Field Laboratory for Emerging Stacked Unconventional Plays (ESUP)

Project No. DE-FE0031576

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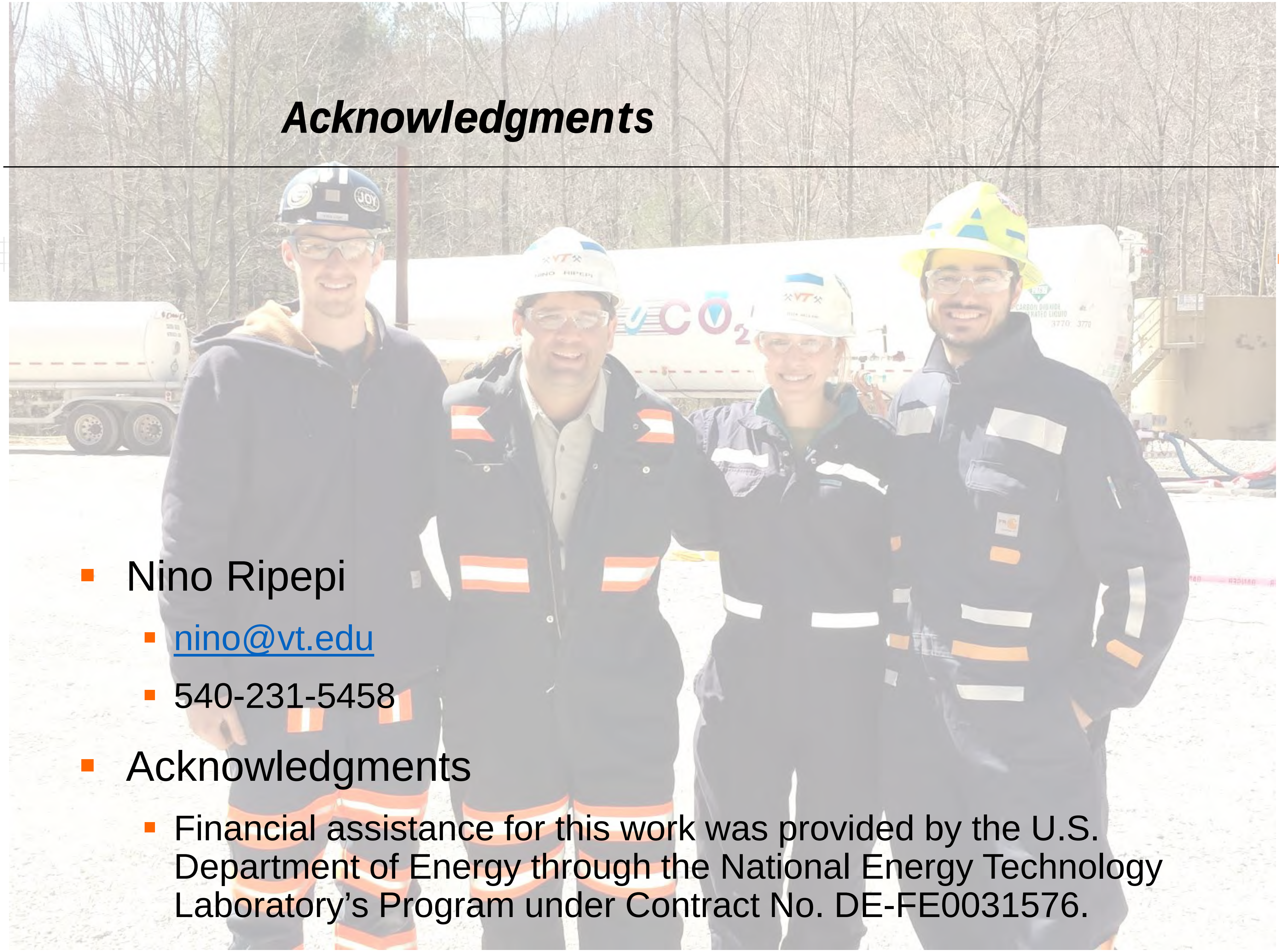

Acknowledgments

- Nino Ripepi
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  - 540-231-5458

- Acknowledgments
  - Financial assistance for this work was provided by the U.S. Department of Energy through the National Energy Technology Laboratory's Program under Contract No. DE-FE0031576.

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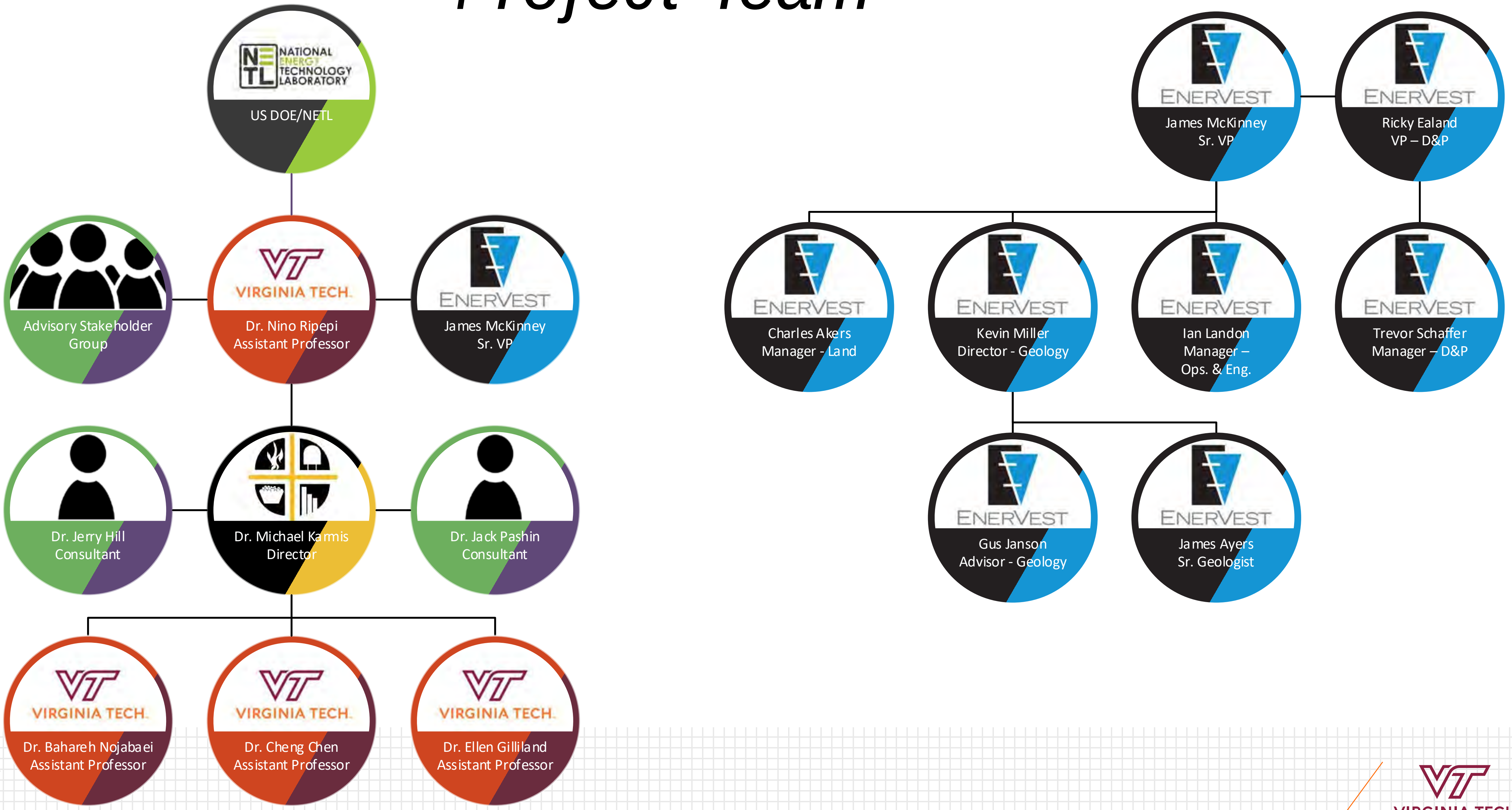
Objective, Project Team and Duration

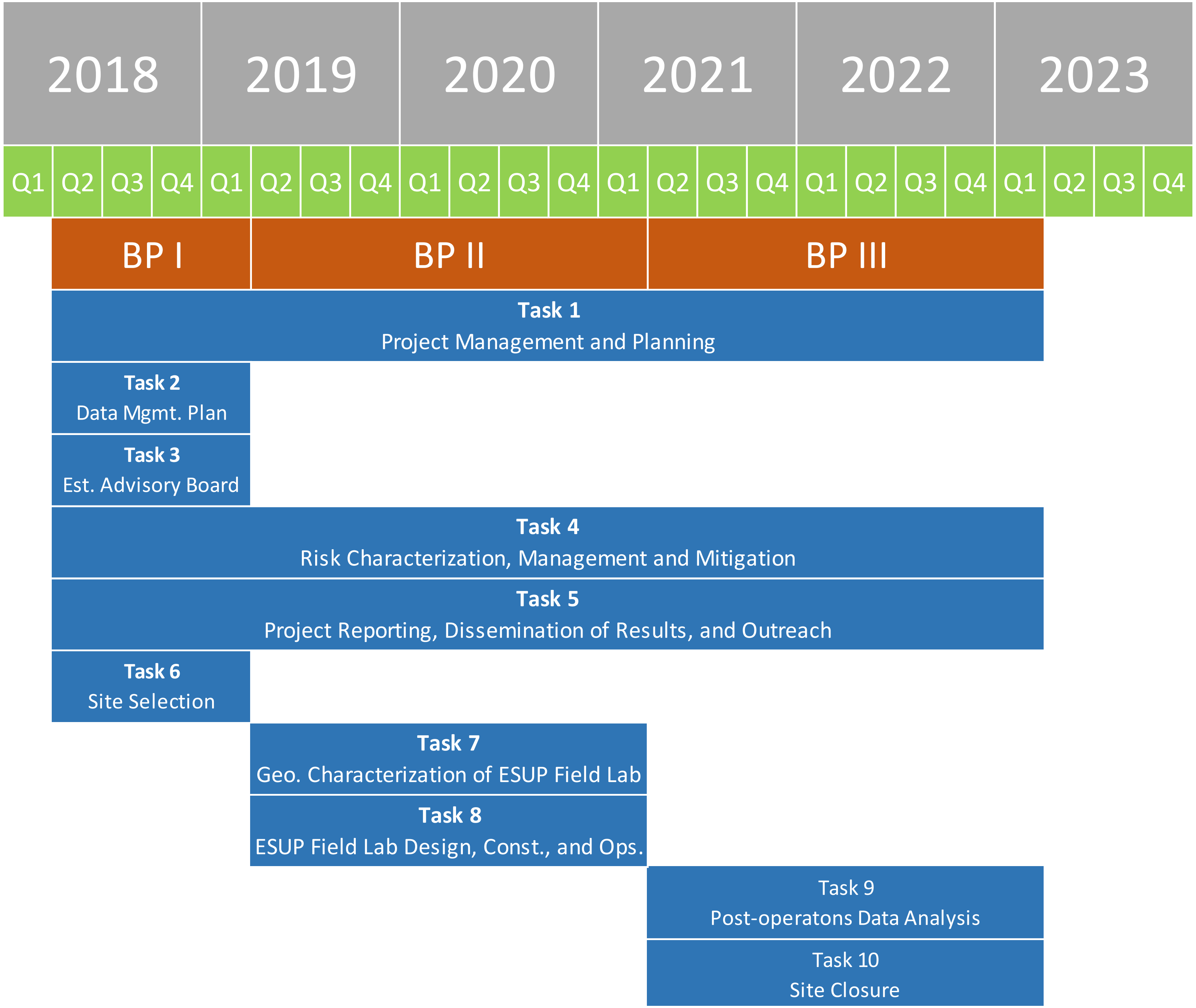
- Objective:
  - Investigate and characterize the resource potential for multi-play production of emerging unconventional reservoirs in Central Appalachia.
- Project Team
  - Virginia Tech
  - Virginia Center for Coal & Energy Research
  - EnerVest Operating, LLC
  - Pashin Geoscience, LLC
  - Gerald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

