Unlocking the Tight Oil Reservoirs of the Powder River Basin, Wyoming

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U.S. Department of Energy

National Energy Technology Laboratory
Resource Sustainability Project Review Meeting
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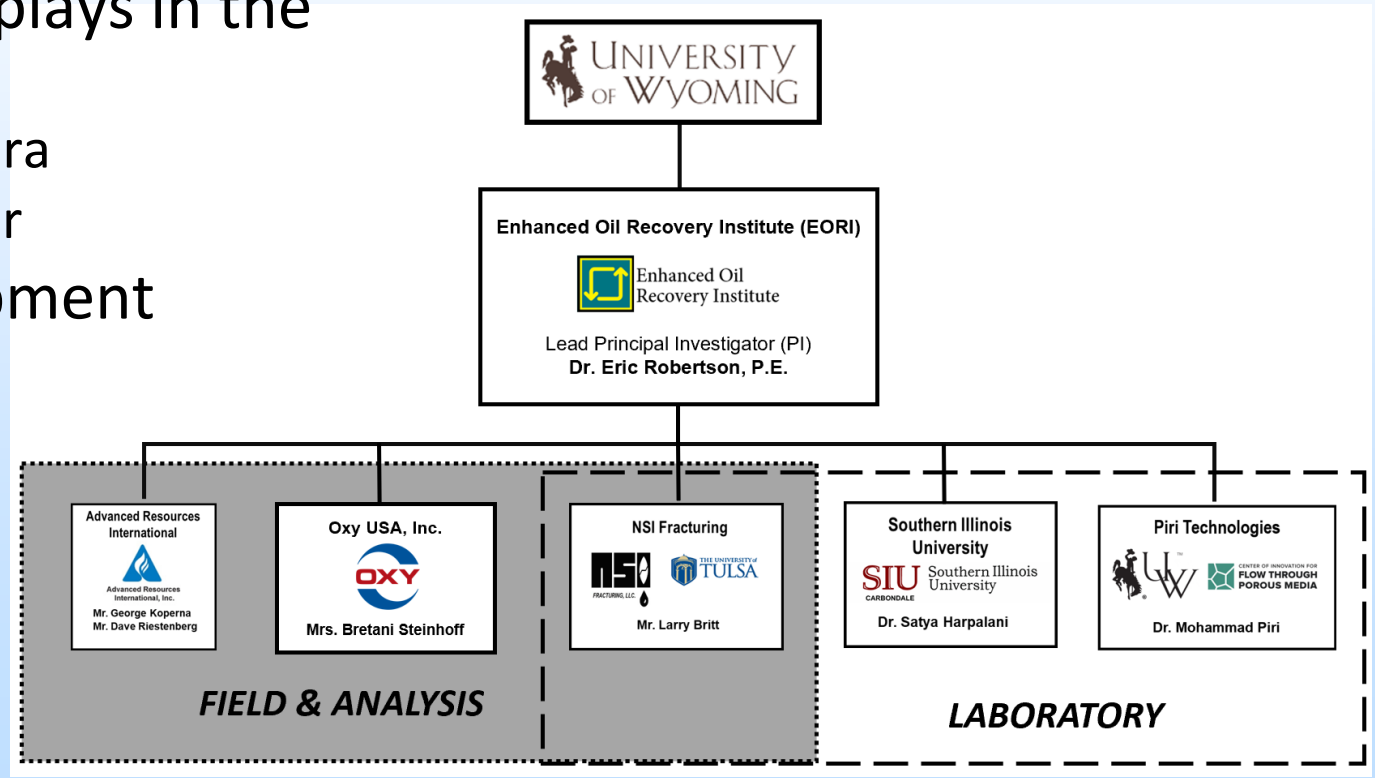
Project Funding and Dates

- Project Funding: Total of $14,898,759 for 4-year project
  - $7,833,908 in Federal
  - $7,064,850 in Industry cost share (47.42%)
- Important Project Dates
  - Project kicked-off in October 2019
  - 1-yr, no-cost extension granted in July 2020
  - Asking for an additional NCE to finish out the work and reports
    - Projected completion of the project is July 2025

