach
4/1/19: Sampling and Analysis Plan
3/1/2020: Baseline Monitoring Report
Task 7
Geo. Characterization of ESUP Field Lab
4/1/19: Drill Vertical Char. Well
12/1/19: ESUP Field Lab Design and Plan, Compliance
Task 8
ESUP Field Lab Design, Const., and Ops.
12/1/19: GO/NO-GO 2


2020
2021
Jan Feb Mar Apr May Jun Jul Aug Sep Oct Nov Dec Jan Feb Mar Apr May Jun Jul Aug Sep Oct Nov Dec
BP II
Task 1
Project Management and Planning
Task 4
Risk Characterization, Management and Mitigation
Task 5
Project Reporting, Dissemination of Results, and Outreach
4/1/20: Drill and Complete Lower Huron Well(s)
Task 7
Geo. Characterization of ESUP Field Lab
6/1/20: Drilling and Completion Reports
3/1/2021: Updated Geo. Char., Res. Model Reports
Task 8
ESUP Field Lab Design, Const., and Ops.
6/1/20: GO/NO-GO 3


2022
2023
Jan Feb Mar Apr May Jun Jul Aug Sep Oct Nov Dec Jan Feb Mar Apr May Jun Jul Aug Sep Oct Nov Dec
BP III
Task 1
Project Management and Planning
Task 4
Risk Characterization, Management and Mitigation
4/1/2023: Submit Data to EDX
Task 5
Project Reporting, Dissemination of Results, and Outreach
4/1/2023: ESPU Field lab Report
Task 9
Post-operations Data Analysis
Task 10
Site Closure

Advisory Stakeholder Group (ASG)

- High priority task
- Have selected 9 Board Members that include:
  - Technical Experts with experience in geology, drilling, completion technologies and shale development in the region
  - Local Community leaders, including elected officials
  - Environmental Community representative
  - State Agencies representative
  - NETL / DOE representative

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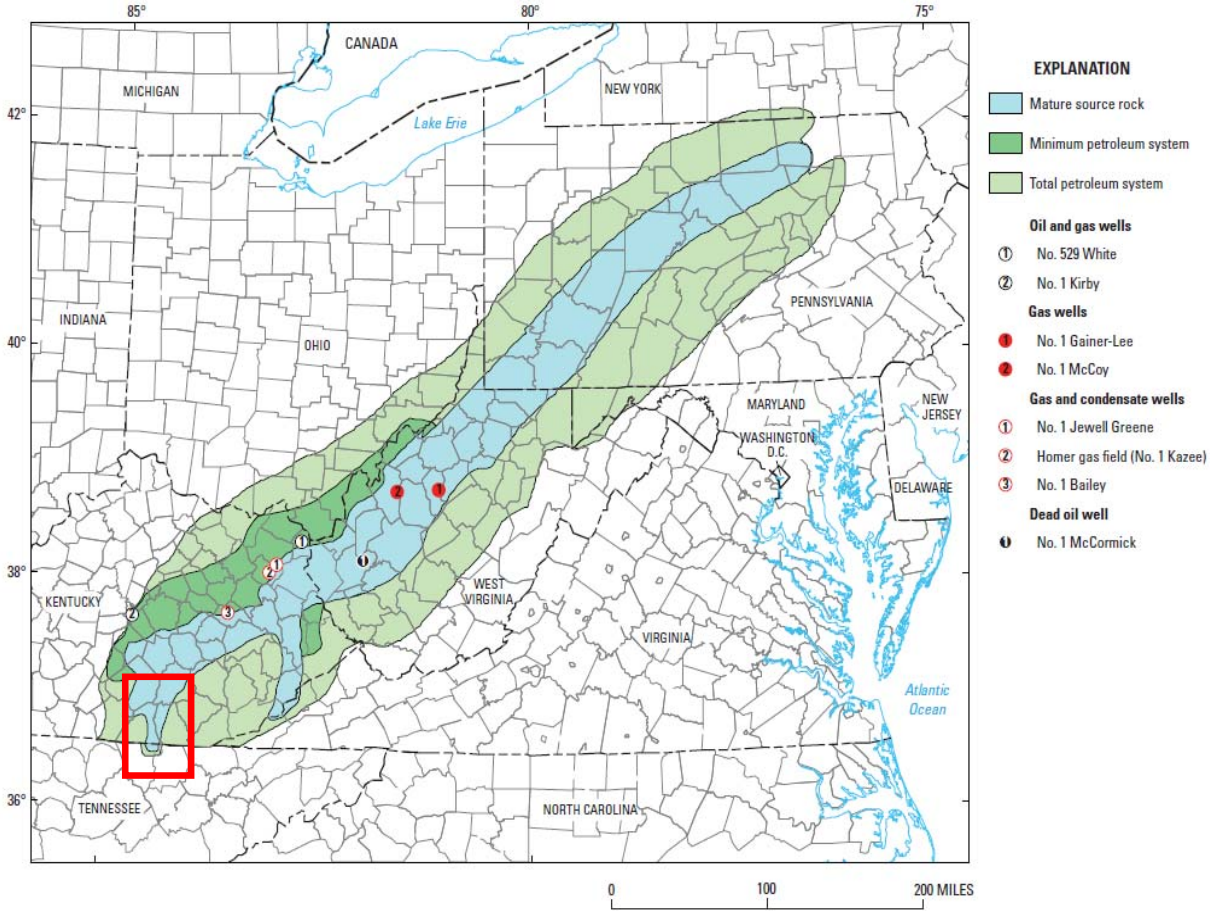
Conasauga/Conasauga-Rome Petroleum System

- Geochemical evidence suggests Cambrian source rocks are present in the Rome Trough
  - Correlated with oils in Homer Gas field, KY
- Rome Trough primarily in eastern KY, WV, and PA
- Floyd Embayment (red) extends system boundaries into SW VA



USGS, 2014

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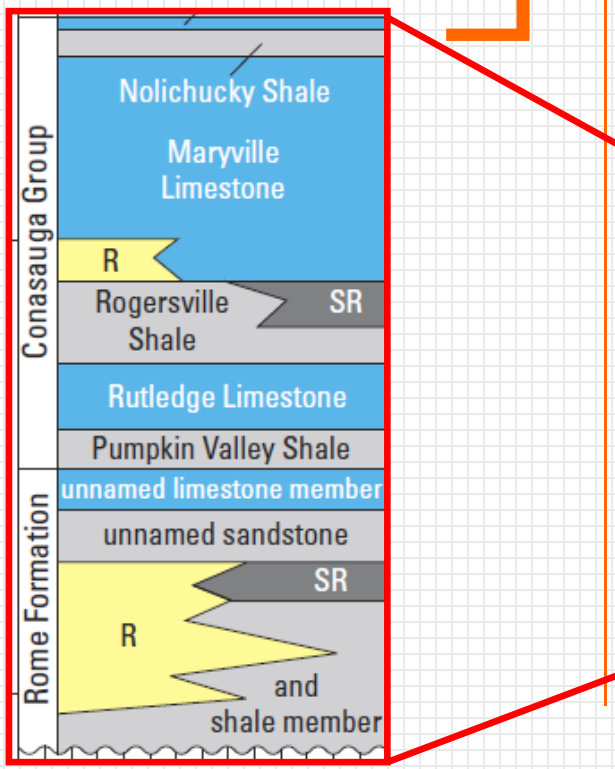
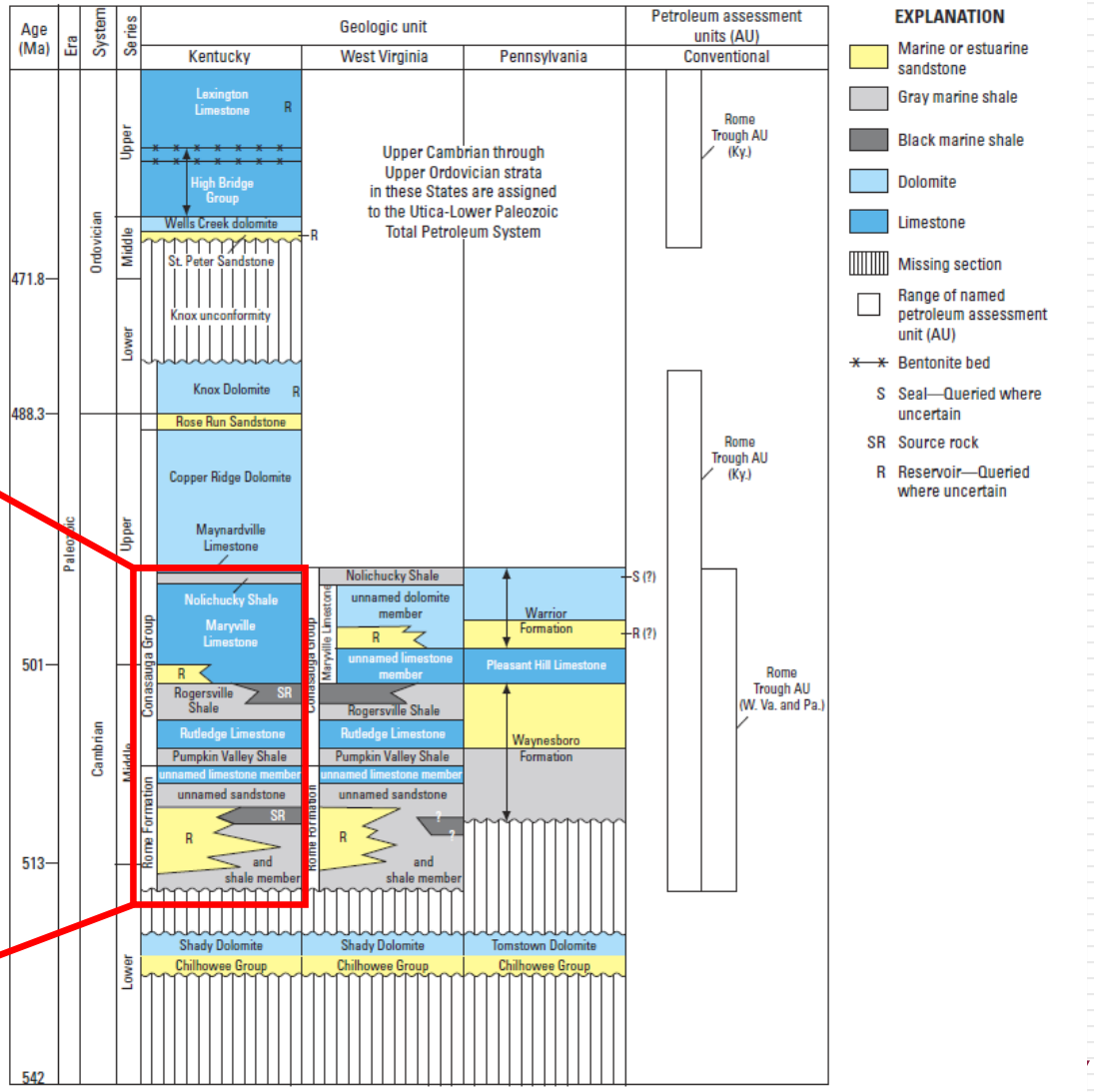
Conasauga/Conasauga-Rome Petroleum System