Project Team



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**.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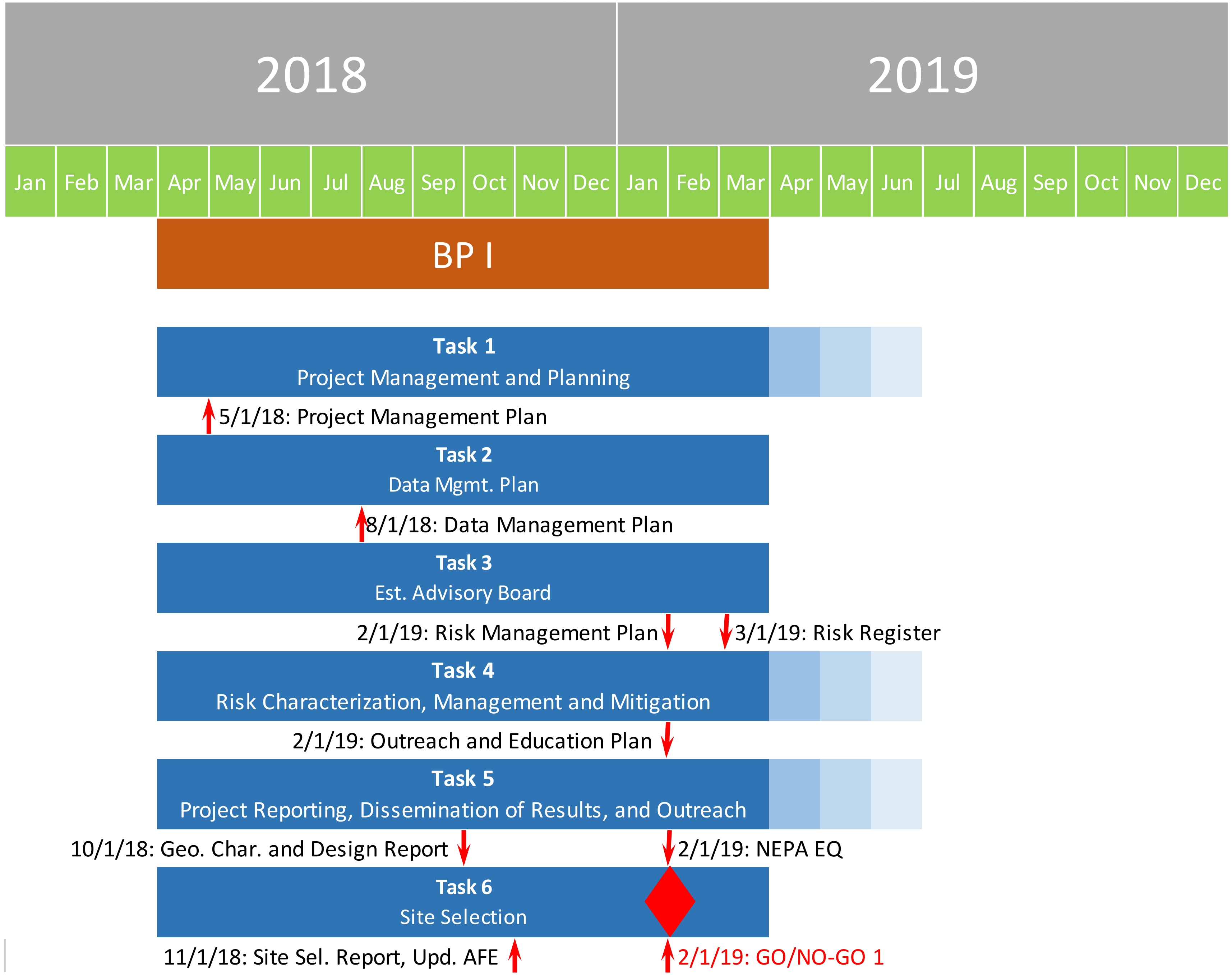
BP I
BP II
BP III
Task 1
Project Management and Planning
Task 2
Data Mgmt. Plan
Task 3
Est. Advisory Board
Task 4
Risk Characterization, Management and Mitigation
Task 5
Project Reporting, Dissemination of Results, and Outreach
Task 6
Site Selection
Task 7
Geo. Characterization of ESUP Field Lab
Task 8
ESUP Field Lab Design, Const., and Ops.
Task 9
Post-operatons Data Analysis
Task 10
Site Closure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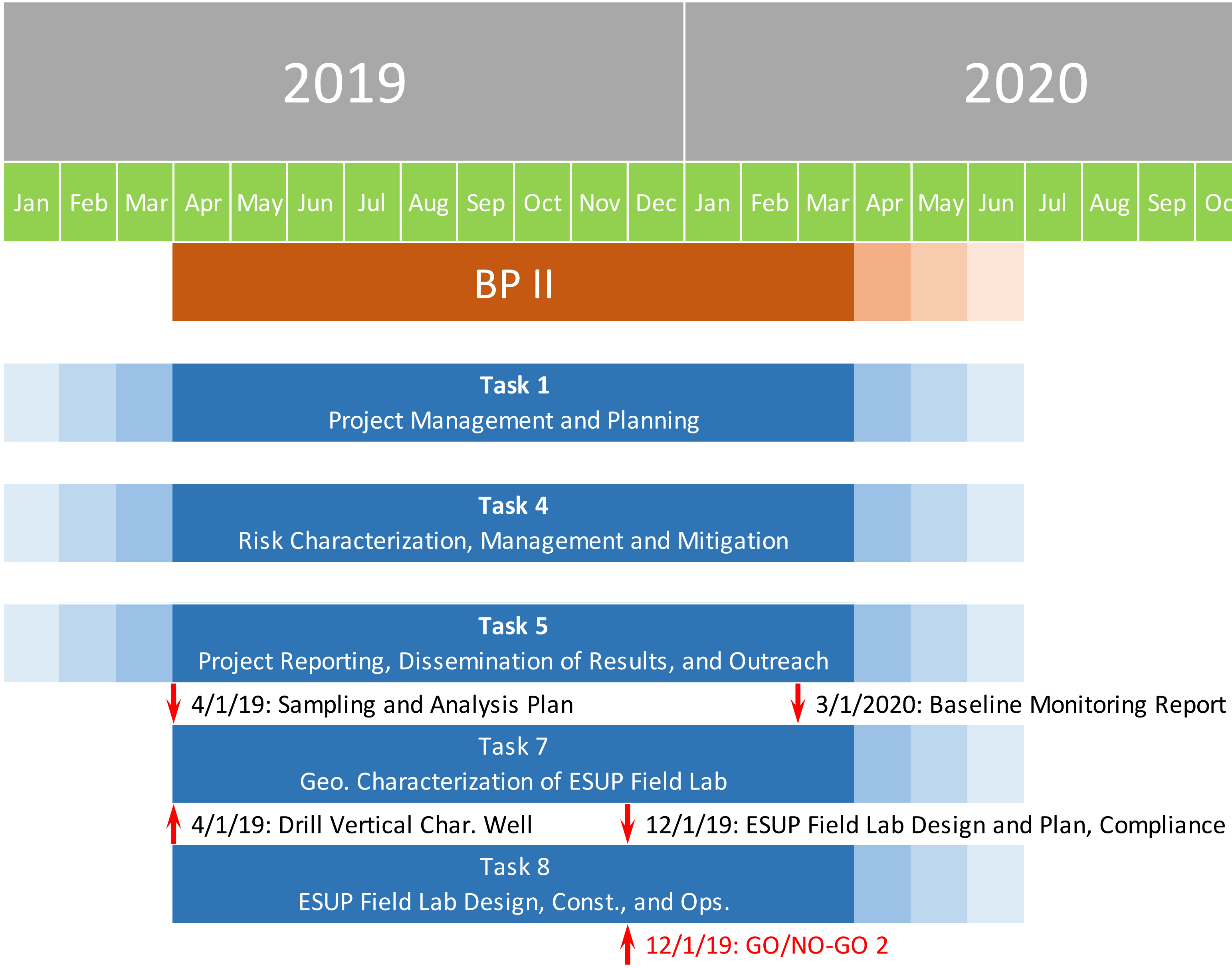
BP I
Task 1
Project Management and Planning
5/1/18: Project Management Plan
Task 2
Data Mgmt. Plan
8/1/18: Data Management Plan
Task 3
Est. Advisory Board
2/1/19: Risk Management Plan
3/1/19: Risk Register
Task 4
Risk Characterization, Management and Mitigation
2/1/19: Outreach and Education Plan
Task 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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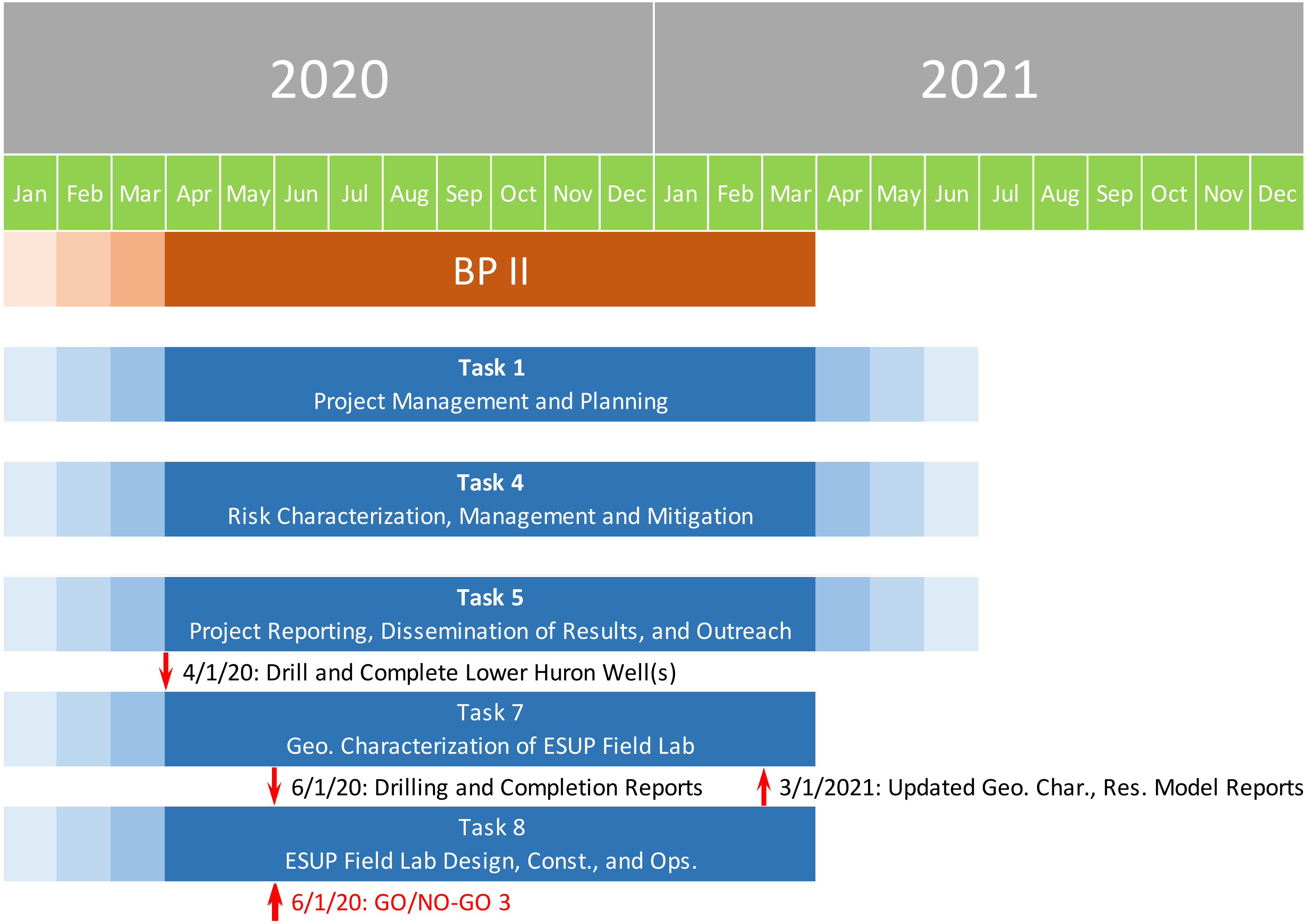
BP II
Task 1
Project Management and Planning
Task 4
Risk Characterization, Management and Mitigation
Task 5
Project Reporting, Dissemination of Results, and Outreach
4/1/19: Sampling and Analysis Plan
3/1/2020: Baseline Monitoring Report
Task 7
Geo. Characterization of ESUP Field Lab
4/1/19: Drill Vertical 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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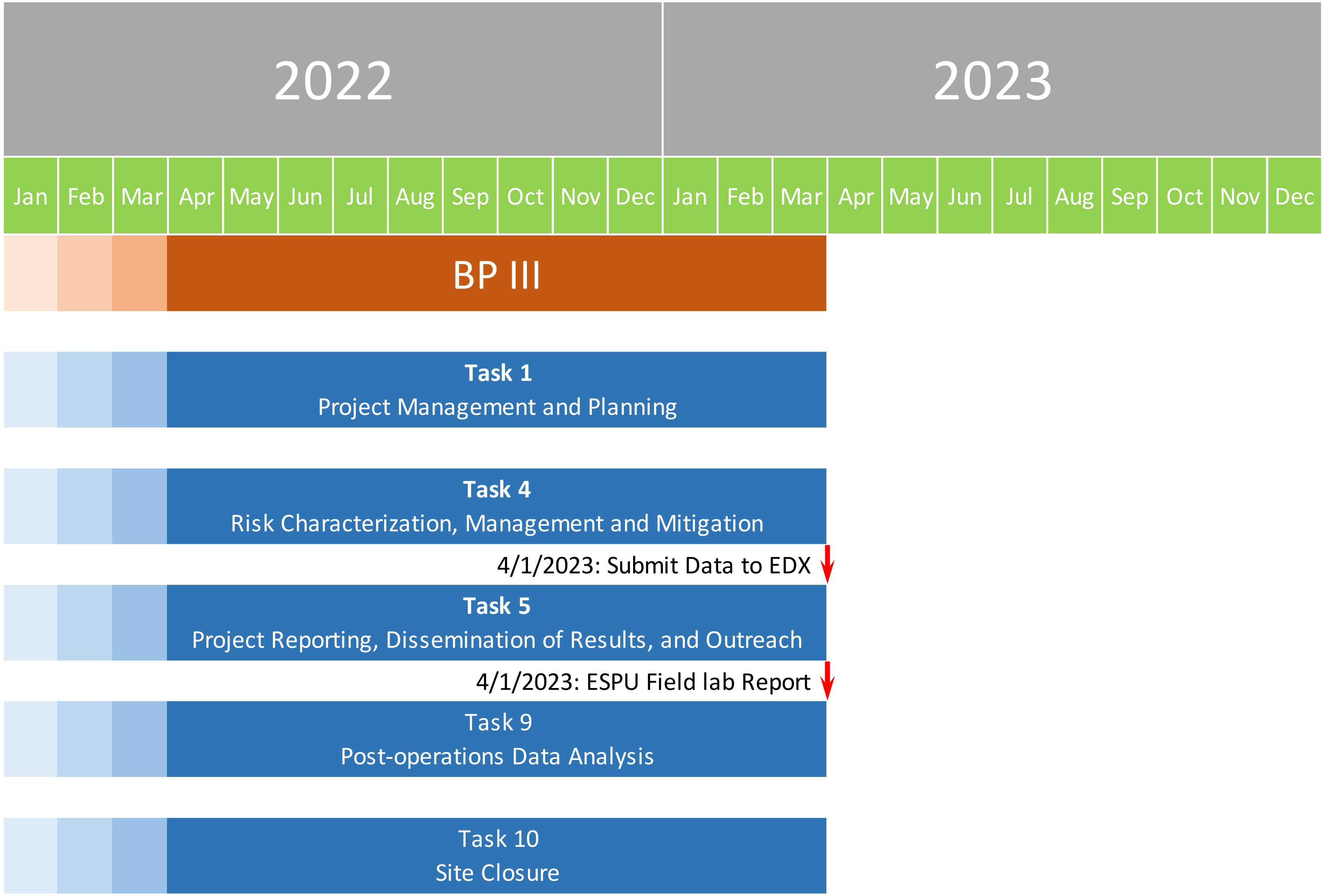
BP II
Task 1
Project Management and Planning
Task 4
Risk Characterization, Management and Mitigation
Task 5
Project Reporting, Dissemination of Results, and Outreach
4/1/20: Drill and Complete Lower Huron Well(s)
Task 7
Geo. Characterization of ESUP Field Lab
6/1/20: Drilling and Completion Reports
3/1/2021: Updated Geo. Char., Res. Model Reports
Task 8
ESUP Field Lab Design, Const., and Ops.
6/1/20: GO/NO-GO 3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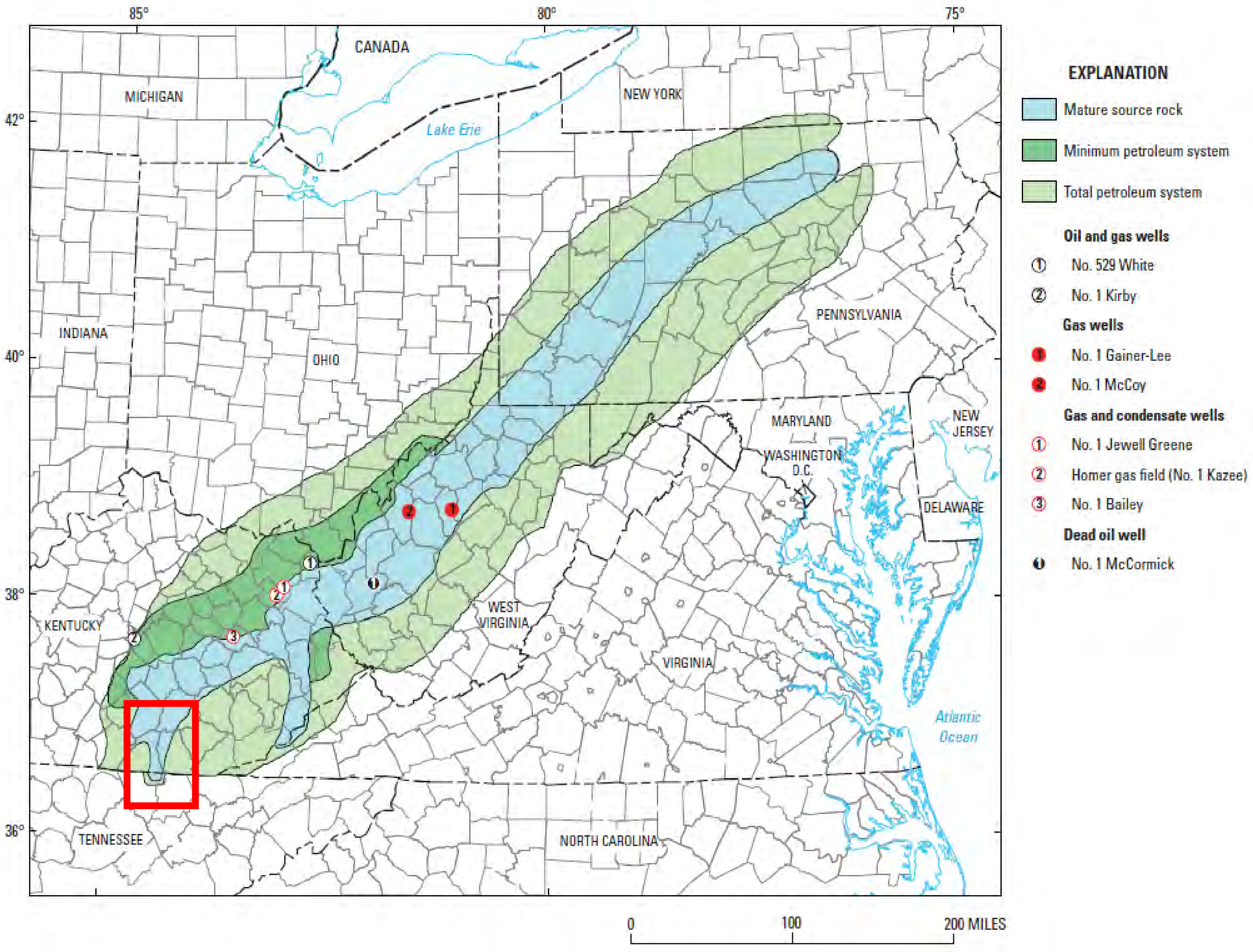
BP III
Task 1
Project Management and Planning
Task 4
Risk Characterization, Management and Mitigation
4/1/2023: Submit Data to EDX
Task 5
Project Reporting, Dissemination of Results, and Outreach
4/1/2023: ESPU Field lab Report
Task 9
Post-operations Data Analysis
Task 10
Site Closure

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

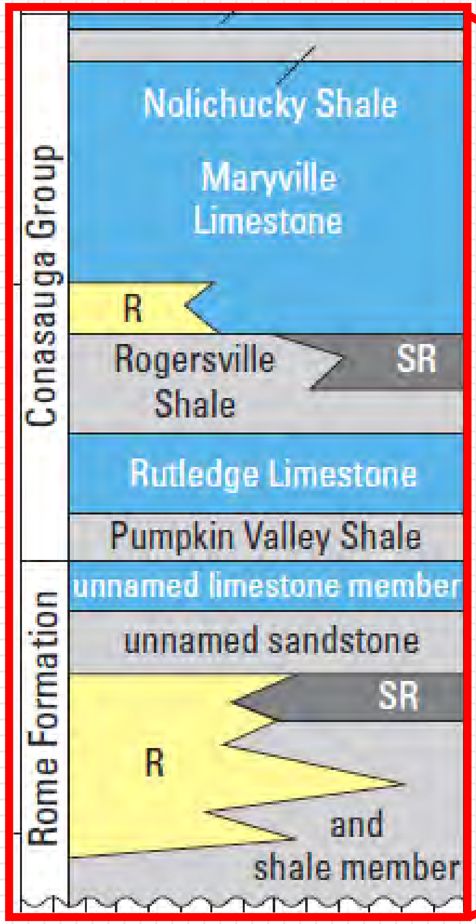
Conasauga/Conasauga-Rome Petroleum System

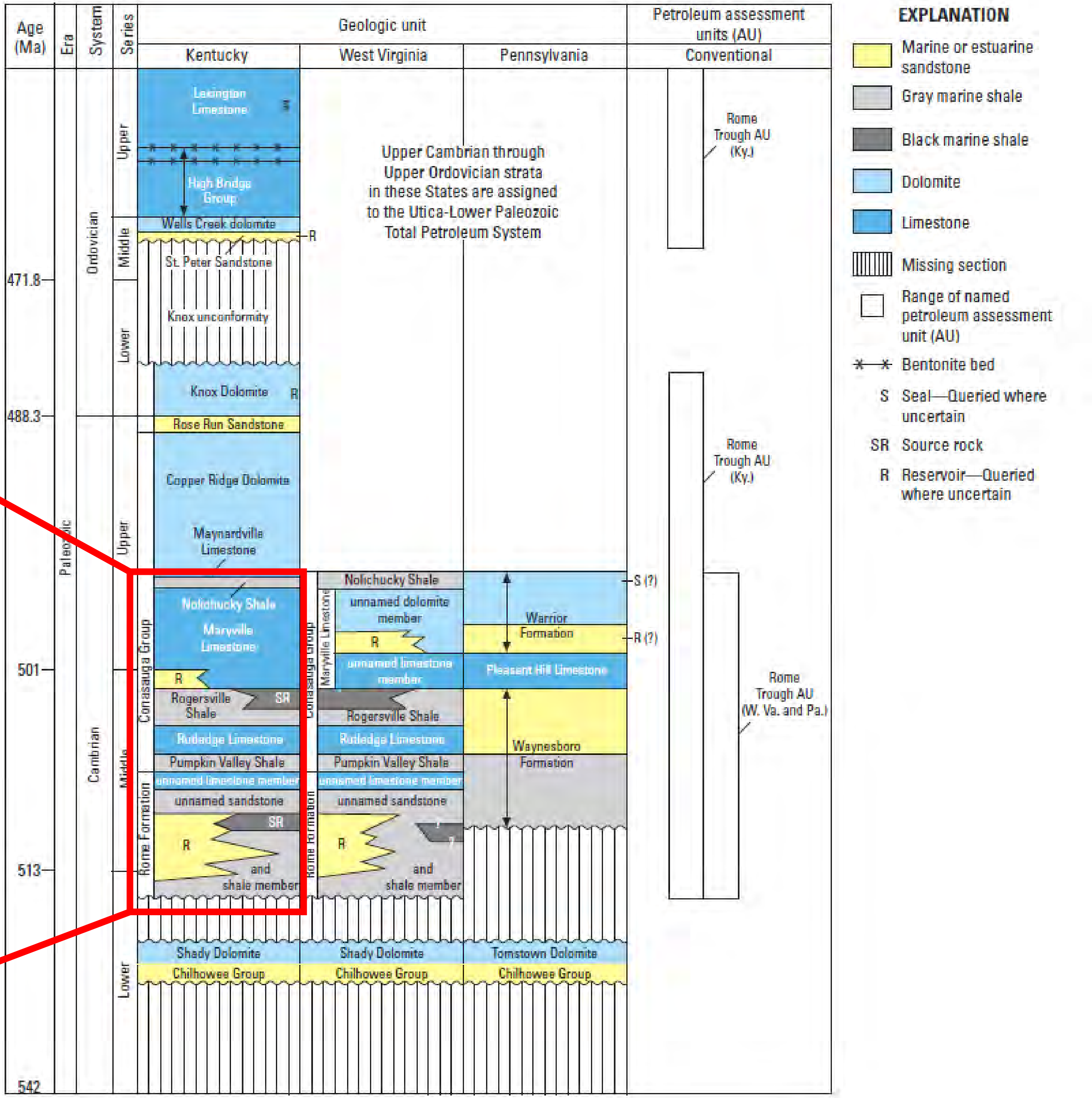
- Geochemical evidence suggests Cambrian source rocks are present in the Rome Trough
  - Correlated with oils in Homer Gas field, KY
- Rome Trough primarily in eastern KY, WV, and PA
- Floyd Embayment (red) extends system boundaries into SW VA



USGS, 2014

Conasauga/Conasauga-Rome Petroleum System

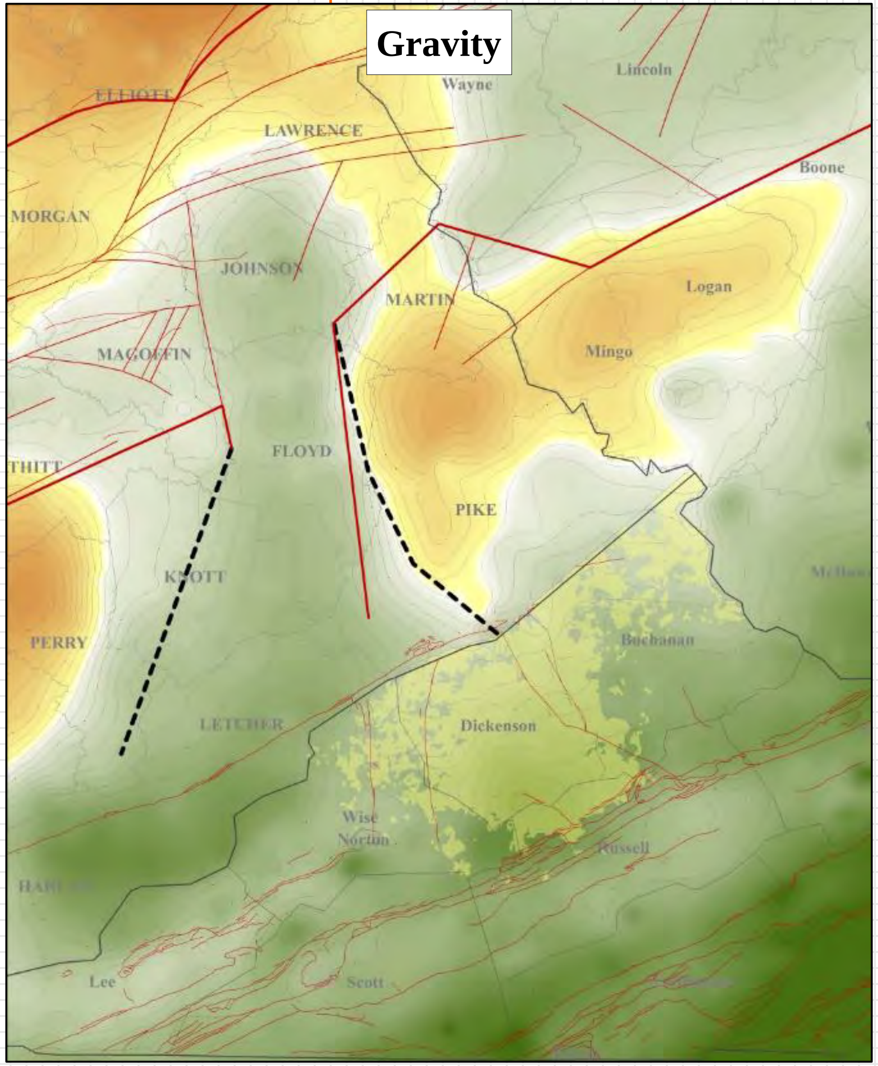


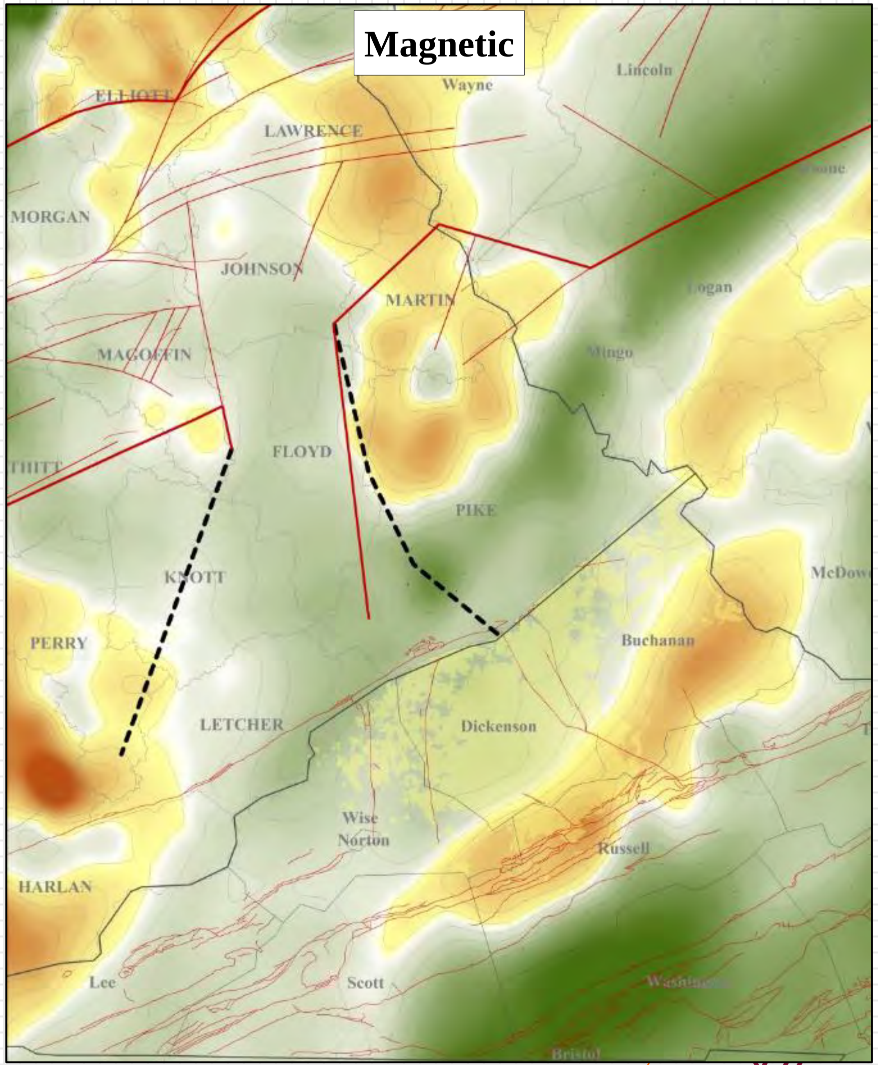


USGS, 2014

Rome Trough Structure
Gravity and Magnetic Data

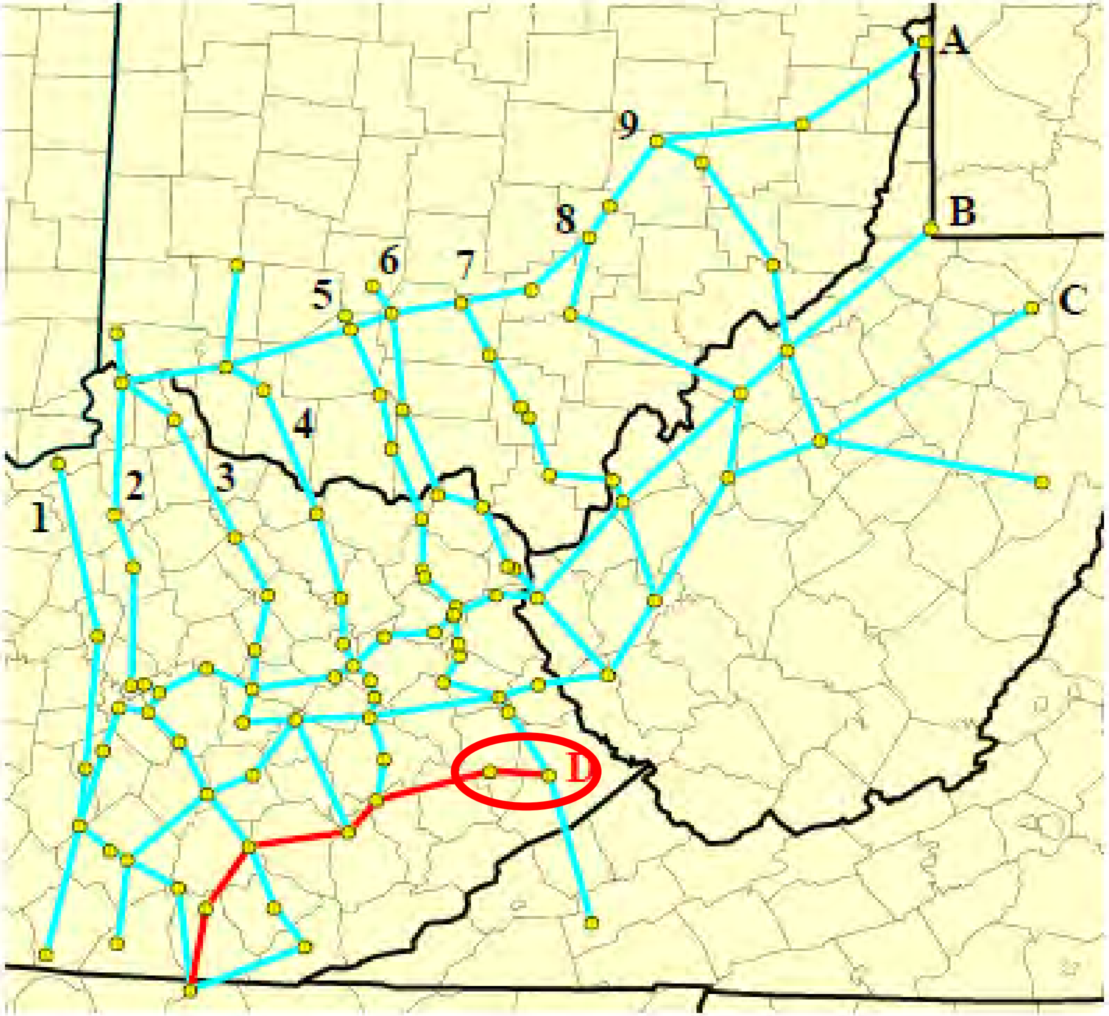
- Magnetic and gravity anomalies are proxies for Rome Trough and Precambrian structure
- The borders of the Floyd Embayment are ambiguous and are poorly understood in Virginia
- Gravity and magnetic data suggests that the Floyd Embayment intersects western portions EnerVest acreage