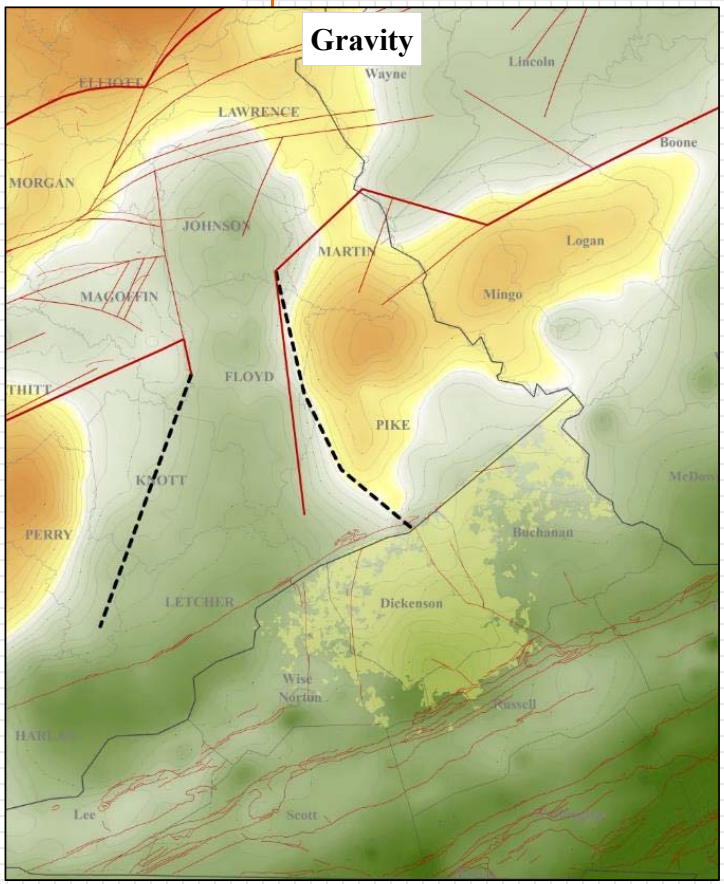


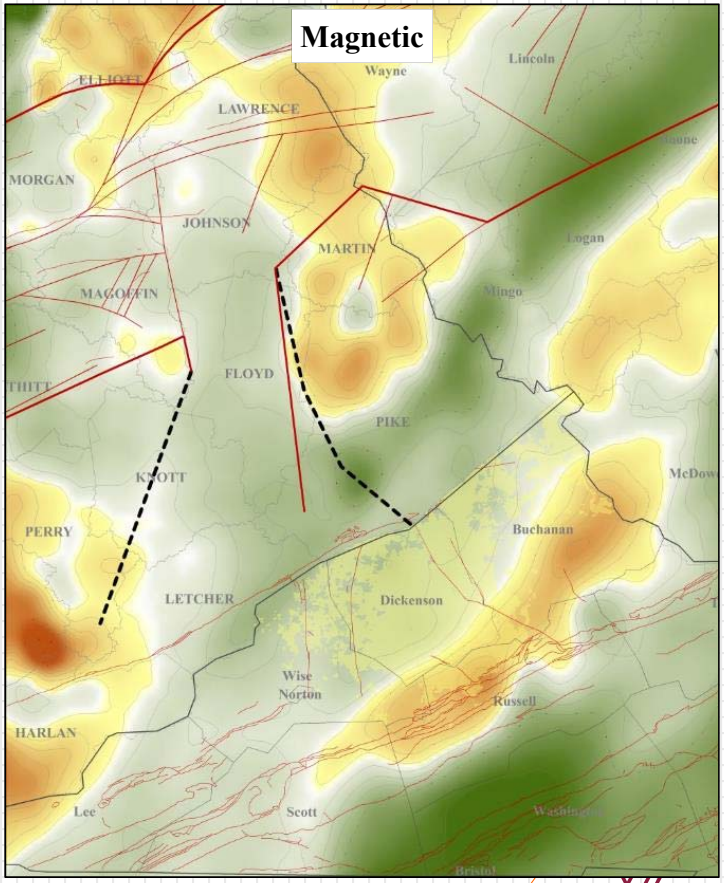


USGS, 2014

Rome Trough Structure
Gravity and Magnetic Data

- Magnetic and gravity anomalies are proxies for Rome Trough and Precambrian structure
- The borders of the Floyd Embayment are ambiguous and are poorly understood in Virginia
- Gravity and magnetic data suggests that the Floyd Embayment intersects western portions EnerVest acreage





EnerVest, 2018

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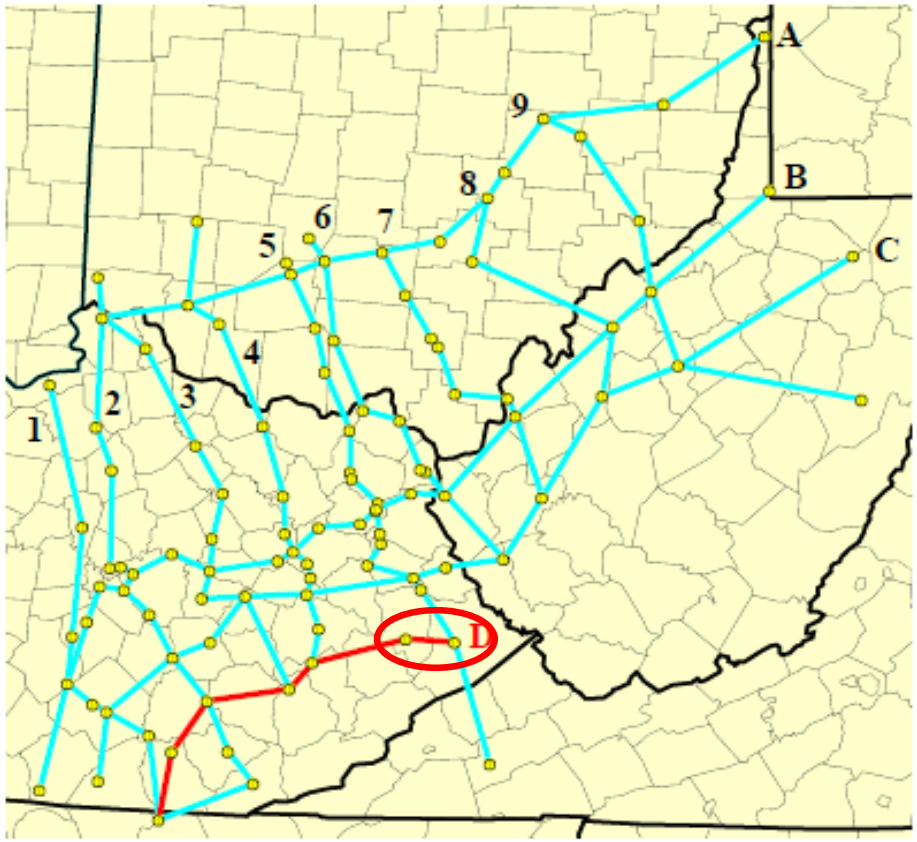
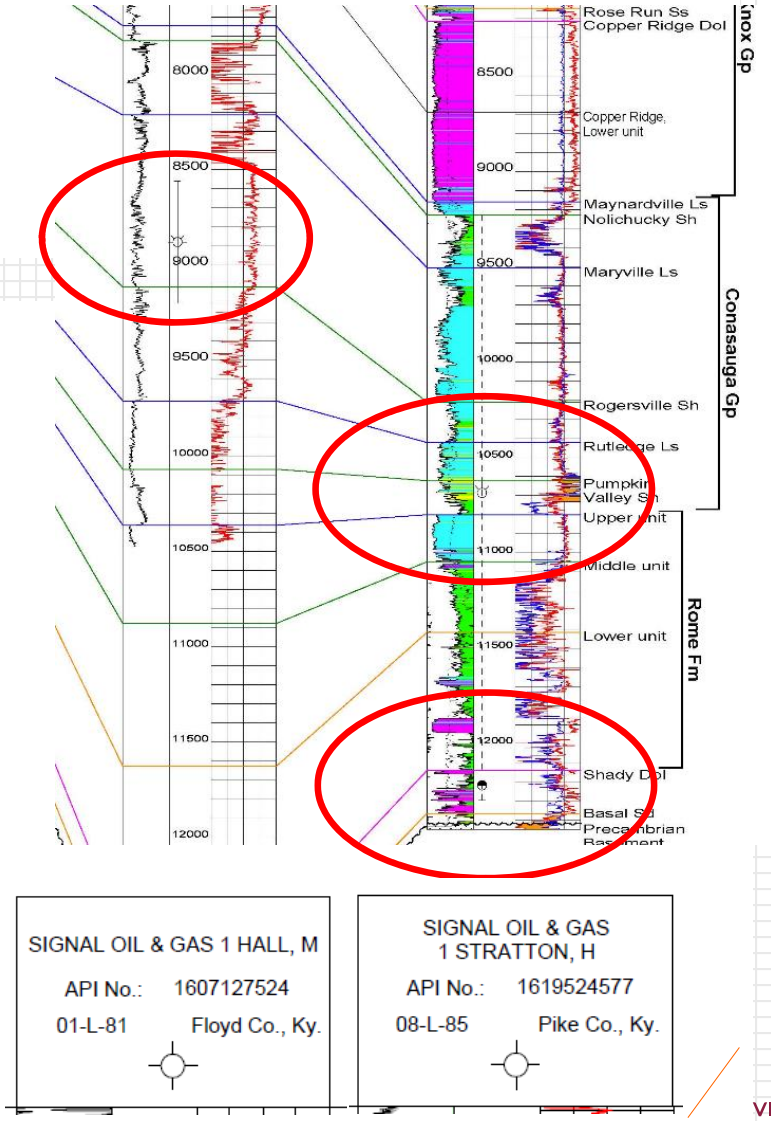
Oil and Gas Shows near VA





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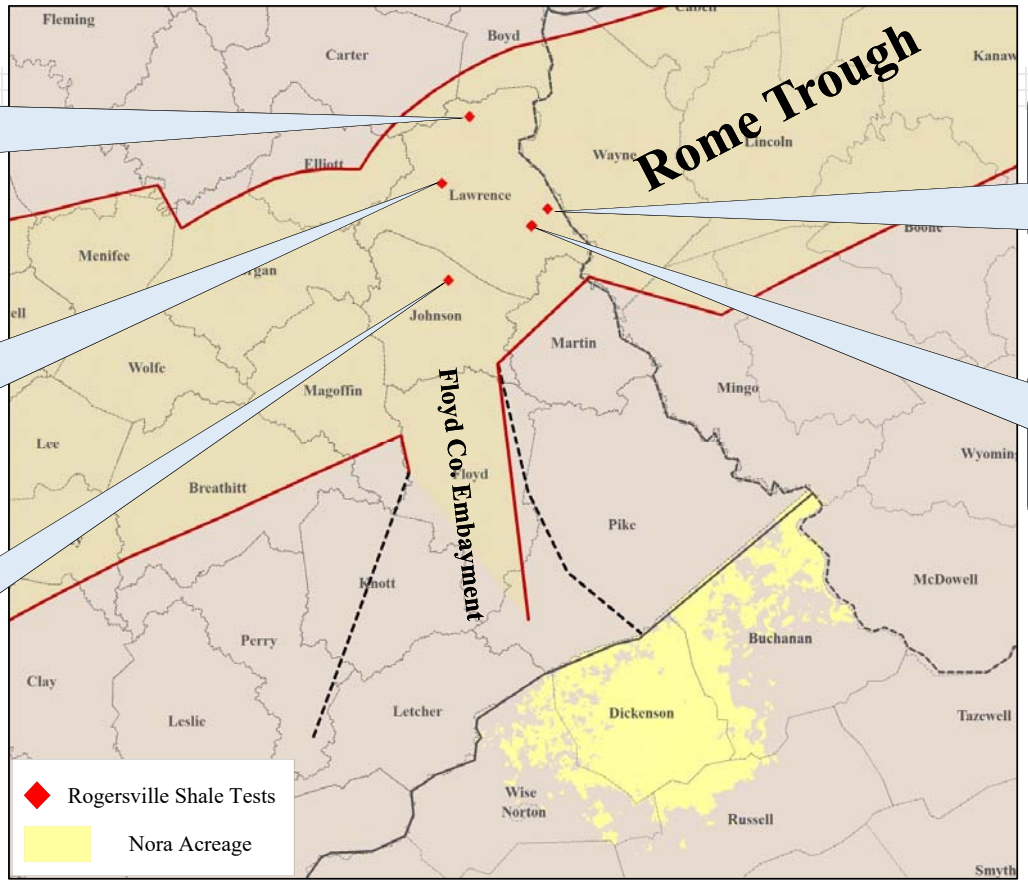
Recent Rogersville Shale Activity



Stevens J et al #LAW 1
Chesapeake Appalachia

Vertical Strat Test

TD Date: 5/19/2015
Fm @ TD: Rome Fm
TD: 11,651 ft.