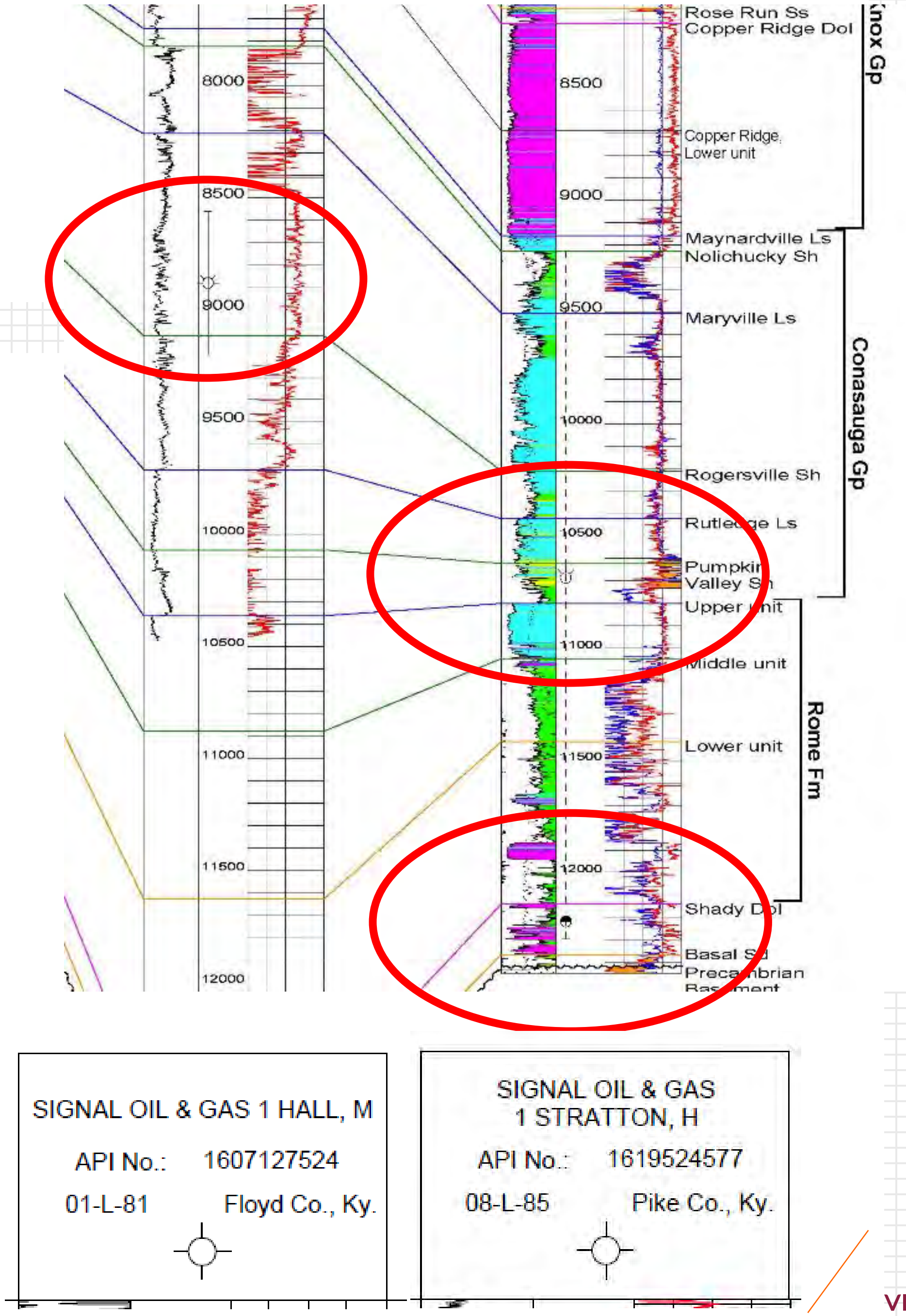




EnerVest, 2018

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)

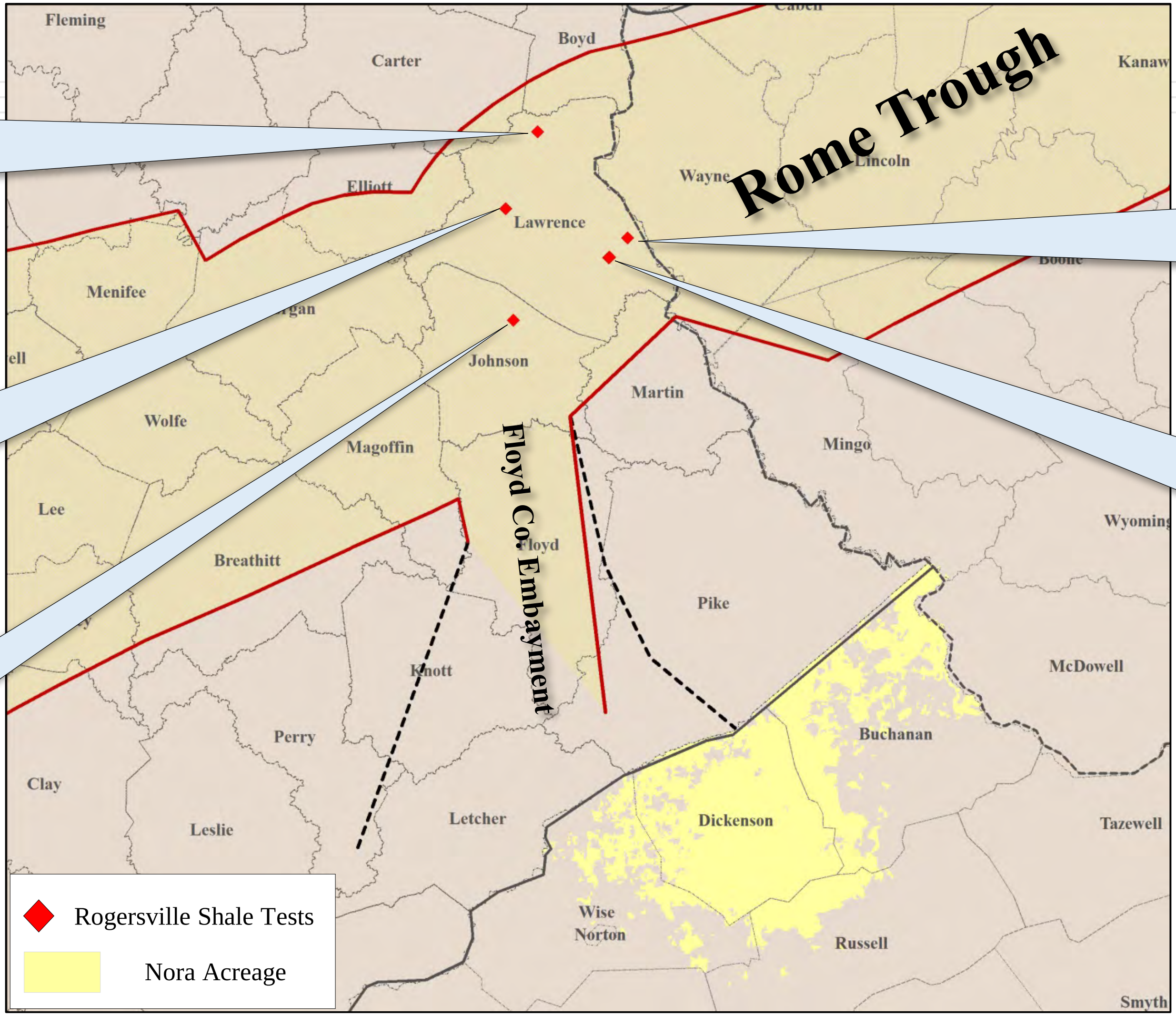
Vertical Strat Test

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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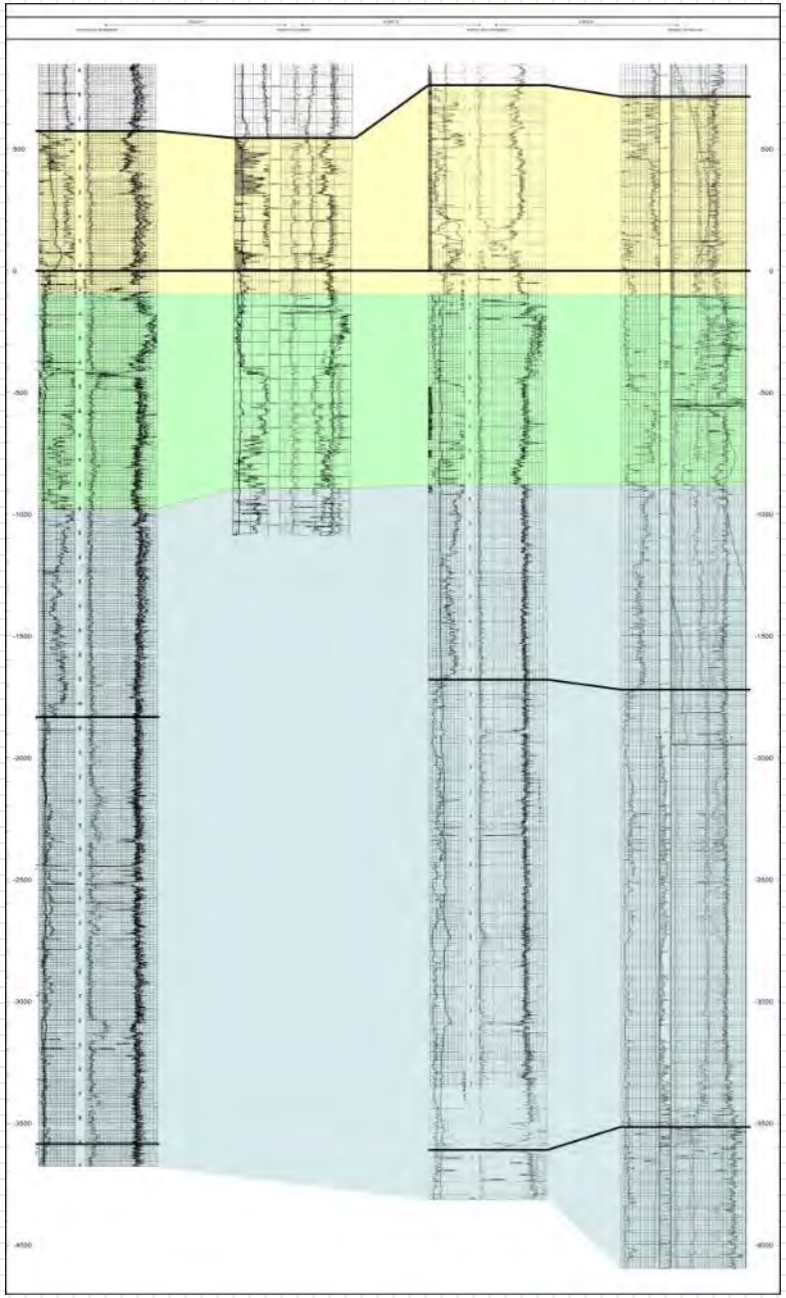
Deep Targets for Vertical Characterization Well

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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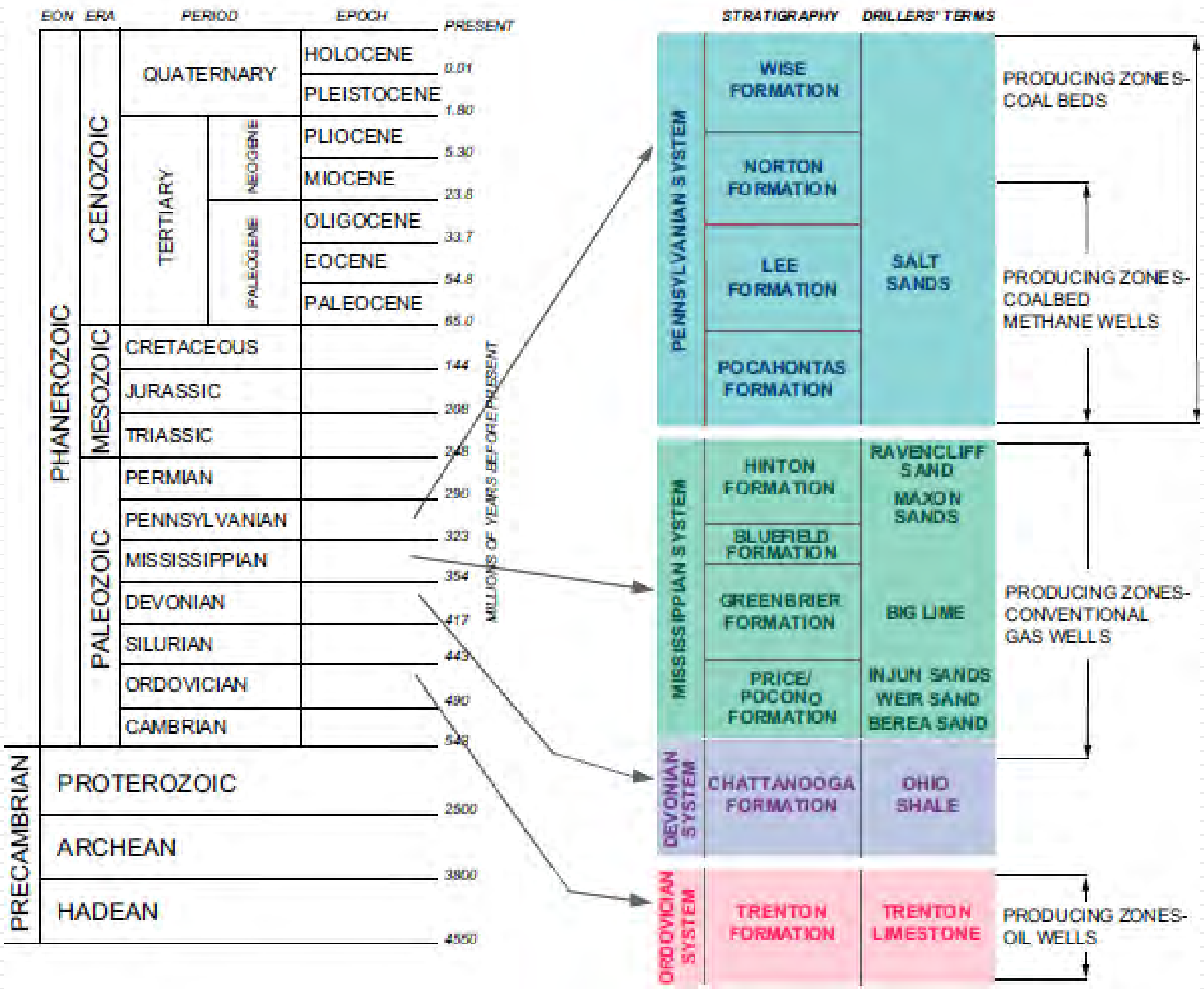
Nora Field - Stratigraphy