Young S #1
Bruin Exploration (Cimarex)

Vertical Strat Test

TD Date: 5/30/2014
Fm @ TD: Rome Fm
TD: 12,169 ft.

EQT Prod Co #572360 H
Horizontal Tech Energy Co (EQT)

Horizontal Rogersville Test

TD Date: 6/7/2015
Fm @ TD: Rogersville Shale
TD: 13,383 ft. MD
Shut In

JH Northrup Estates #LAW 1
Chesapeake Appalachia

Vertical Strat Test

TD Date: 9/3/2015
Fm @ TD: Shady Dolomite
TD:15,950 ft.

Walbridge Holdings #1H
Bruin Exploration (Cimarex)

Horizontal Rogersville Test

TD Date: 2/23/2017
Fm @ TD: Rogersville Shale
TD: 16,108 ft. MD
Temporarily Abandoned

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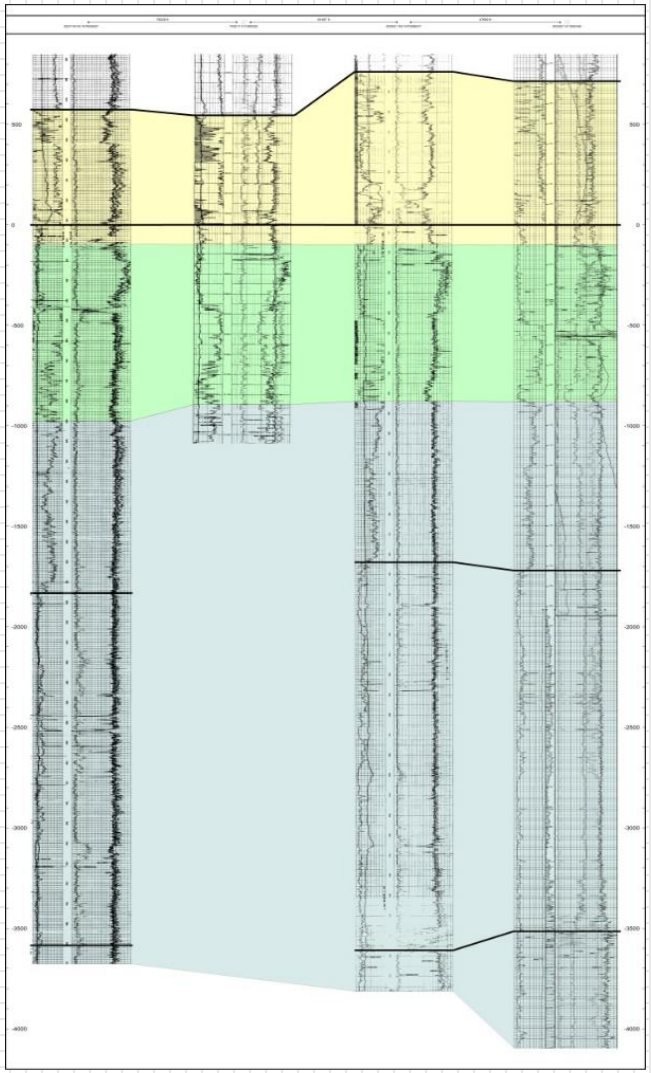
Deep Targets for Vertical Characterization Well

Devonian	Huron Shale	✡
	Olentangy Shale	
	Rhinestreet Shale	✡
	Marcellus Shale	✡
	Corniferous (Onondaga) Ls	
	Oriskany Ss	✡
Silurian	Salina Dol / Ls	
	Keefer Ss / Big Six Ss	✡
	Clinton Group / Rose Hill Fm	✡
	Tuscarora Ss / Clinch Ss	✡
Ordovician	Juniata / Sequatchie Shale	
	Trenton Ls	✡
	Black River Ls	✡
	Beekmantown Grp / Knox Dol / Rose Run Ss	✡
Cambrian	Copper Ridge / Conococheague Dol	
	Conasauga (Nolichucky / Rogersville / Pumpkin Valley Shale)	✡
	Rome Fm	
	Basal Ss	
	PreCambrian Basement	



EnerVest, 2018

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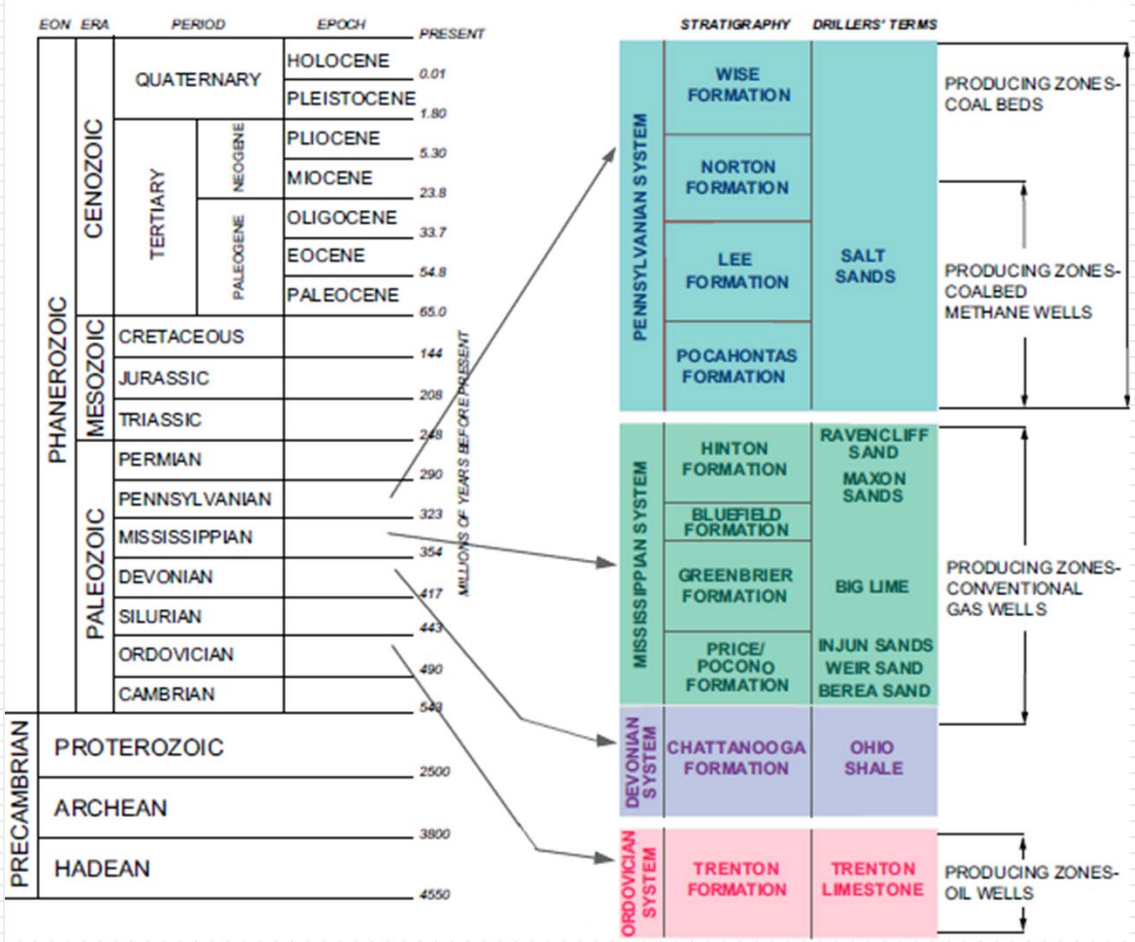
Nora Field - Stratigraphy

- Current Shallower Stacked Plays
  - **Coalbed Methane (Pennsylvanian)**
  - **Big Lime (Mississippian)**
  - **Weir Sand (Mississippian)**
  - **Berea Sand (Mississippian)**
  - **Lower Huron Shale (Devonian)**



VA DMME, 2017

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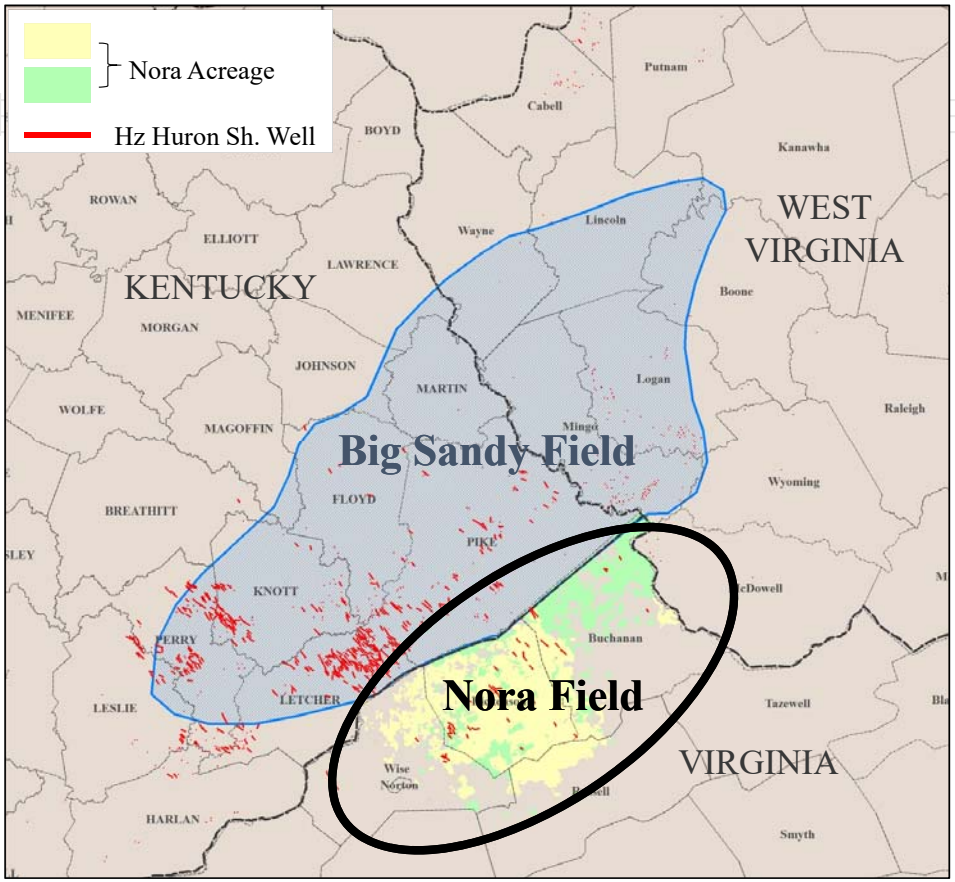
The Lower Huron in the Big Sandy and Nora Gas Fields

- Reservoir pressure gradient lower than any of the major US shale plays (0.22 psi/ft)
- Historic completions dominated by N2 fracs and limited ability to place proppant



Big Sandy Field Summary

Discovery:	1915
Location:	E Kentucky – SW West Virginia
Wells Drilled:	>10,000
1st Hz Well:	2006 (IHS Data)
Hz Wells Drilled:	~950 (IHS Data)
Cum Prod:	>2.5 Tcfg (estimated)
Target(s):	Lower Huron Sh., Cleveland Sh.
Reservoir:	Naturally Fractured Black Shale
Huron Thickness:	100-300 ft.