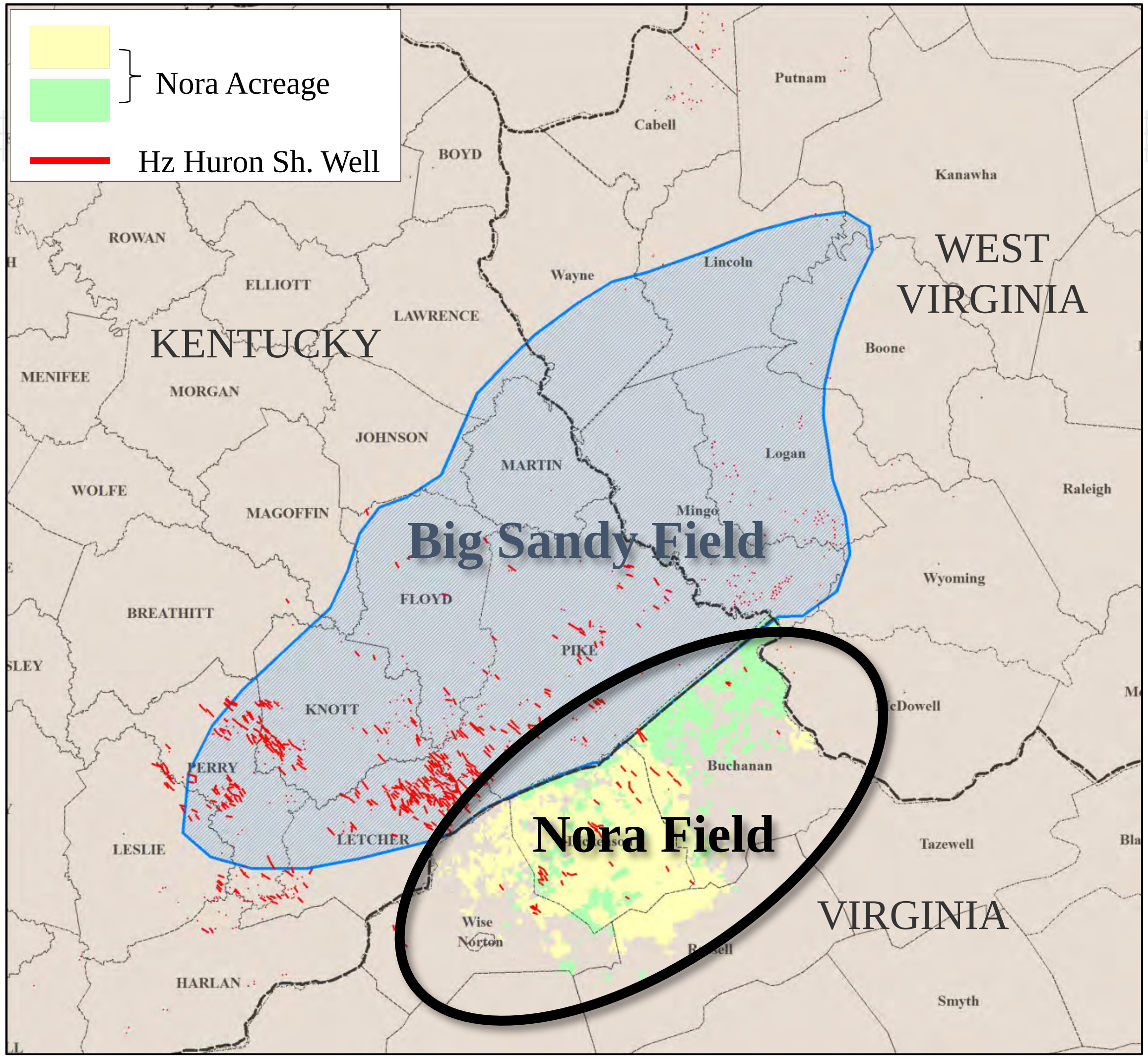
- Current Shallower Stacked Plays
  - **Coalbed Methane (Pennsylvanian)**
  - **Big Lime (Mississippian)**
  - **Weir Sand (Mississippian)**
  - **Berea Sand (Mississippian)**
  - **Lower Huron Shale (Devonian)**



VA DMME, 2017

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.

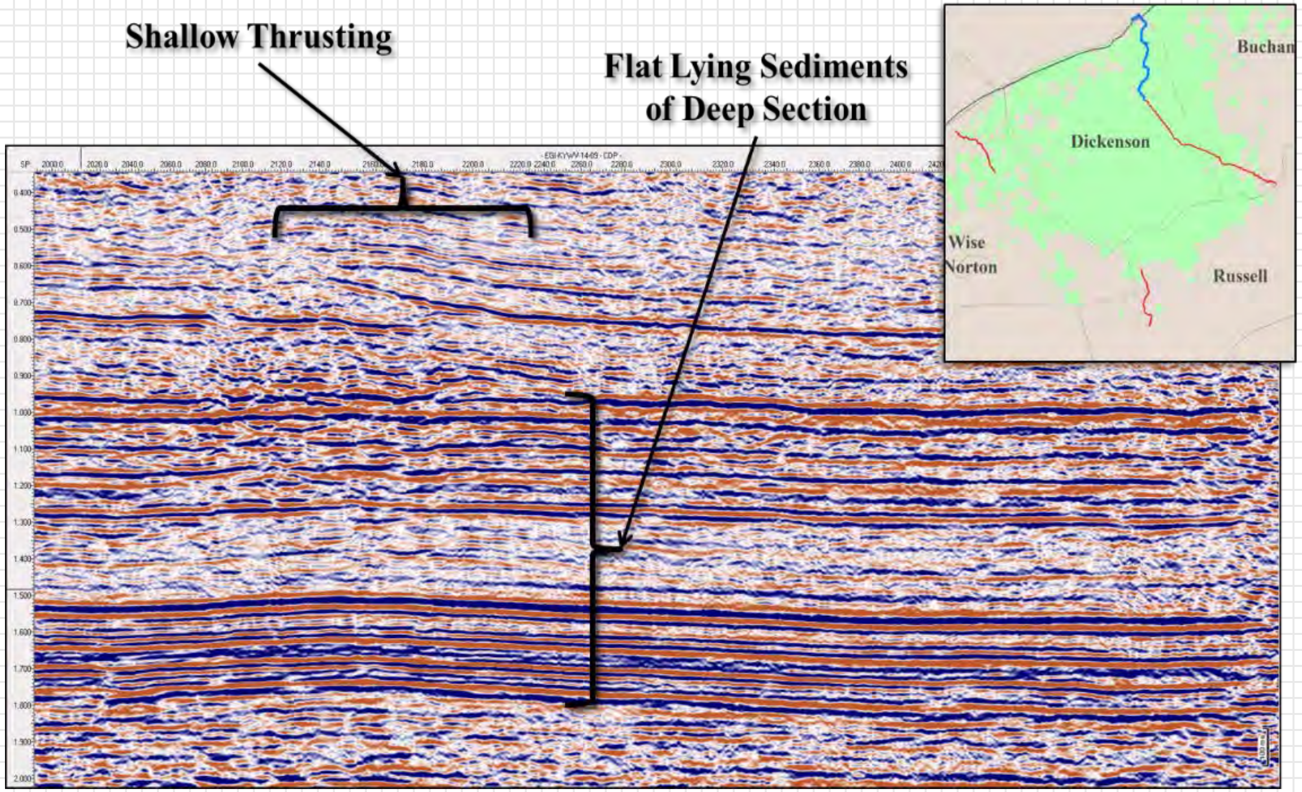
Source: The Atlas of Major Appalachian Gas Plays

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.

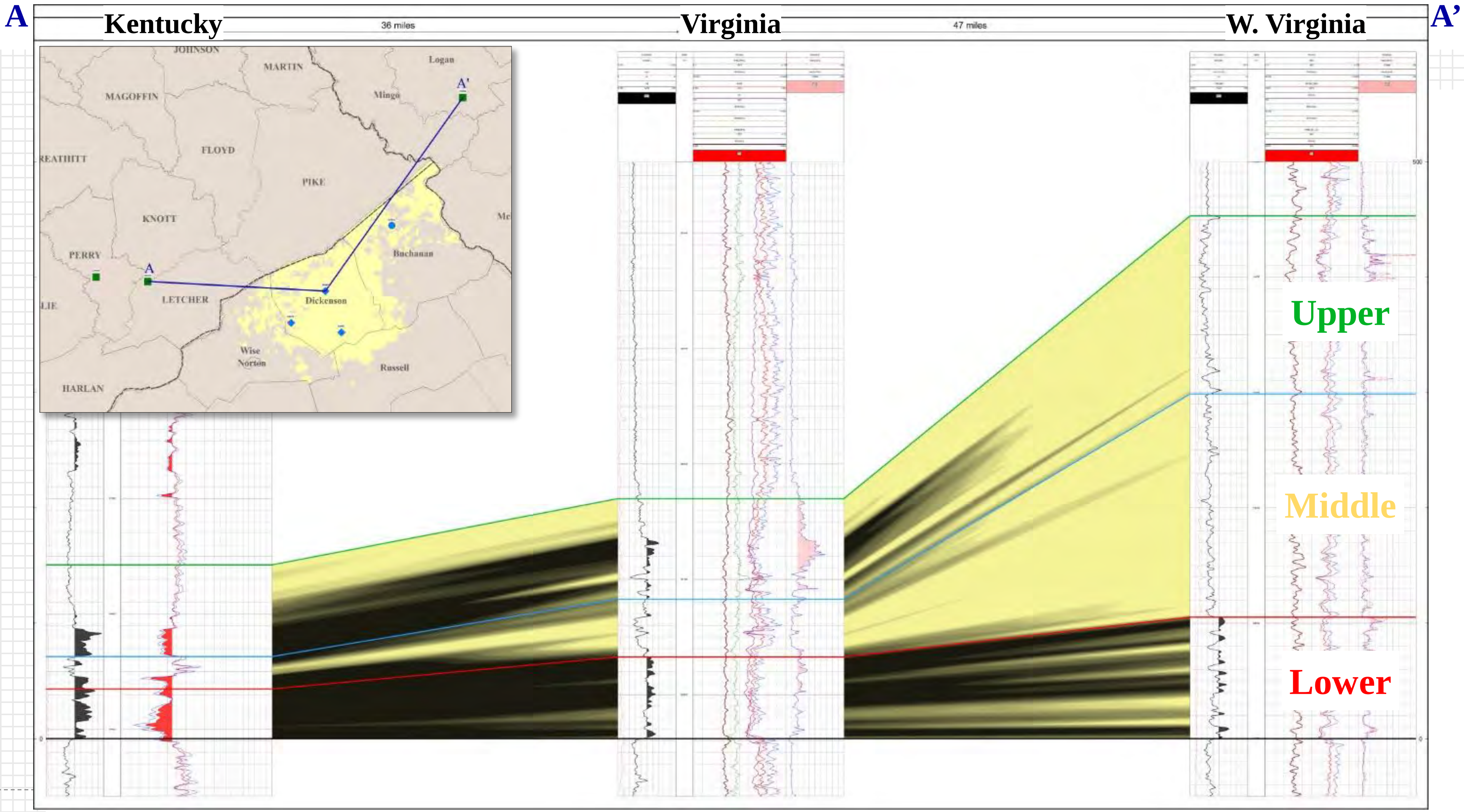
Nora Gas Field, Virginia

- Flat Lying Deep Sediments



US Energy Information Administration, 2007)

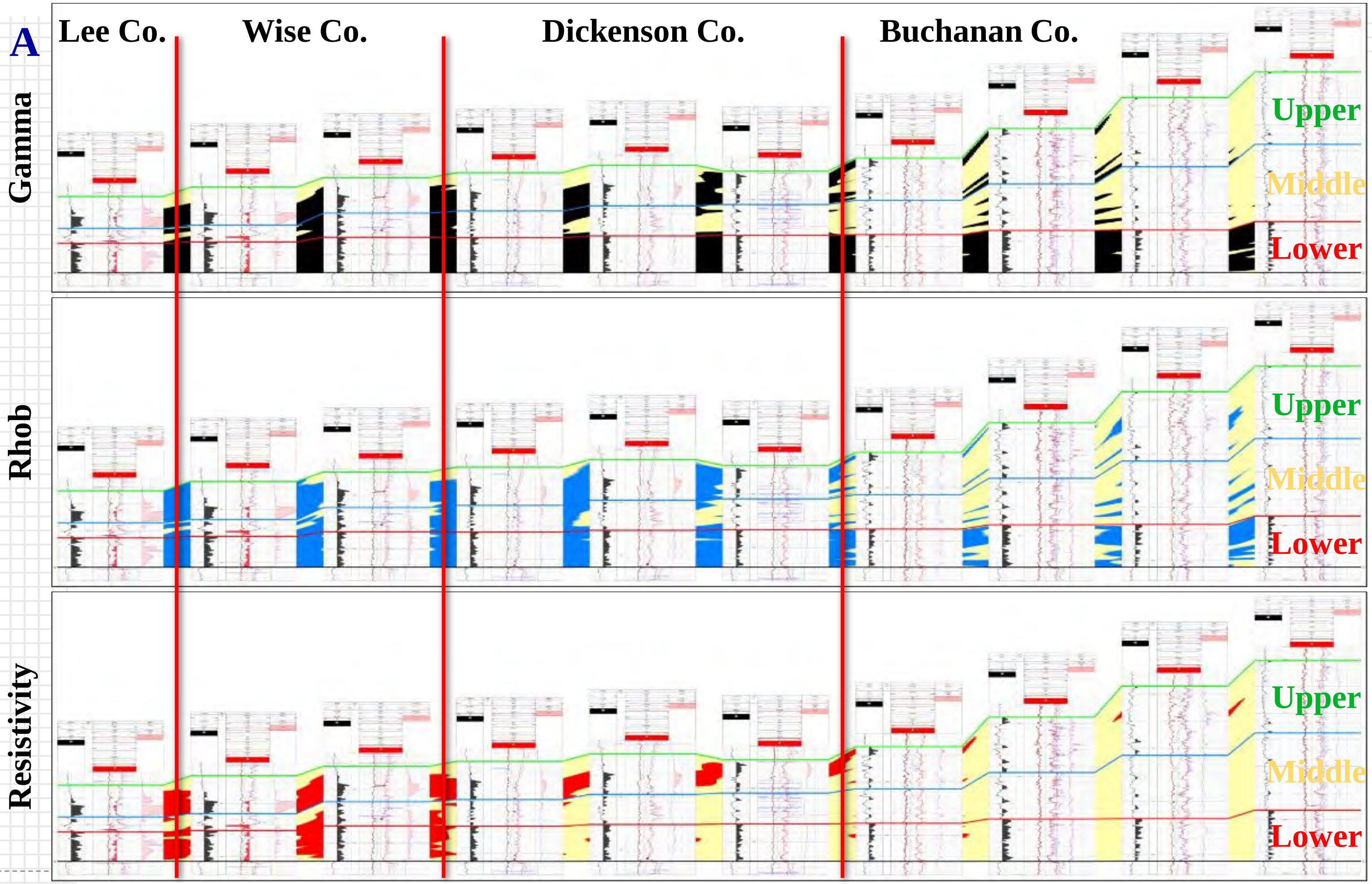
Lower Huron Delineation/Nomenclature

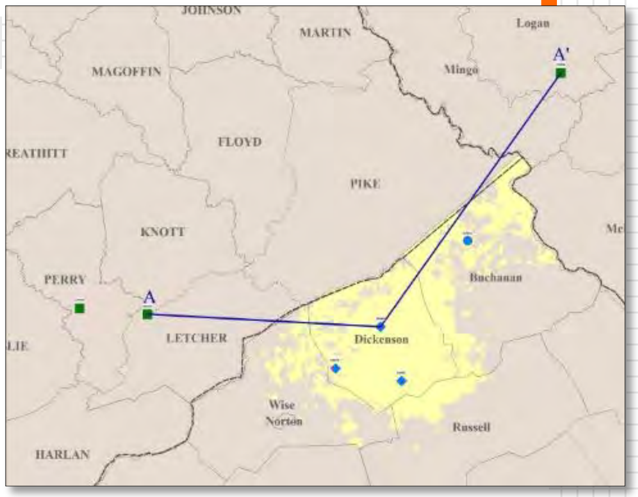


EnerVest, 2018

Well Log TOC Correlation

Gamma, Rhob, Resistivity Interpolation = 3% TOC

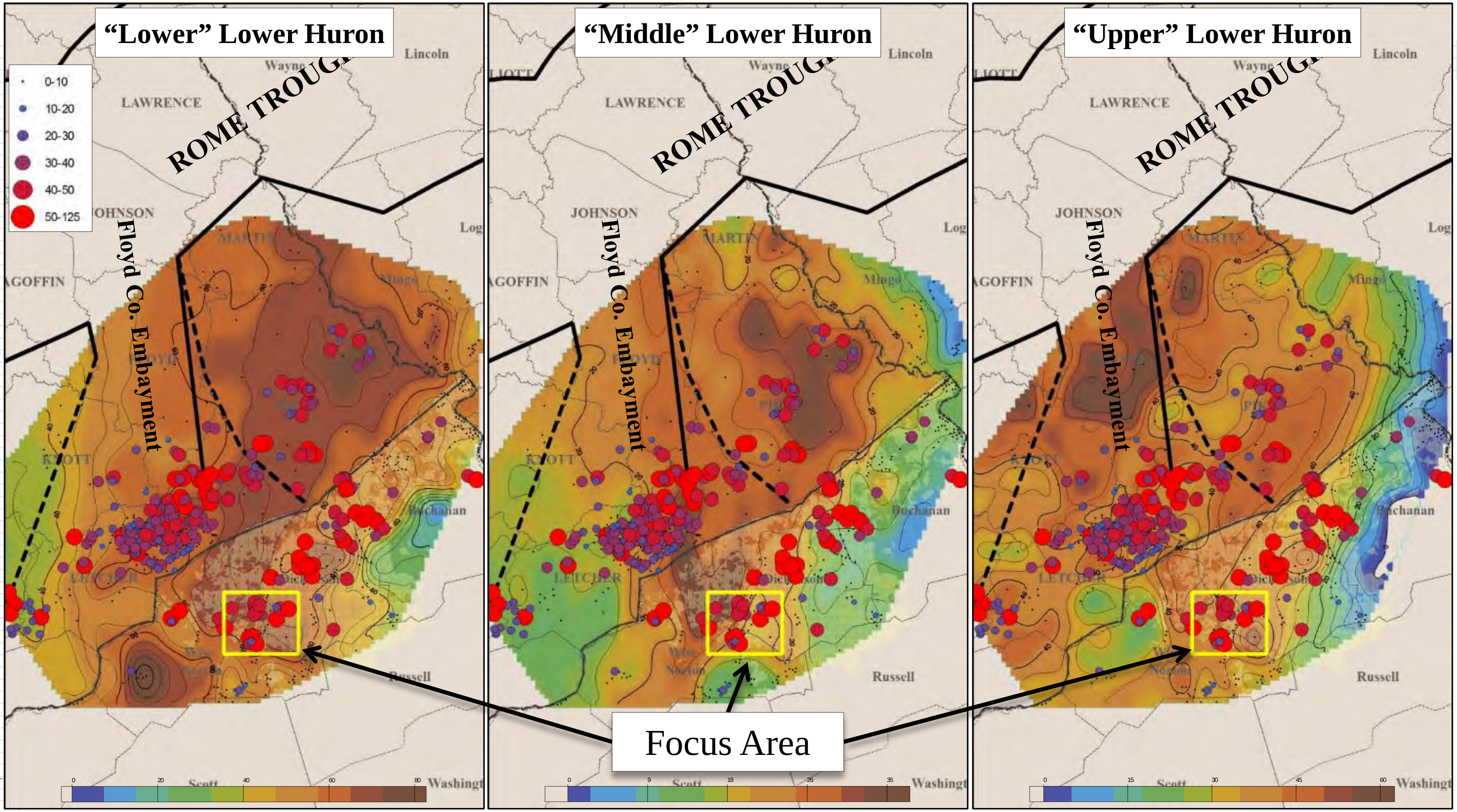




EnerVest, 2018

Focus Area Determination

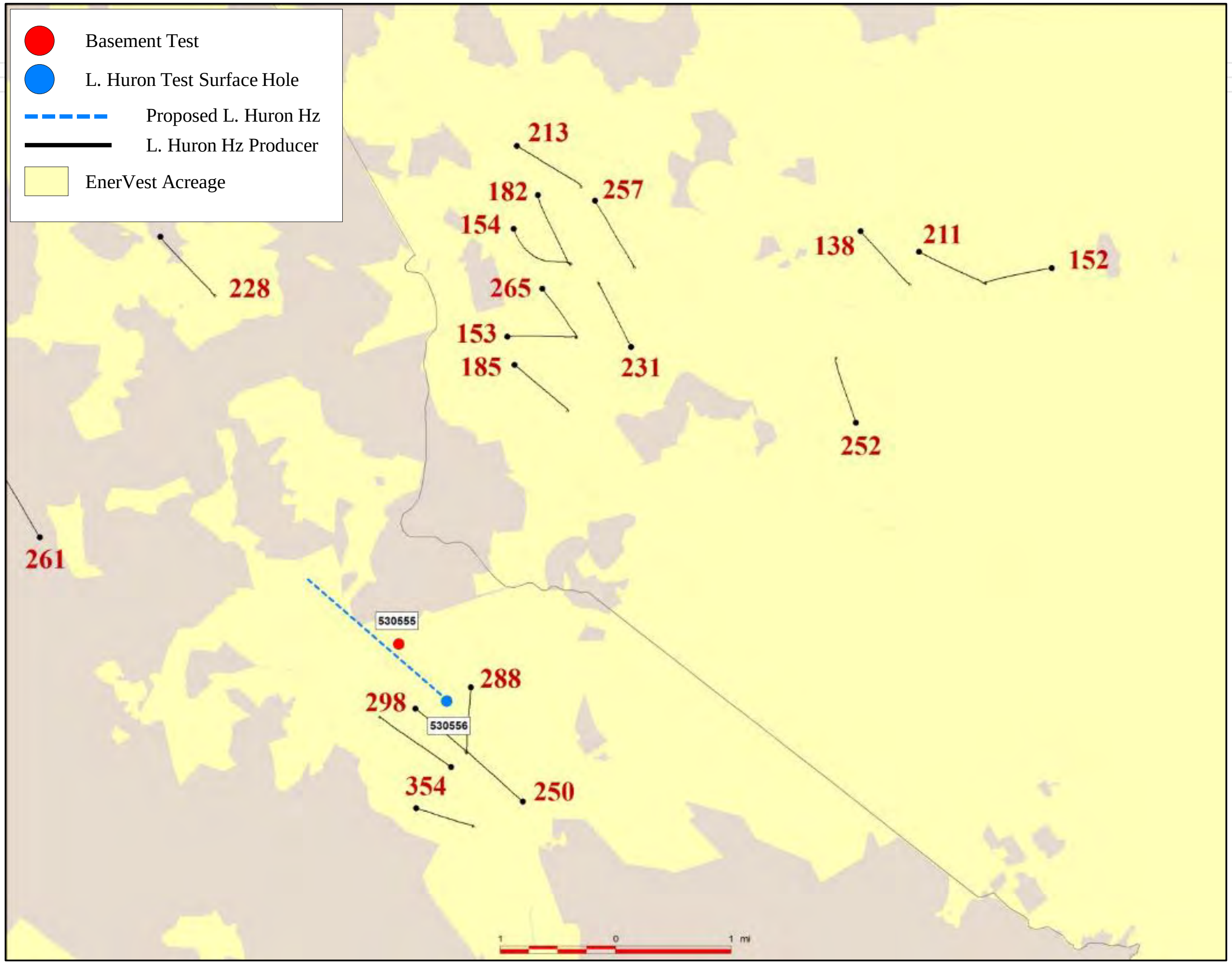
Combined Gamma/Rhob Cutoff Mapping (264 API & 2.64 g/cc = 3% TOC)



EnerVest, 2018

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

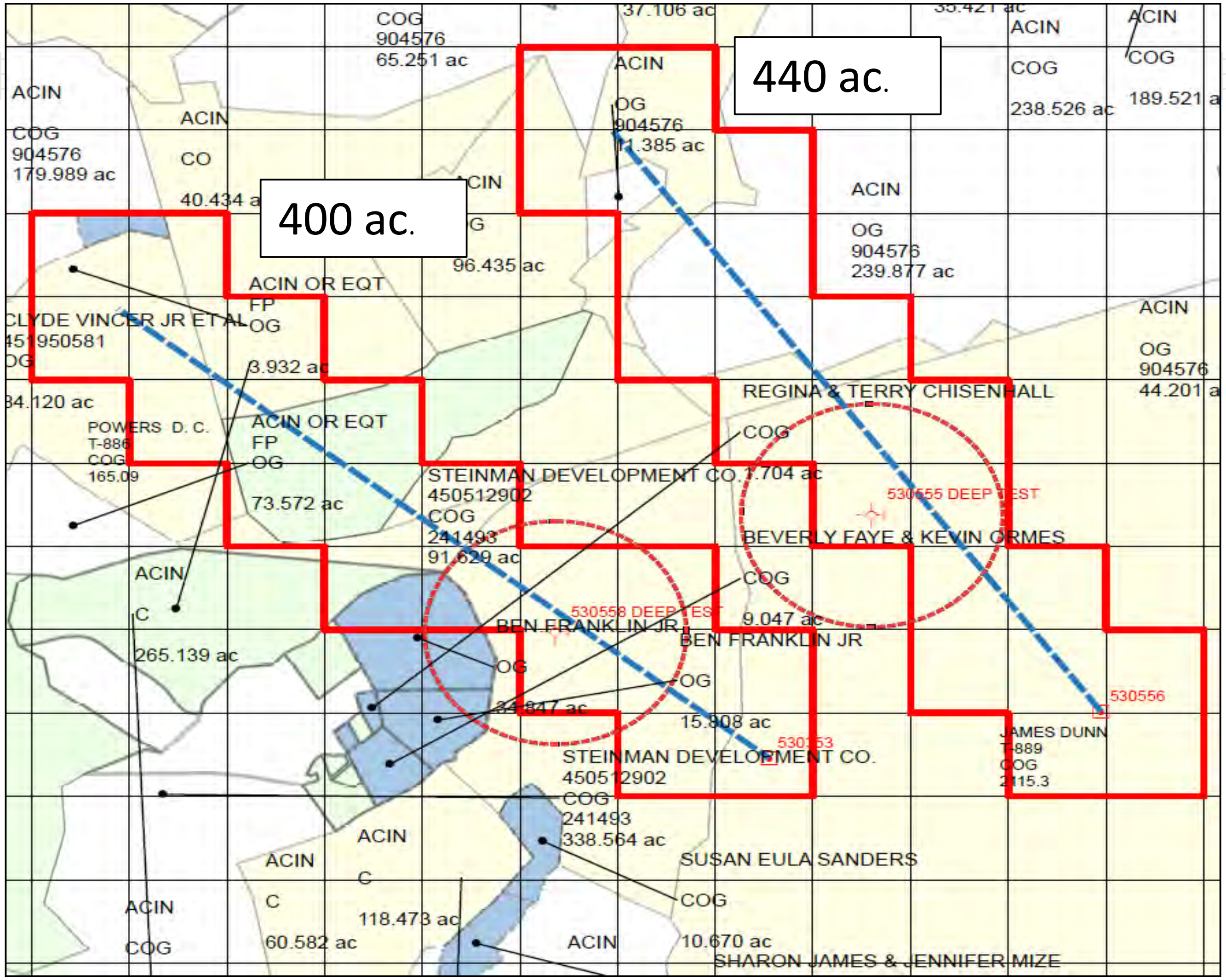


EnerVest, 2018

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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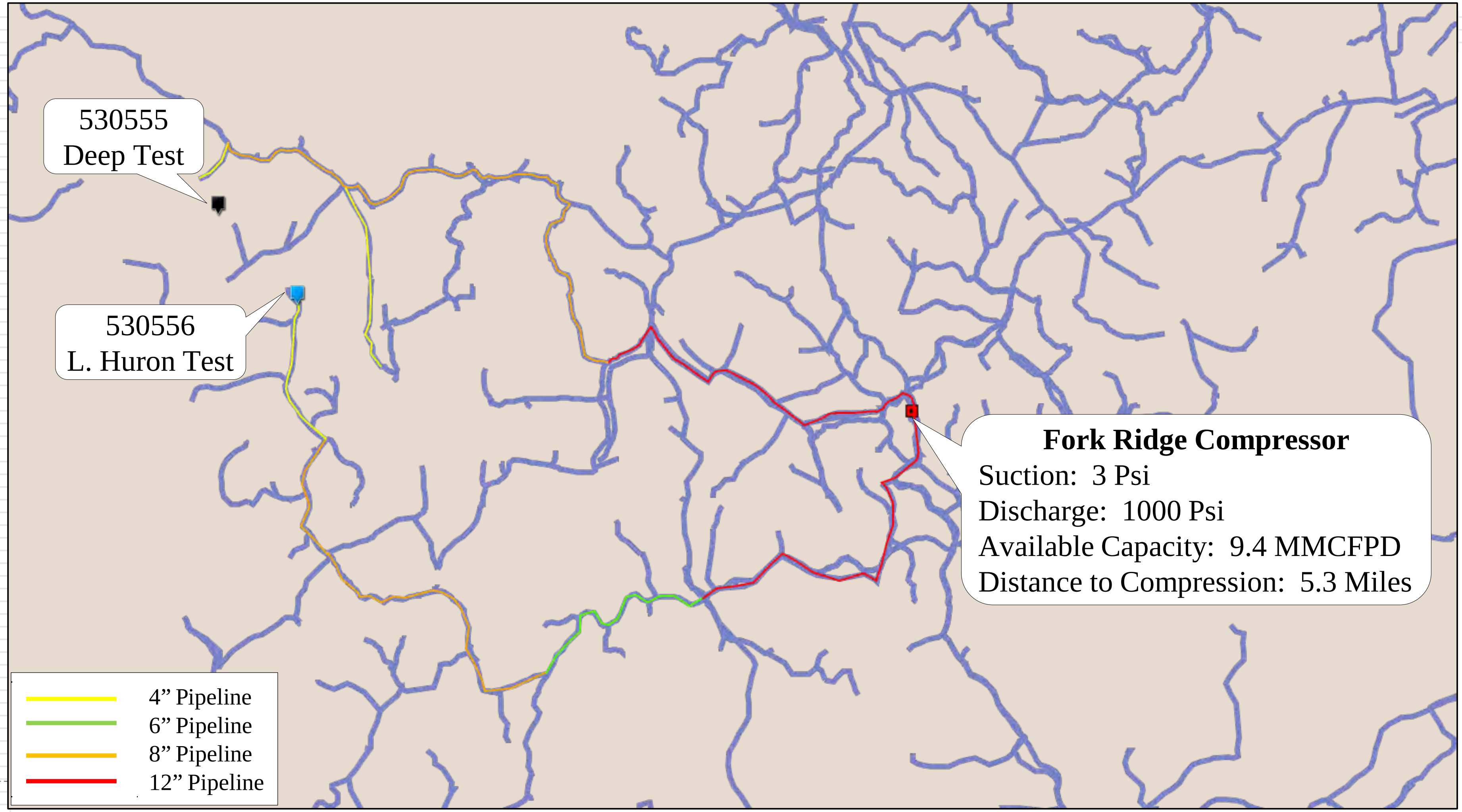
Land Overview