Source: The Atlas of Major Appalachian Gas Plays

Nora Area Summary

Discovery:	1948
Location:	W Virginia
Wells Drilled:	~700 (IHS Data)
1st Hz Well:	2007 (IHS Data)
Hz Wells Drilled:	~60
Target(s):	Lower Huron Sh., Rhinestreet Sh.
Reservoir:	Black Shale
Huron Thickness:	100-300 ft.

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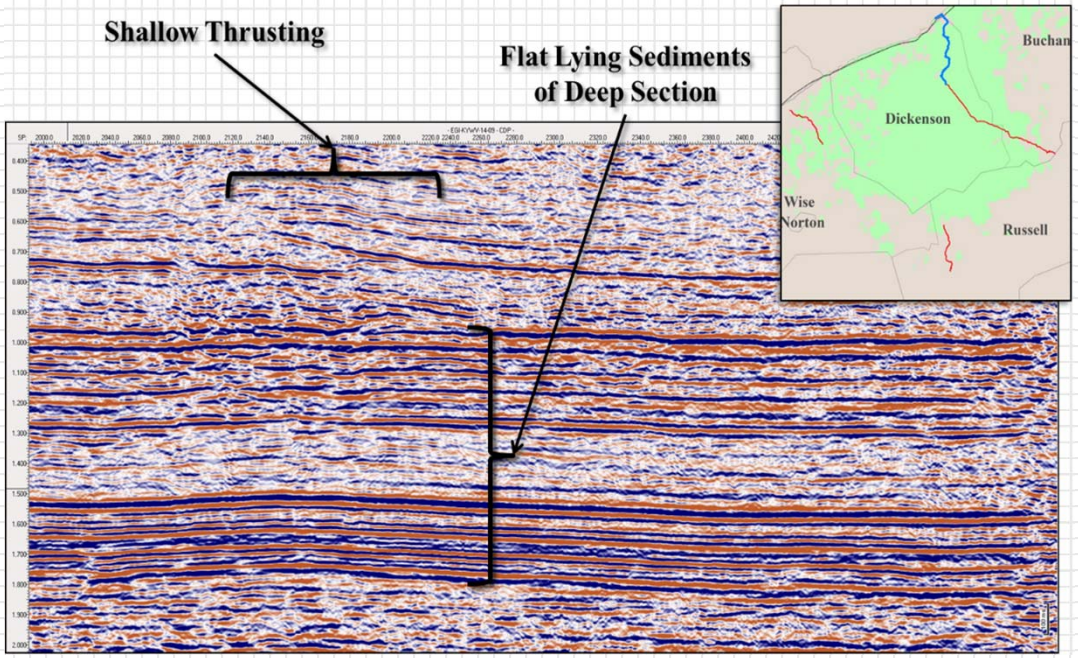
Nora Gas Field, Virginia

- Flat Lying Deep Sediments



US Energy Information Administration, 2007)

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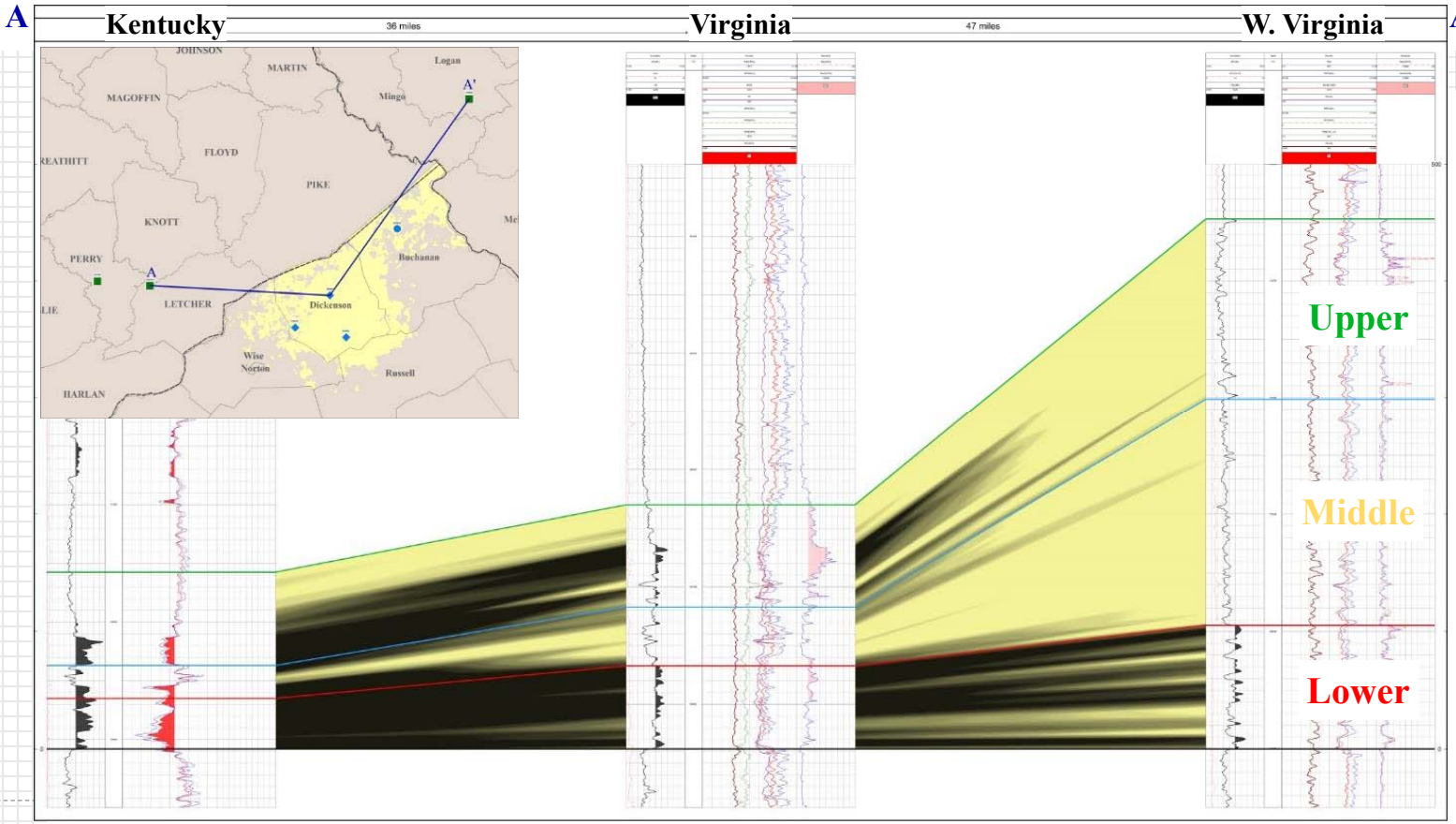
Lower Huron Delineation/Nomenclature



EnerVest, 2018

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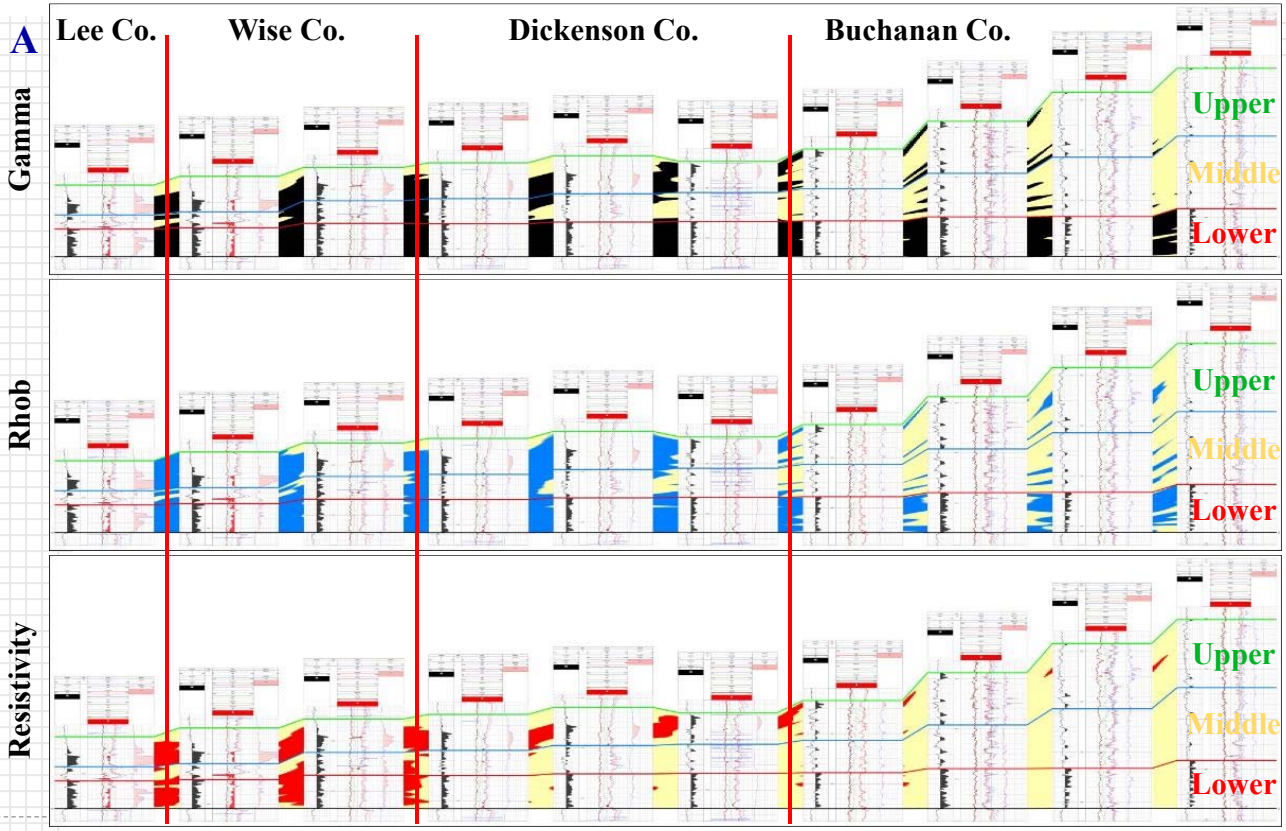
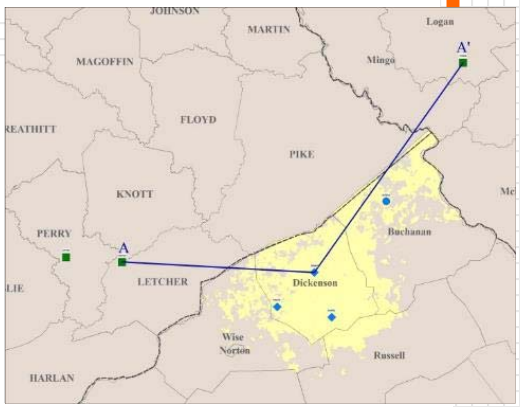
Well Log TOC Correlation

Gamma, Rhob, Resistivity Interpolation = 3% TOC





EnerVest, 2018

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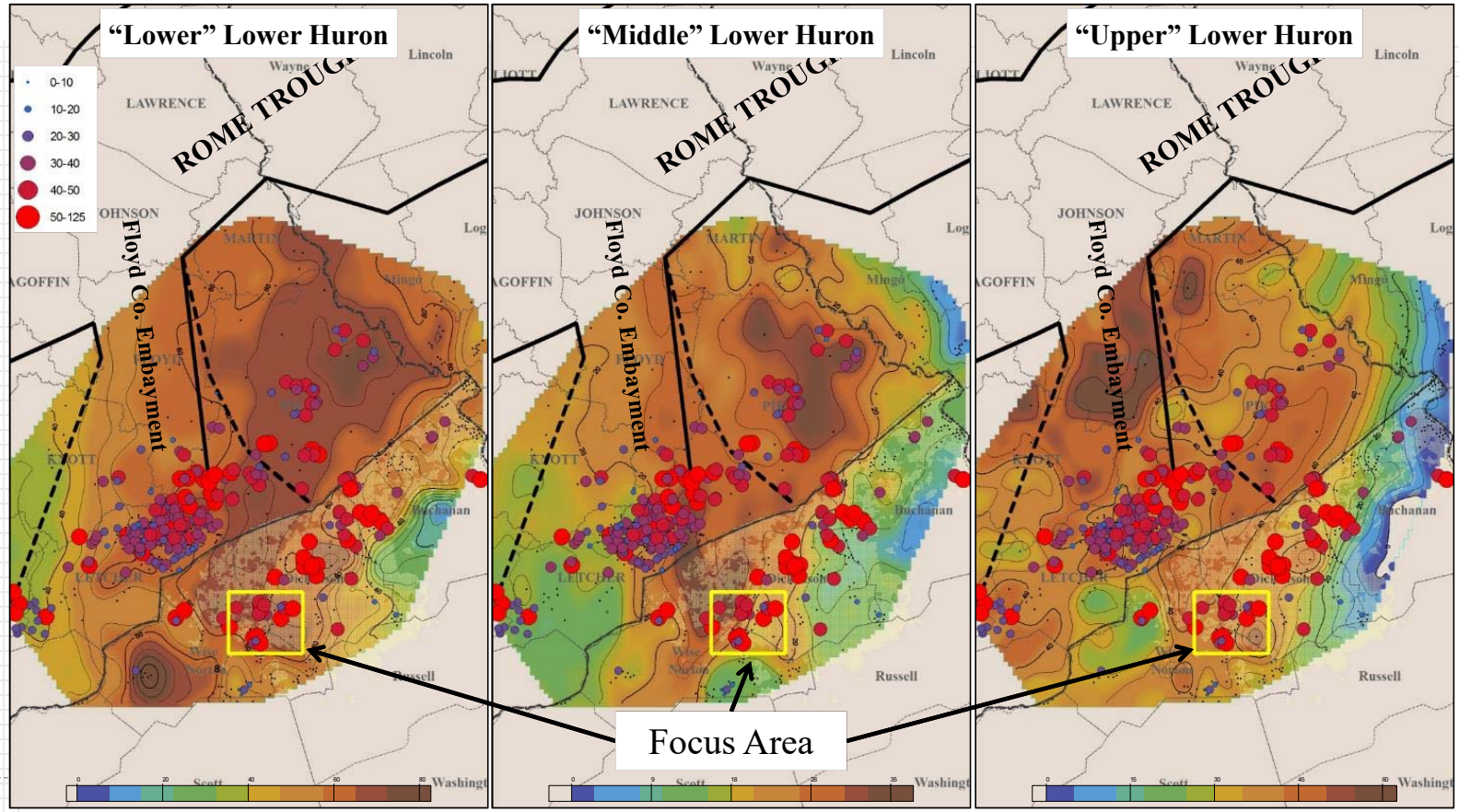
Focus Area Determination

Combined Gamma/Rhob Cutoff Mapping (264 API & 2.64 g/cc = 3% TOC)



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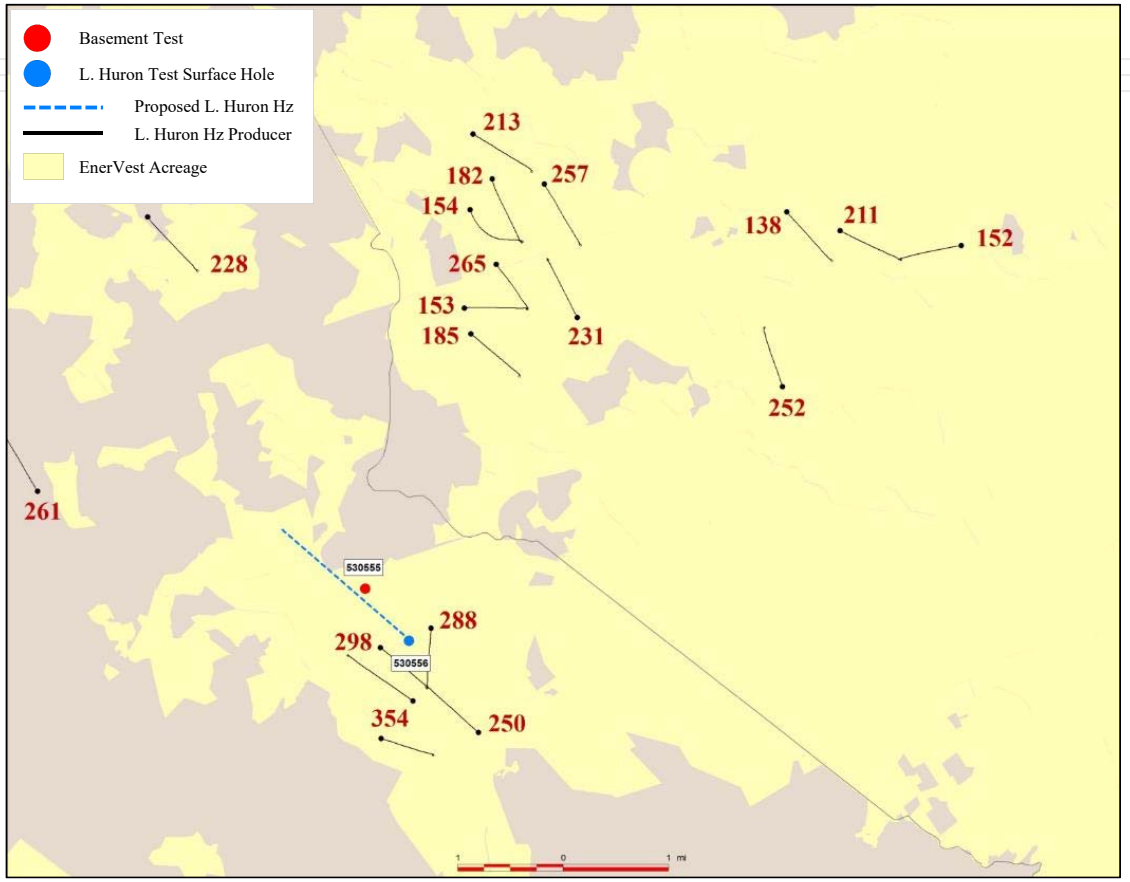
Potential Test Locations

- Petrophysics suggests optimal location for Lower Huron horizontal well
- Gravity and magnetic data suggests location is also suitable for deep vertical well
- Both wells in close proximity is optimal for ESUP Field Laboratory studies



EnerVest, 2018

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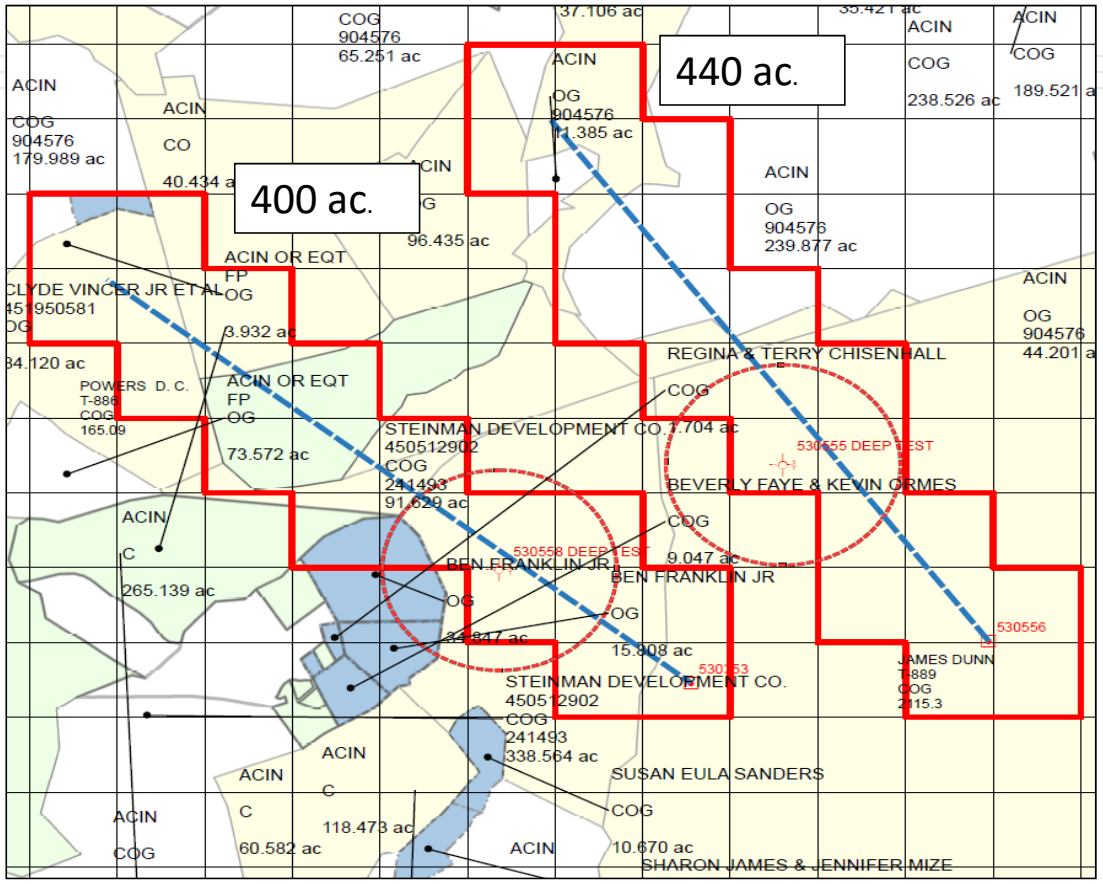
Land Overview

Potential Test Locations

- 1st Potential site favorable with respect to road access and cultural impact
- 2nd Potential site favorable with respect to land control issues
- Both sites are favorable with respect to geology and infrastructure availability