Potential Test Locations: Infrastructure Availability

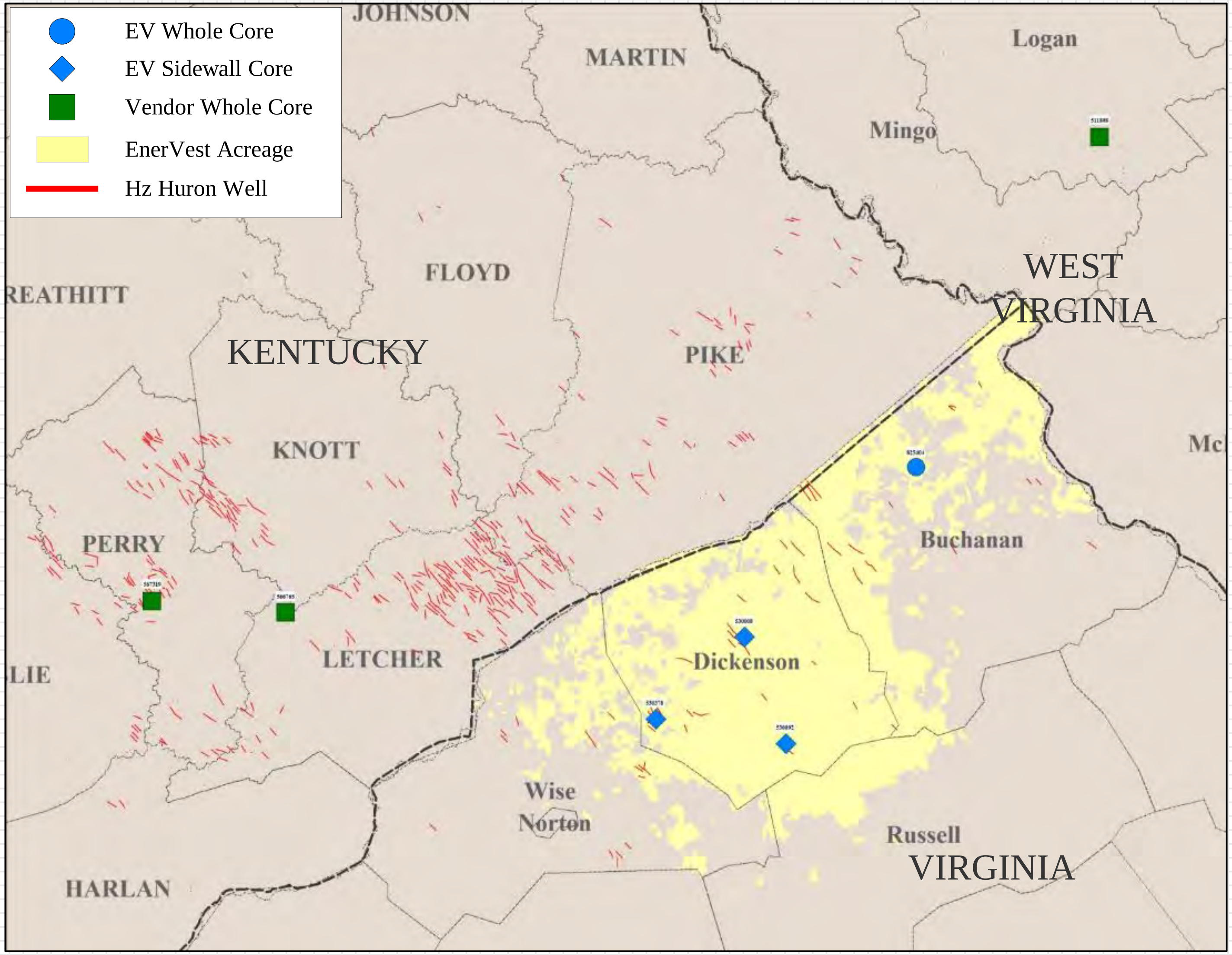


EnerVest, 2018

Lower Huron Core Distribution

Core Inventory

- 4 Whole Cores
- 3 Sidewall Cores
- Archived Cuttings



EnerVest, 2018

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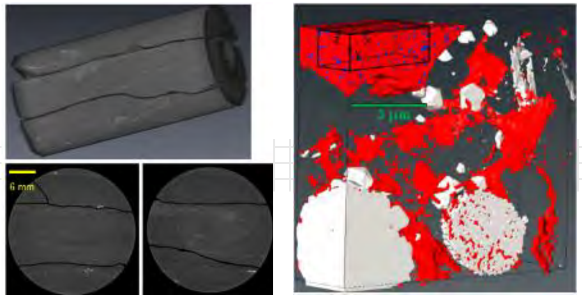
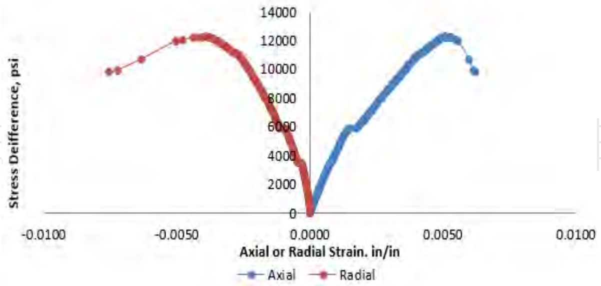
Core Analysis Workflow





Digital Rock Analysis

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

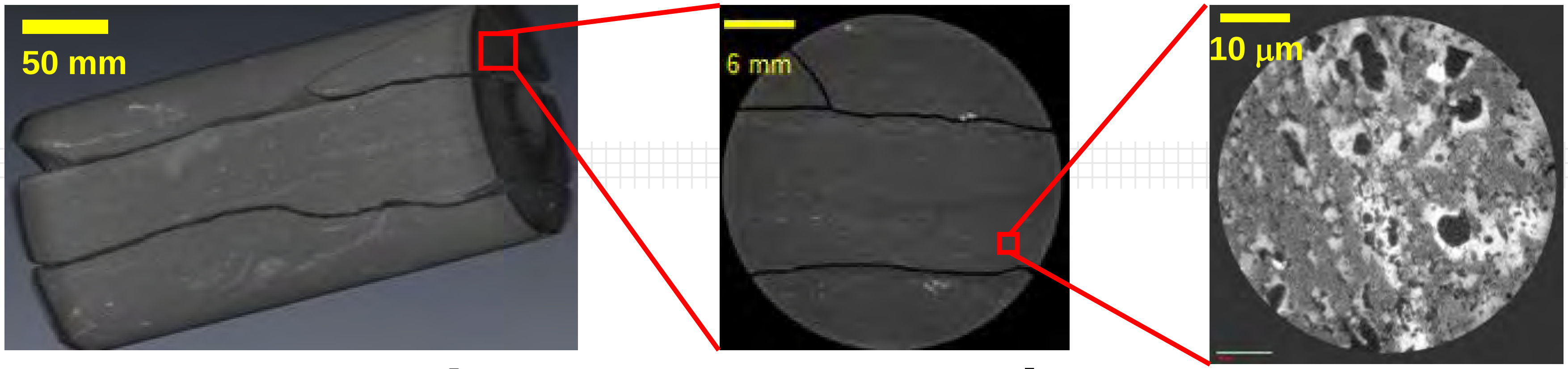
Geomechanical Analysis

- 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

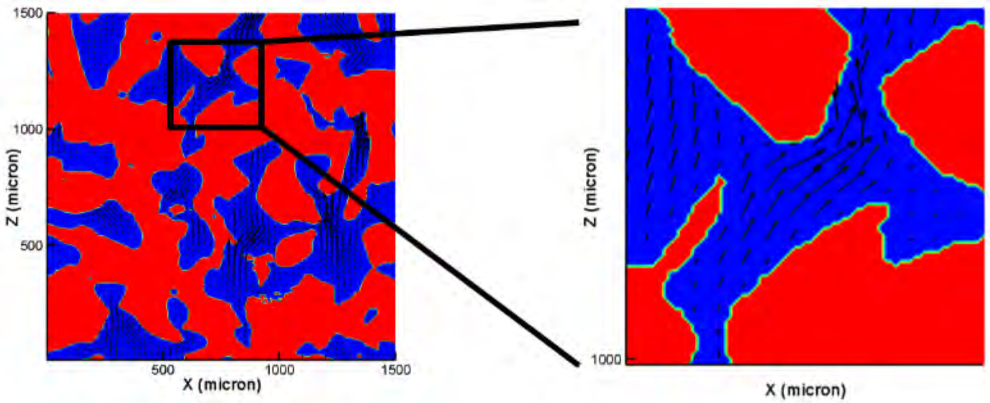
- RockEval tests for total organic carbon (TOC)
- X-ray Diffraction Analysis (XRD) for mineralogy
- Permeability measurement using pulse decay permeameter (PDP-200), NanoK, and SMP-200 (all equipment from CoreLab)
- Fracture Conductivity Cell
- These properties are critical for finding the "sweet spots"

Core Analysis Workflow



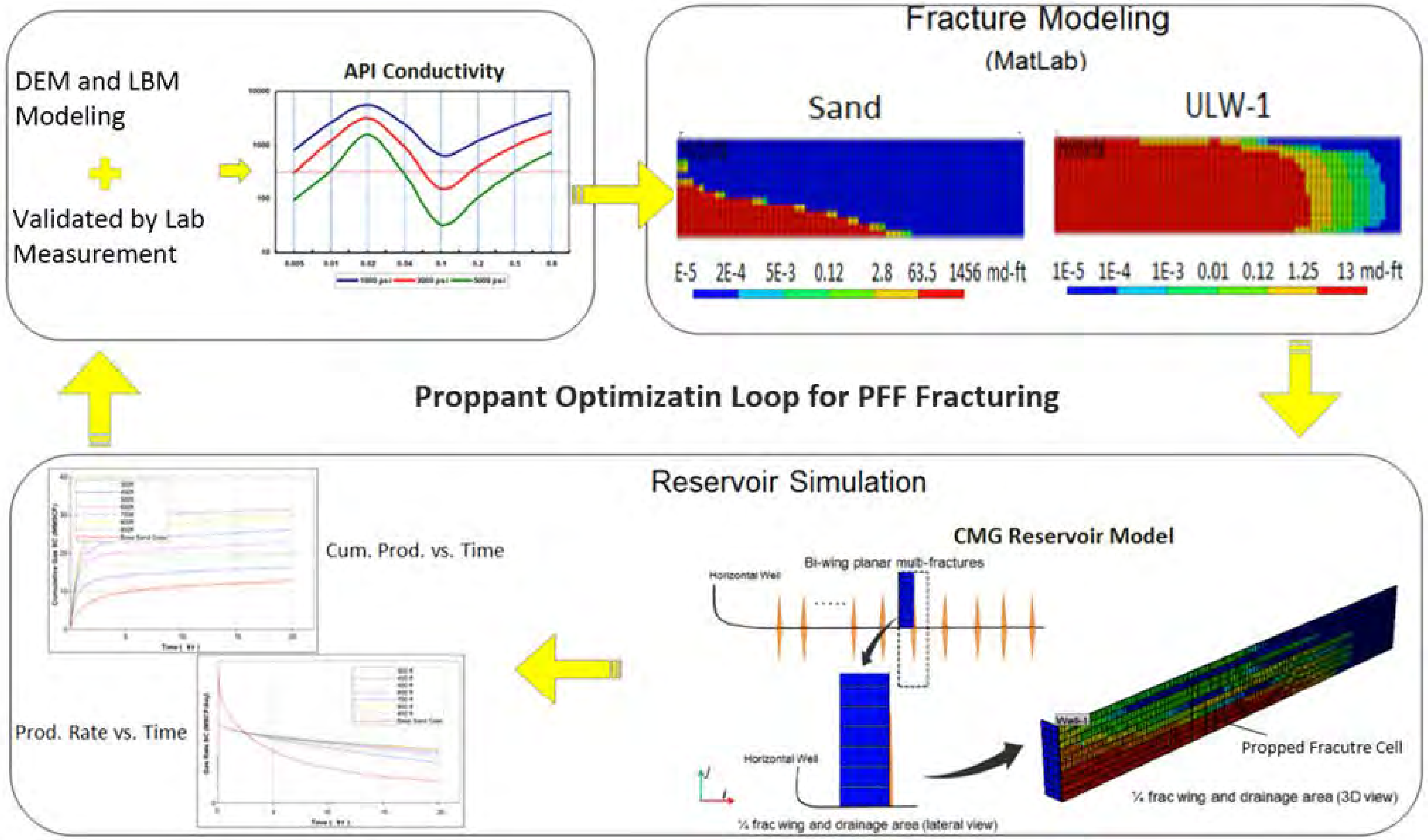
0.25 mm/pixel | 25 µm/pixel | 64 nm/pixel

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.

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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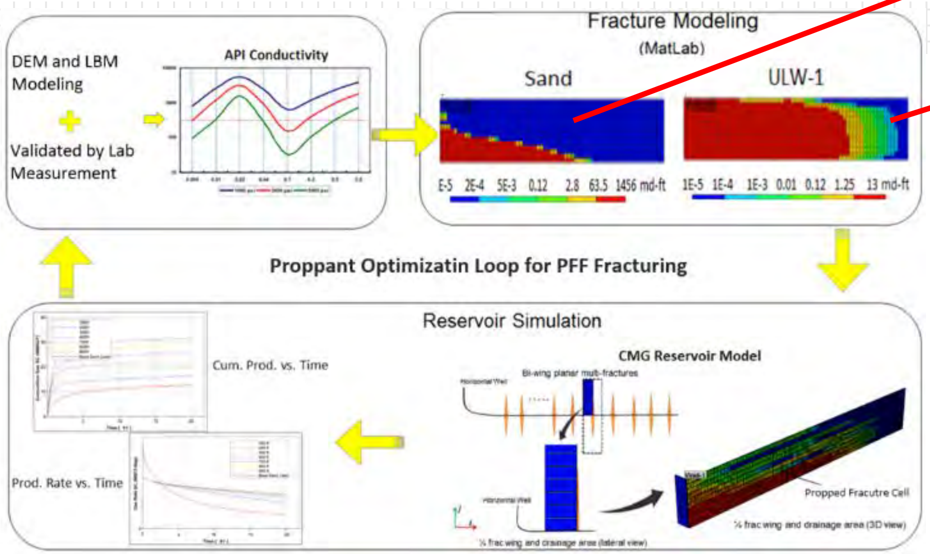
Optimization of Fracturing and Proppant Placement



Regular sand proppant:
Fast settlement near the well

Ultra-light-weight proppant:
Uniform placement along fracture

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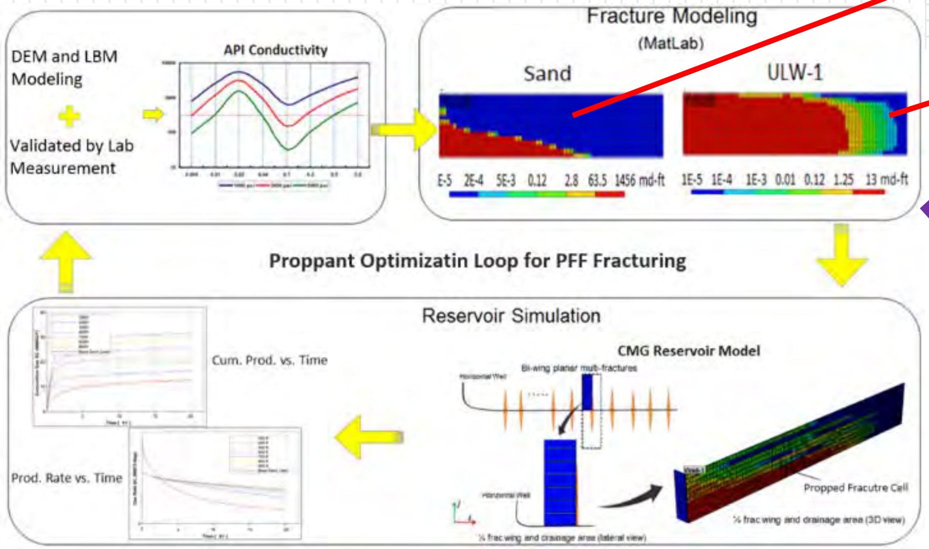
Optimization of Fracturing and Proppant Placement



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

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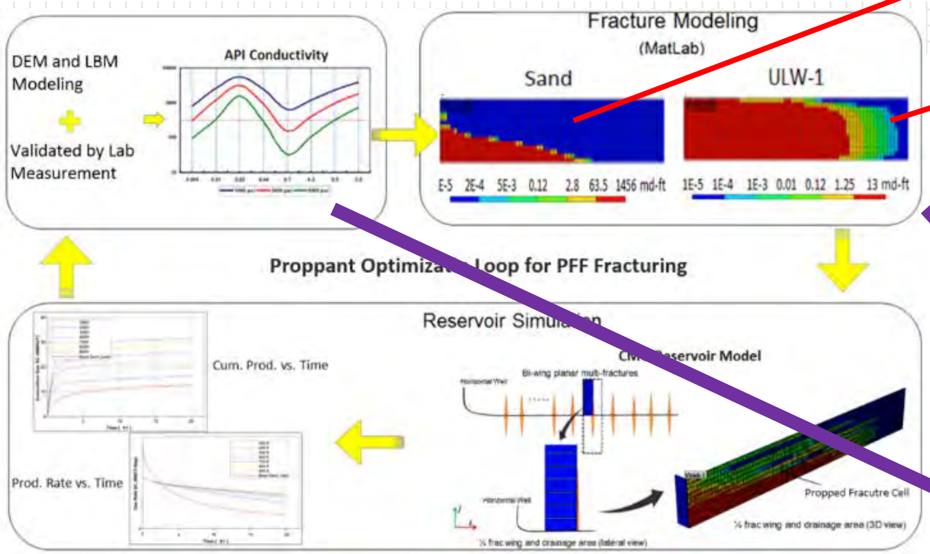
Optimization of Fracturing and Proppant Placement