EnerVest, 2018

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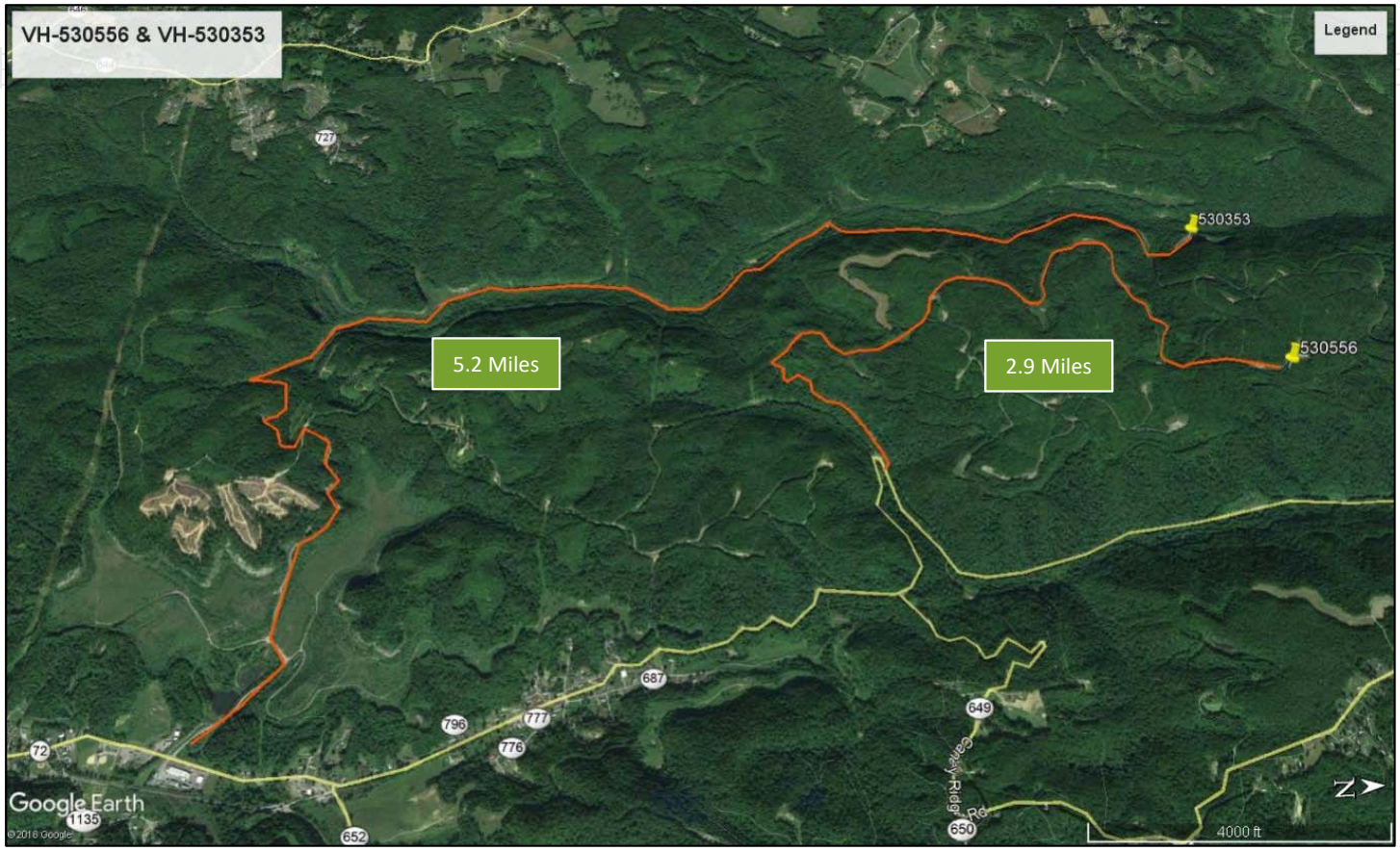
Land Overview

Potential Test Locations: Road Access, Cultural Impact



EnerVest, 2018

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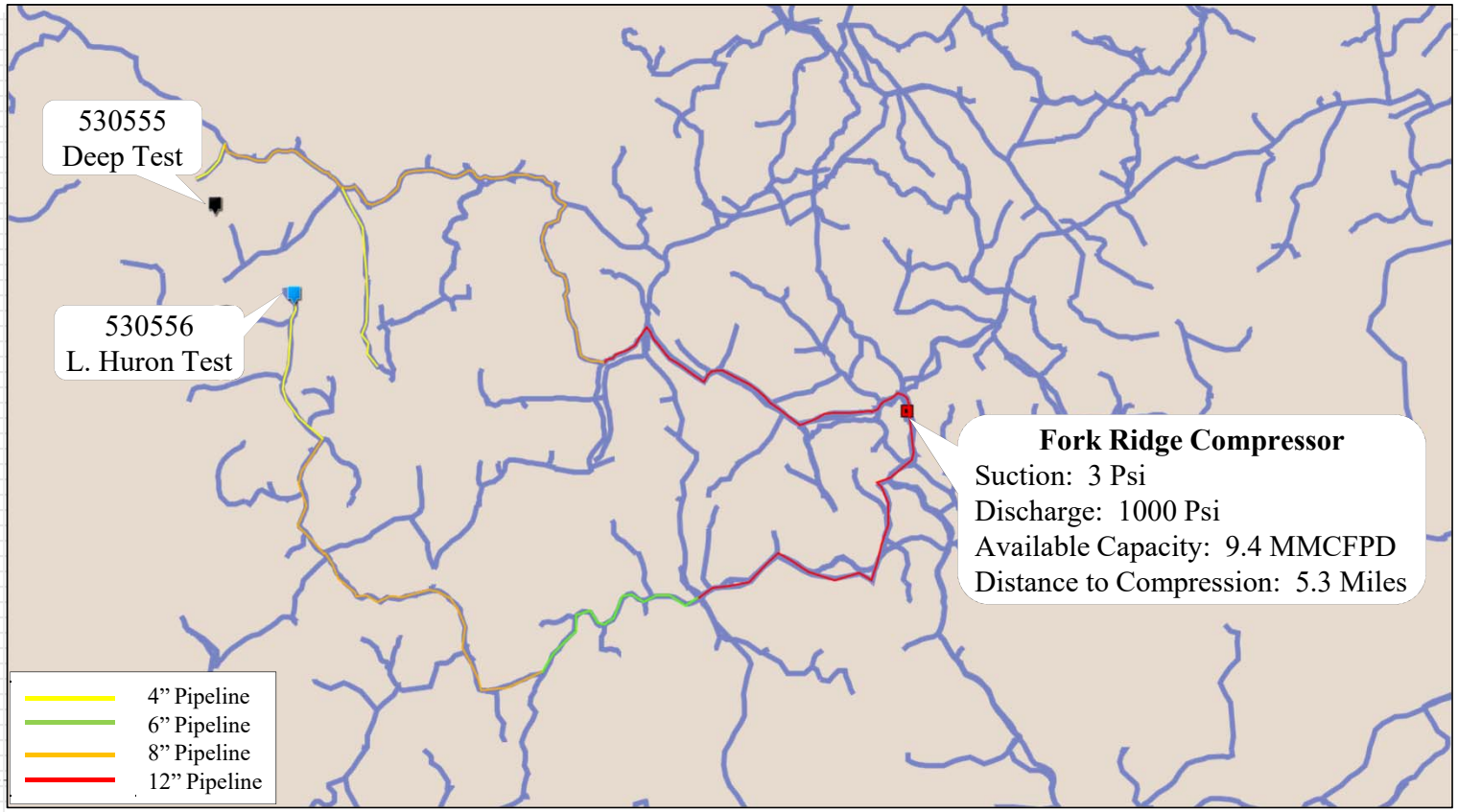
Land Overview

Potential Test Locations: Infrastructure Availability



EnerVest, 2018

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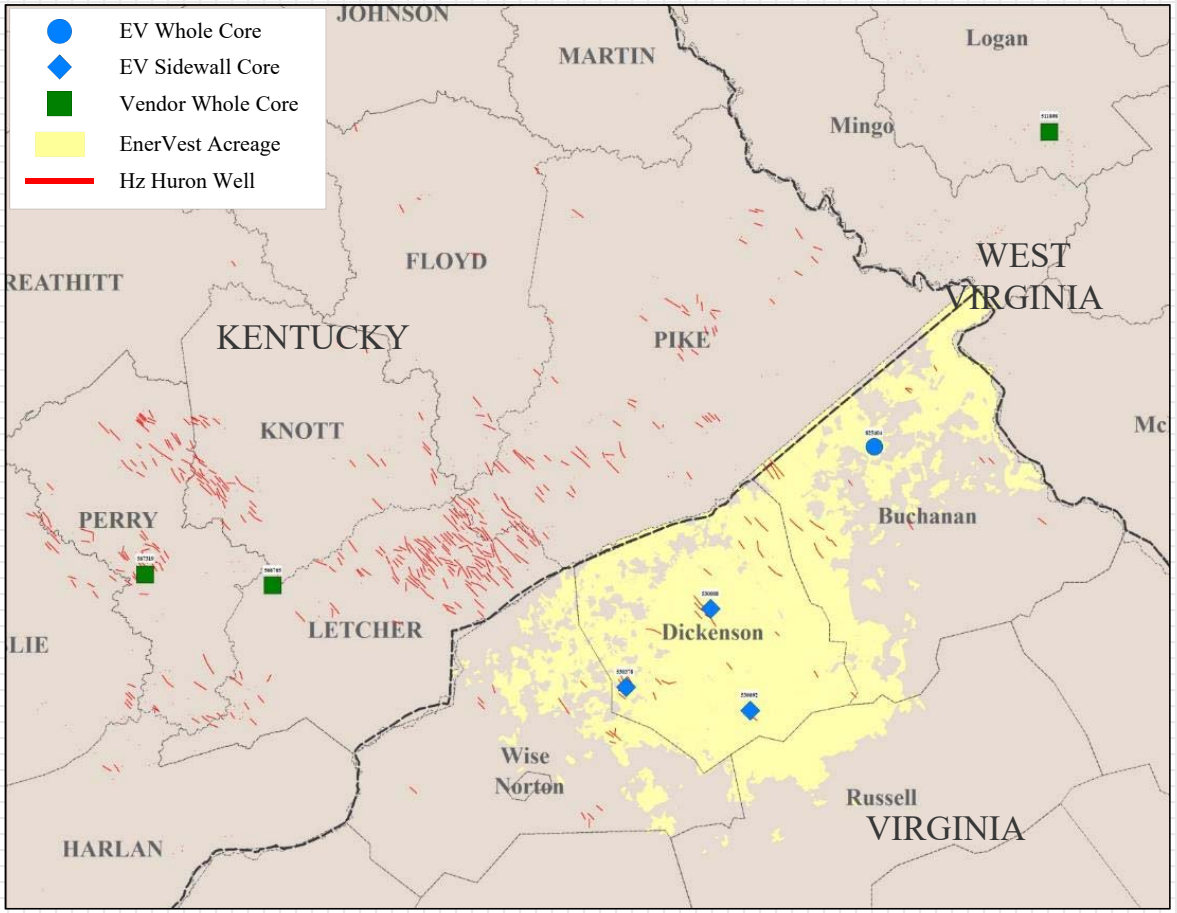
Lower Huron Core Distribution

Core Inventory

- 4 Whole Cores
- 3 Sidewall Cores
- Archived Cuttings



EnerVest, 2018

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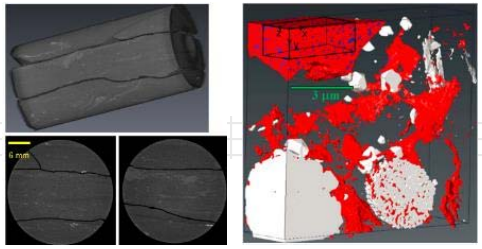
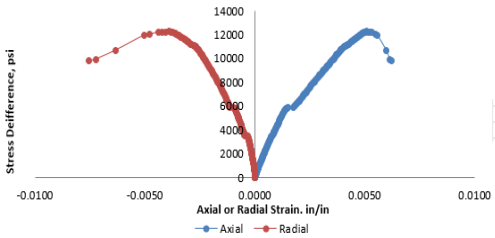
Core Analysis Workflow





Digital Rock Analysis

- X-ray CT and SEM scanning
- Visualization of microfractures
- Rock density variation
- Nano-scale shale structure
- Pore-scale flow modeling

Geomechanical Analysis

- Poisson's ratio and Young's modulus
- Confined and unconfined compressive strength
- Brinell hardness number
- Brazillian tensile strength
- These properties are critical for fracturing design

Petrophysical Analysis

- RockEval tests for total organic carbon (TOC)
- X-ray Diffraction Analysis (XRD) for mineralogy
- Permeability measurement using pulse decay permeameter (PDP-200), NanoK, and SMP-200 (all equipment from CoreLab)
- Fracture Conductivity Cell
- These properties are critical for finding the "sweet spots"

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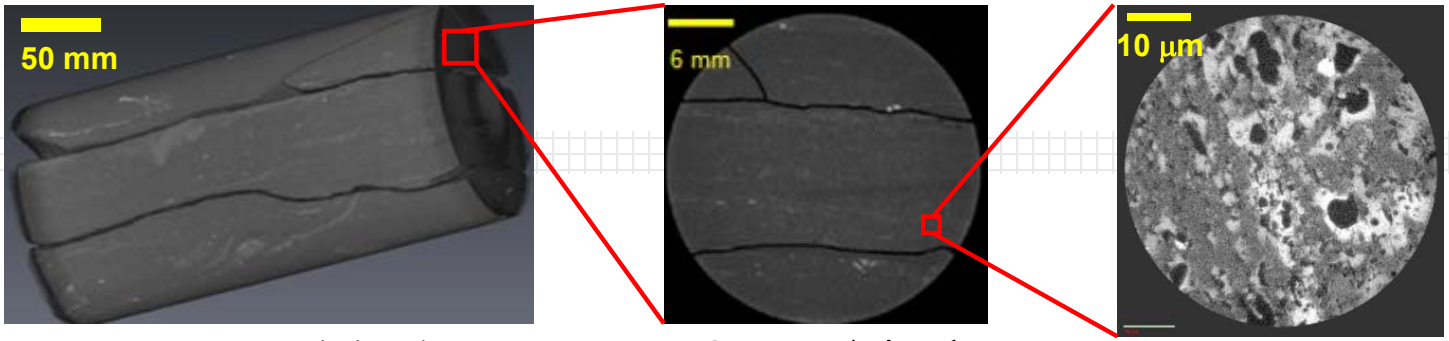
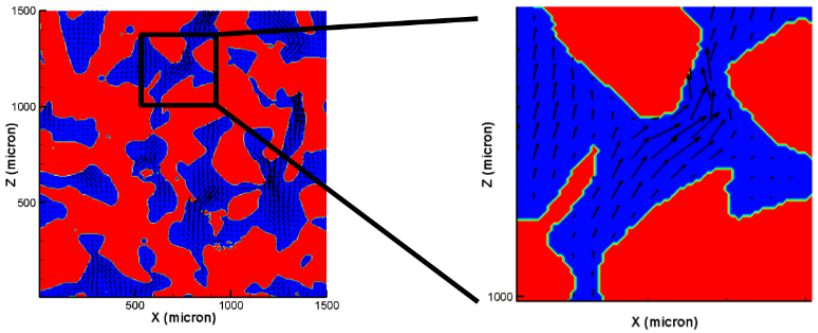
Core Analysis Workflow



0.25 mm/pixel | 25 µm/pixel | 64 nm/pixel

3D, multiscale X-ray CT scanning from core to nm scales.



- Lattice Boltzmann (LB) Method is used for pore flow simulation based on the CT images.
- It is a meso-scale numerical method to recover macroscopic hydrodynamics.

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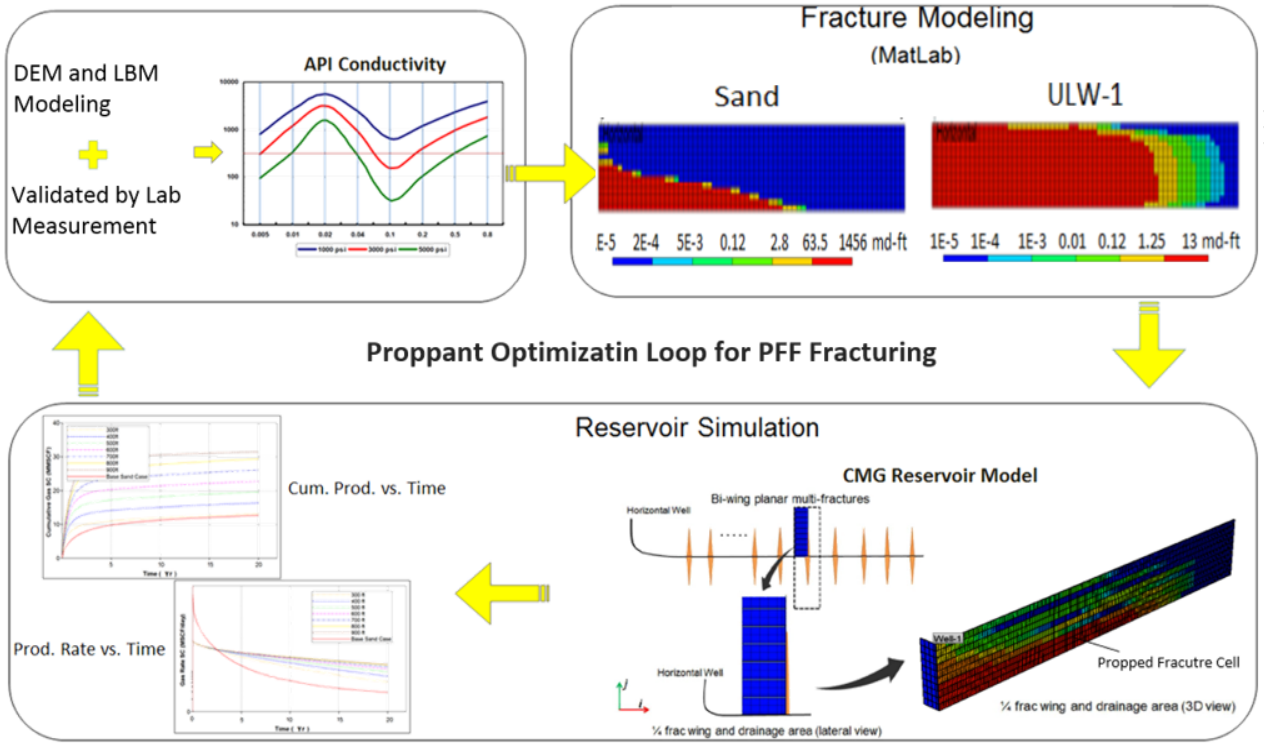
Optimization of Fracturing and Proppant Placement



Proppant pumping optimization to achieve the highest return on fracturing investment (ROFI) (Gu et al., 2017, SPE-185071).

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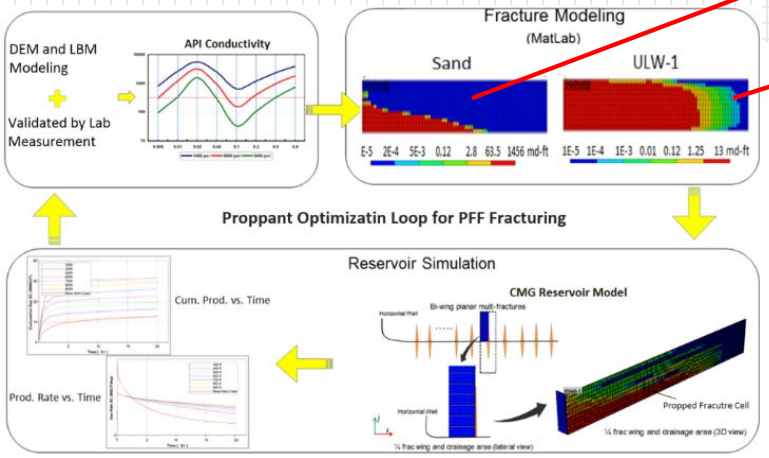
Optimization of Fracturing and Proppant Placement



Regular sand proppant:
Fast settlement near the well

Ultra-light-weight proppant:
Uniform placement along fracture

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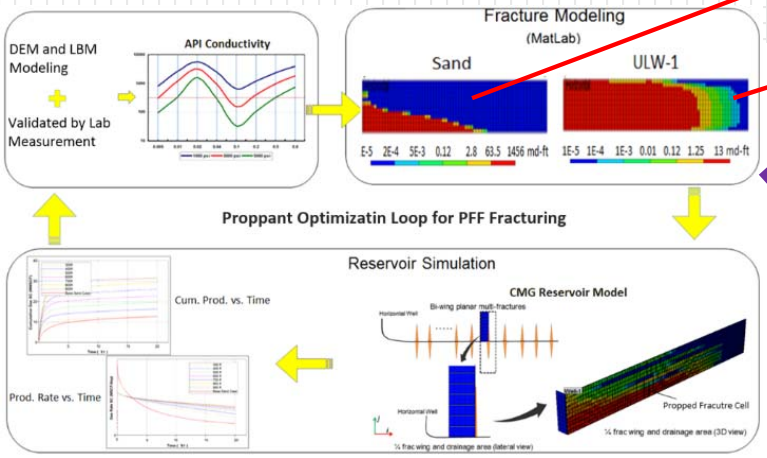
Optimization of Fracturing and Proppant Placement



Regular sand proppant:
Fast settlement near the well

Ultra-light-weight proppant:
Uniform placement along fracture

Fracture modeling gives *proppant concentration* (lb/ft^2) distribution in fracture length and height directions

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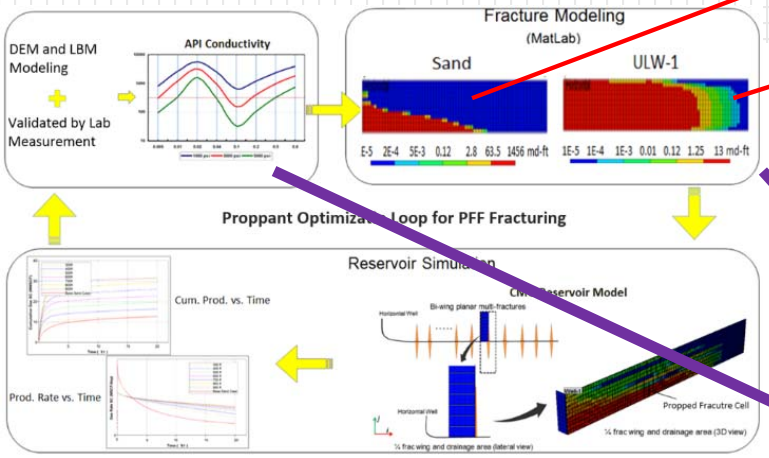
Optimization of Fracturing and Proppant Placement