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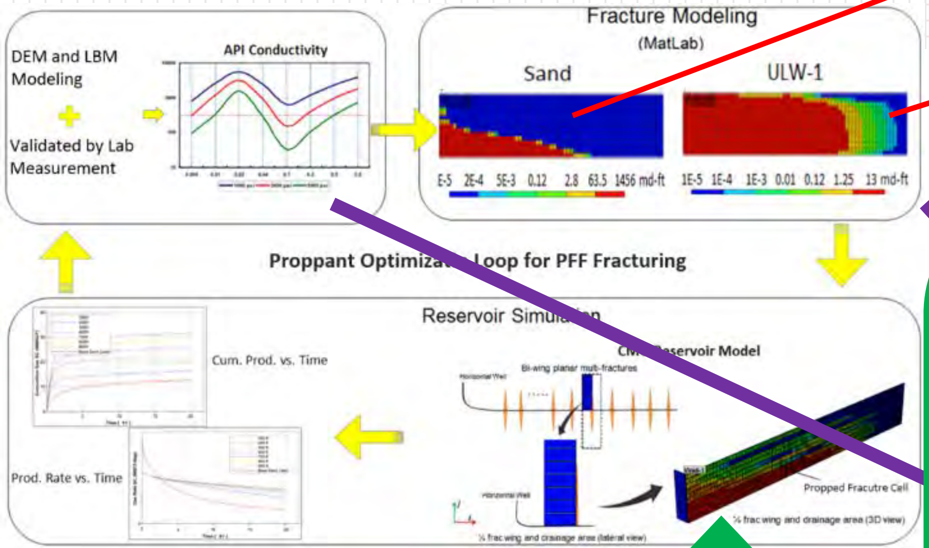
Pore-scale, DEM/LB-coupled modeling gives "*fracture conductivity vs proppant concentration*" curves under various closure pressures (Fan et al., 2018)

Optimization of Fracturing and Proppant Placement



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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)

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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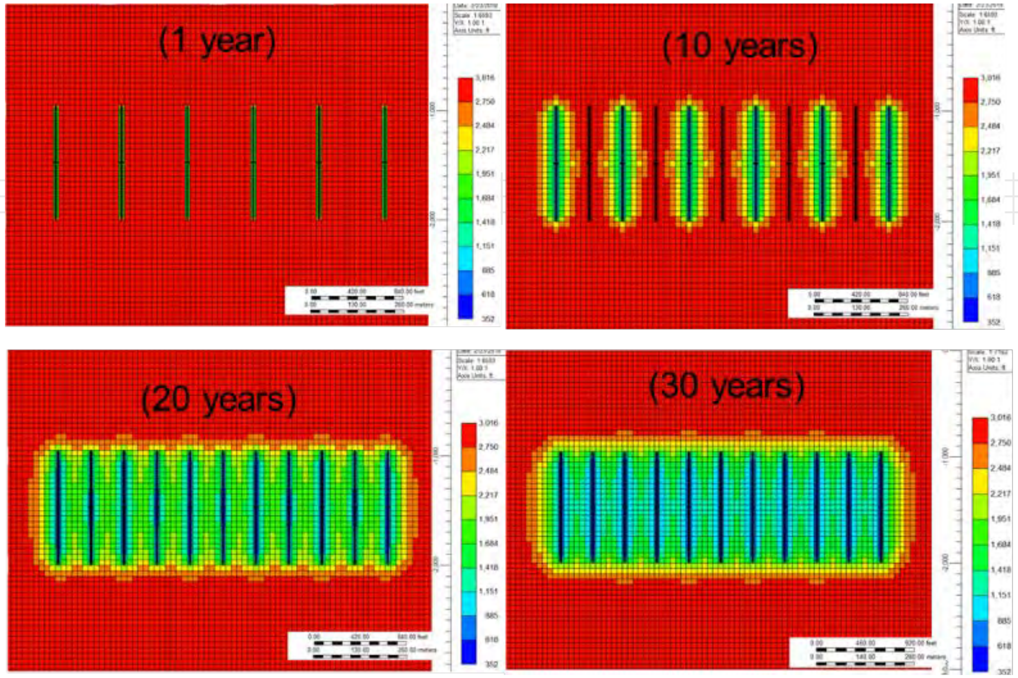
Reservoir Simulation Model

- ❑ 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.

Schlumberger

CMG COMPUTER MODELLING GROUP LTD.

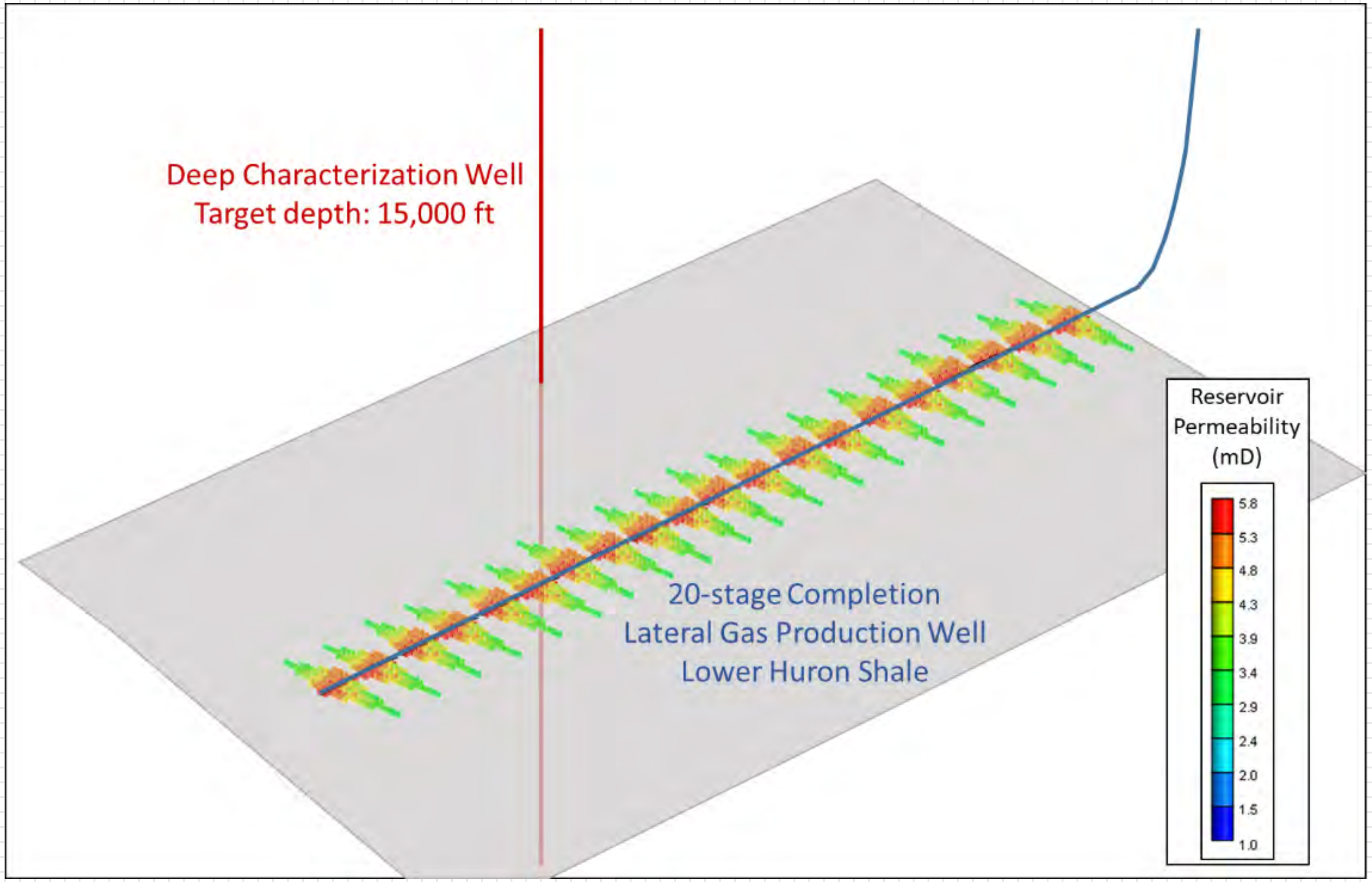
- ❑ The in-house simulation model includes diffusion and nano-porous media confinement effects, and that can simulate reservoir response to hydraulic fracturing with non-aqueous fluids such as CO_2.

- ❑ Fast, yet accurate, compositionally-extended black oil models will be developed that can incorporate the complexities associated with shale reservoirs during treatment and production.

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

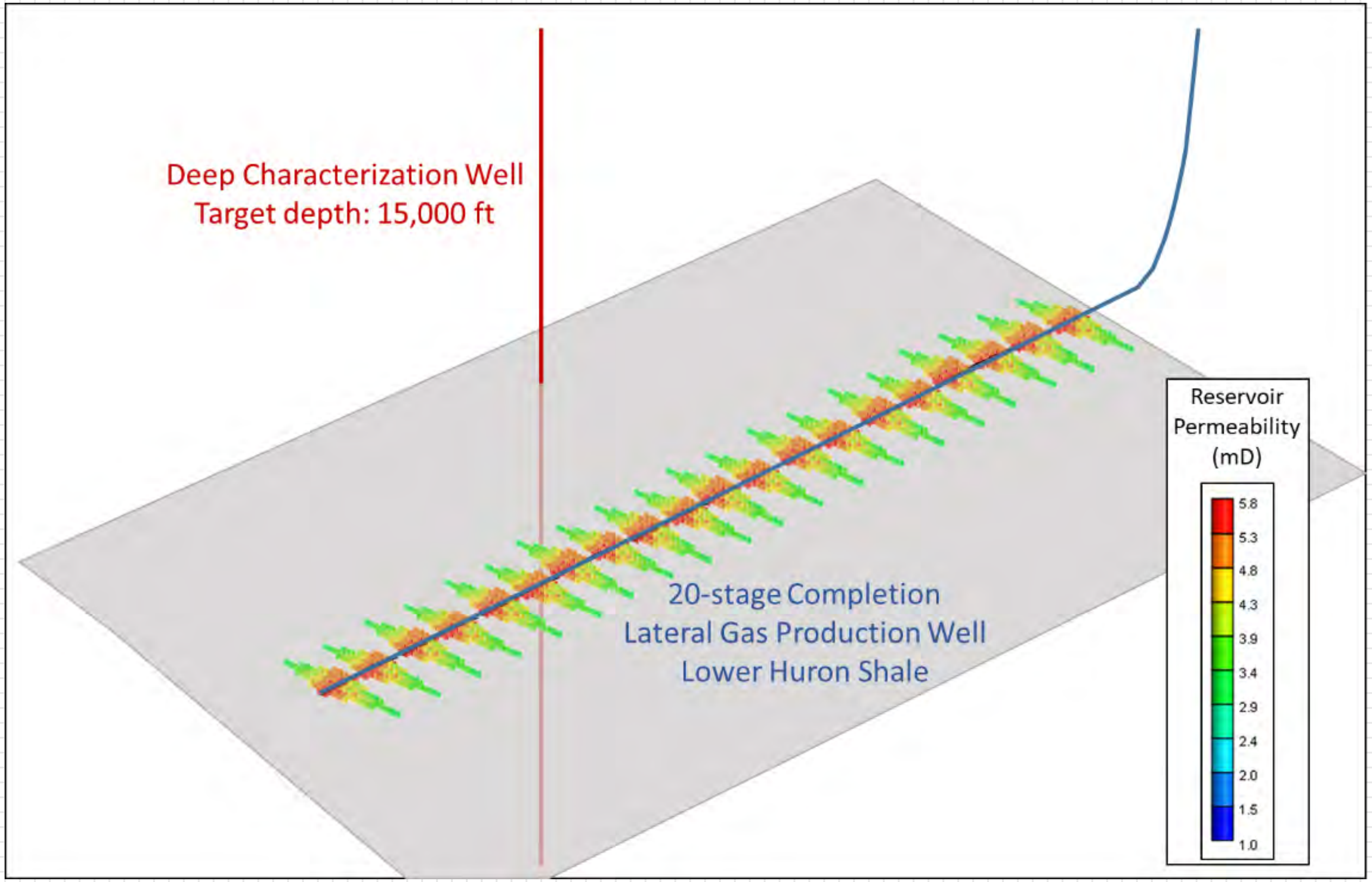
Schematic Overview of ESUP Field Lab



Monitoring Program

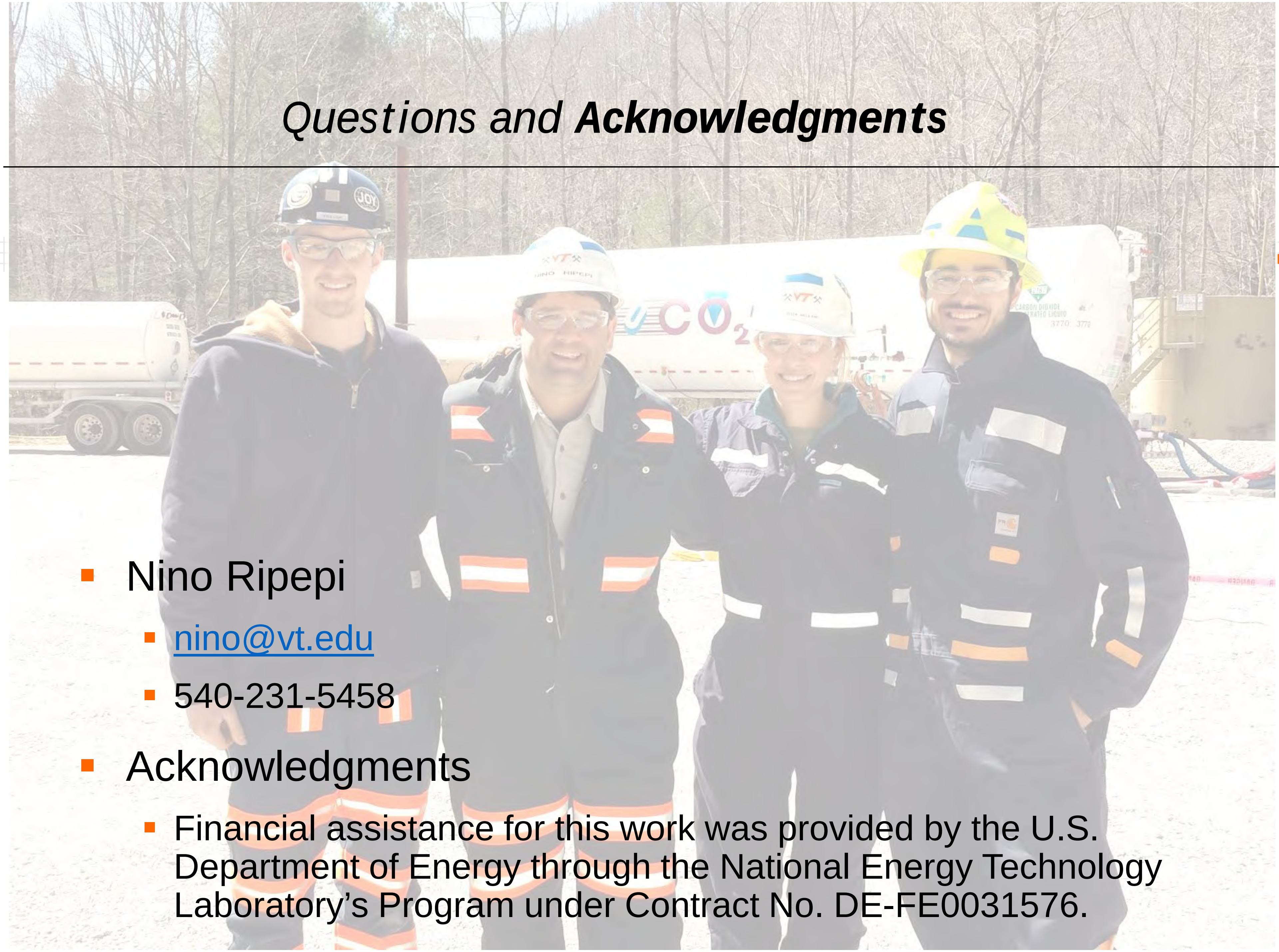
- Potential Methods: Atmospheric, Near-surface, Subsurface, Sub-reservoir Technologies
  - Offset gas and water sampling
  - Tracer studies
  - Reservoir imaging (e.g., microseismic monitoring and DAS)
  - Deep monitoring installation in Deformation monitoring
  - Production monitoring

Schematic Overview of ESUP Field Lab



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

VIRGINIA TECH



*Questions and **Acknowledgments***

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