Regular sand proppant:
Fast settlement near the well

Ultra-light-weight proppant:
Uniform placement along fracture

Fracture modeling gives *proppant concentration* (lb/ft^2) distribution in fracture length and height directions

Pore-scale, DEM/LB-coupled modeling gives "*fracture conductivity vs proppant concentration*" curves under various closure pressures (Fan et al., 2018)

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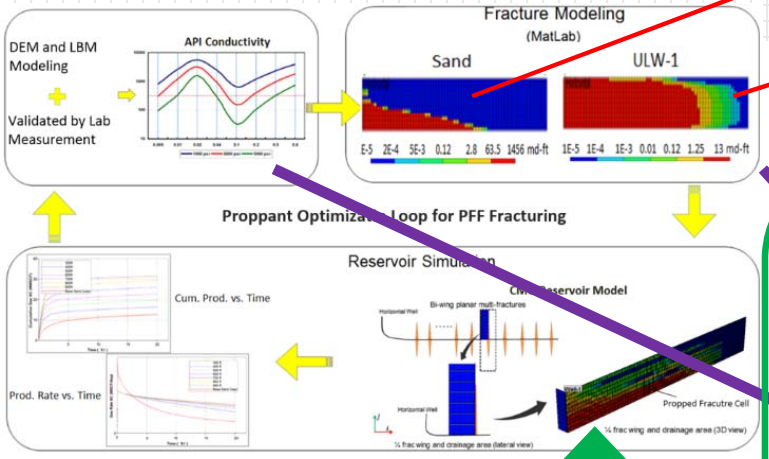
Optimization of Fracturing and Proppant Placement



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These two pieces of information are combined to obtain *fracture conductivity* distribution in the hydraulic fracture for larger-scale reservoir simulation

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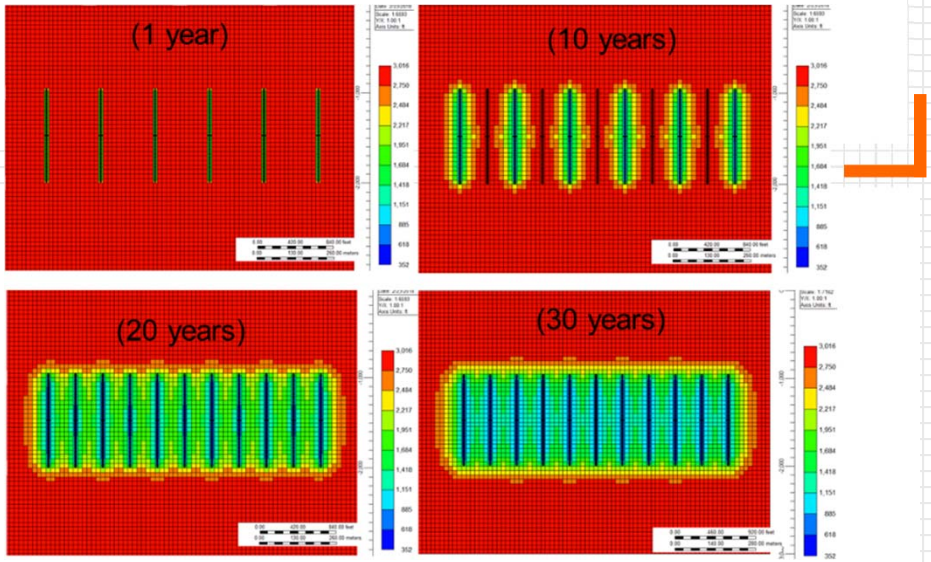
Reservoir Simulation Model

- Simulations will be used to design the ESUP Field Laboratory, including designs for drilling, completions, and monitoring.
- The modeling effort will include the use of a commercial reservoir simulator and the development of an in-house simulation tool.



- The in-house simulation model includes diffusion and nano-porous media confinement effects, and that can simulate reservoir response to hydraulic fracturing with non-aqueous fluids such as CO2.
- Fast, yet accurate, compositionally-extended black oil models will be developed that can incorporate the complexities associated with shale reservoirs during treatment and production.

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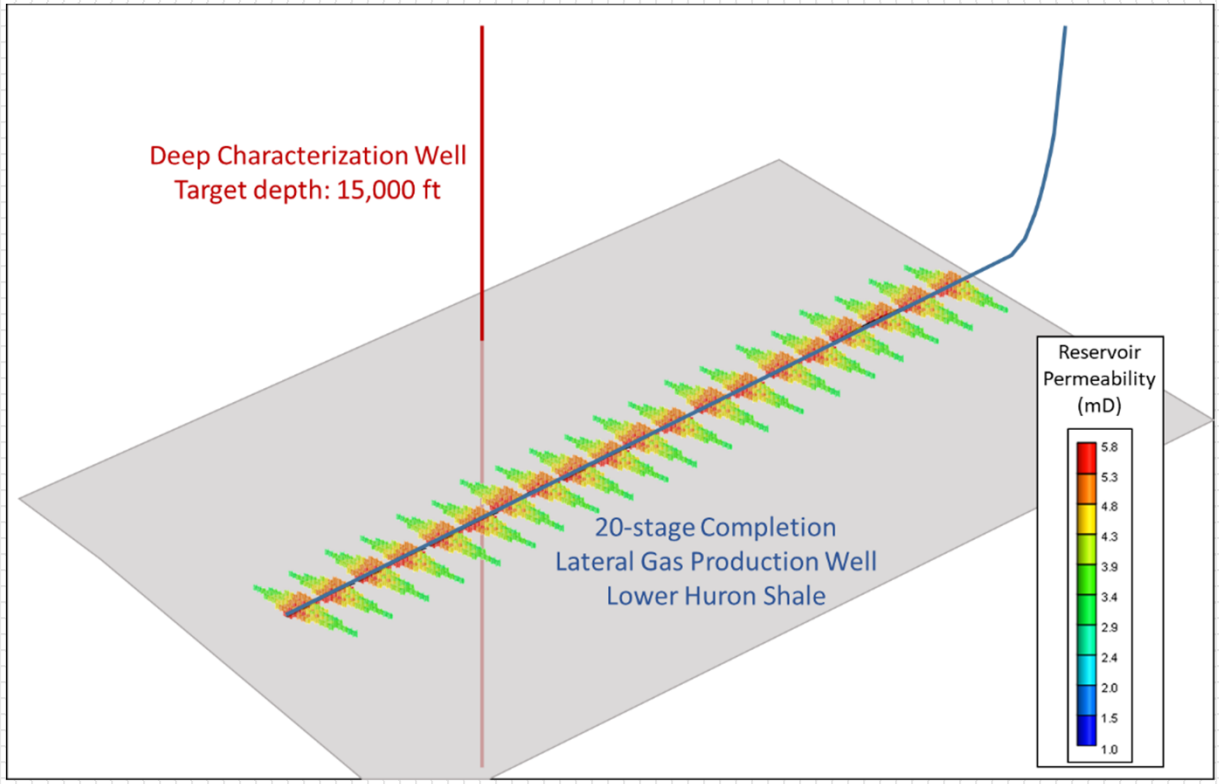
Monitoring Program

- Monitoring + Operations Timeline
  - Historical data→ Simulations→ Define Area of Review (AOR)
  - Baseline data acquisition
  - Monitoring while Drilling
  - Characterization data→ HF design
    - Non-aqueous fluid
    - Alternative/multiple proppants
  - Monitoring of HF treatment
  - Post-operations monitoring

Schematic Overview of ESUP Field Lab



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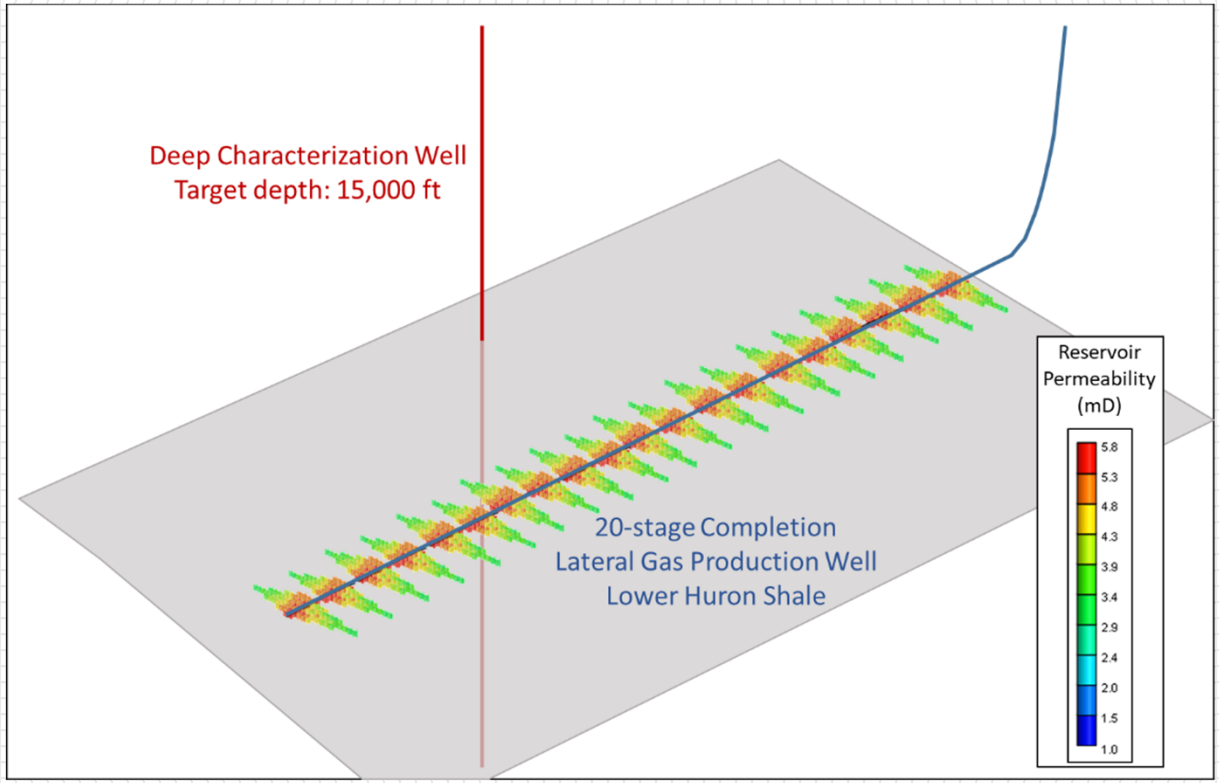
Monitoring Program

- Potential Methods: Atmospheric, Near-surface, Subsurface, Sub-reservoir Technologies
  - Offset gas and water sampling
  - Tracer studies
  - Reservoir imaging (e.g., microseismic monitoring and DAS)
  - Deep monitoring installation in Deformation monitoring
  - Production monitoring

Schematic Overview of ESUP Field Lab



- Deliverables: Sampling and Analysis Plan, Initial (Baseline) Monitoring Report, Final Scientific/Technical Report, NETL-EDX Final Project Files

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Questions and Acknowledgments

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