Project Objectives and Participants

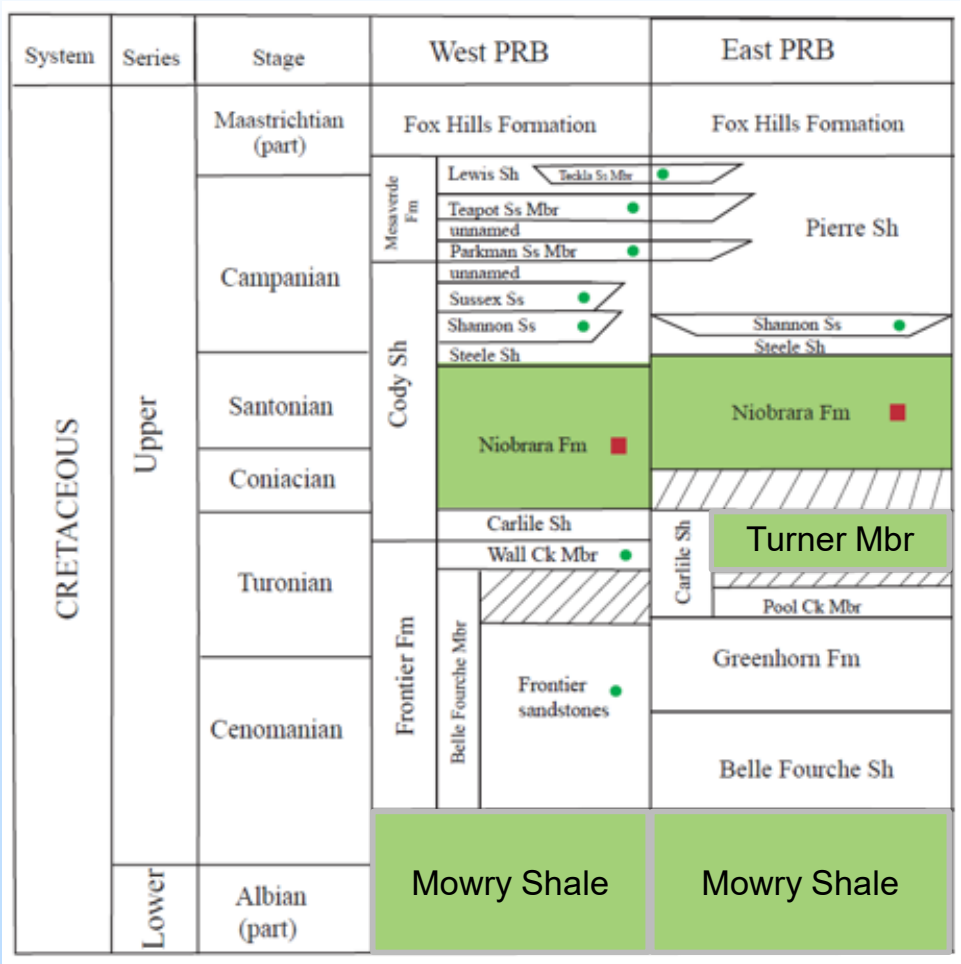
- Overall Project Objectives
  - Establish field laboratory to study emerging unconventional plays in the Powder River Basin
    - Shale plays: Mowry, Niobrara
    - Tight sands: Turner/Frontier
  - Create basin-wide development strategy plan
- Project Participants

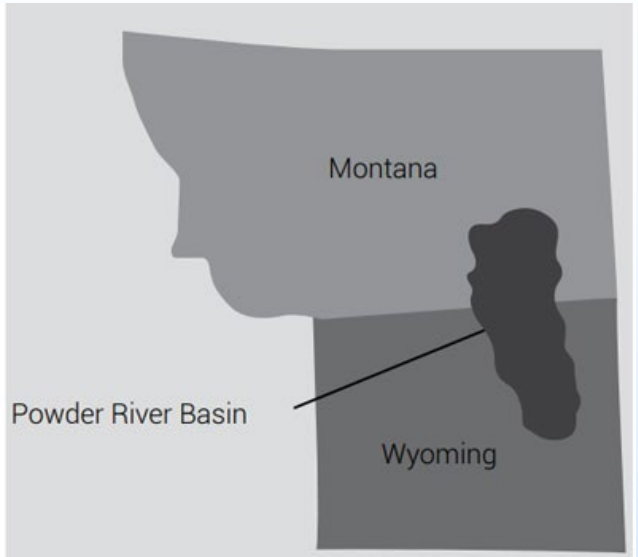


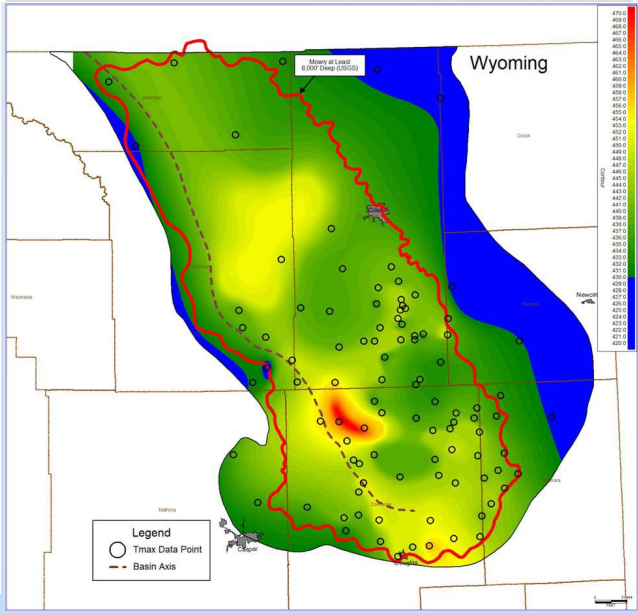
Size of the Prize – Southern Powder Tight Reservoirs

- Mowry has expelled roughly 11.9 billion barrels of oil
- Mean estimates of technically recoverable undiscovered continuous resource
  - Mowry: 198 million bbl, 198 Bcf, and 11.9 million bbl NGL*
  - Niobrara: 227 million bbl, 227 Bcf, and 13.6 million bbl NGL*

Stratigraphic Column



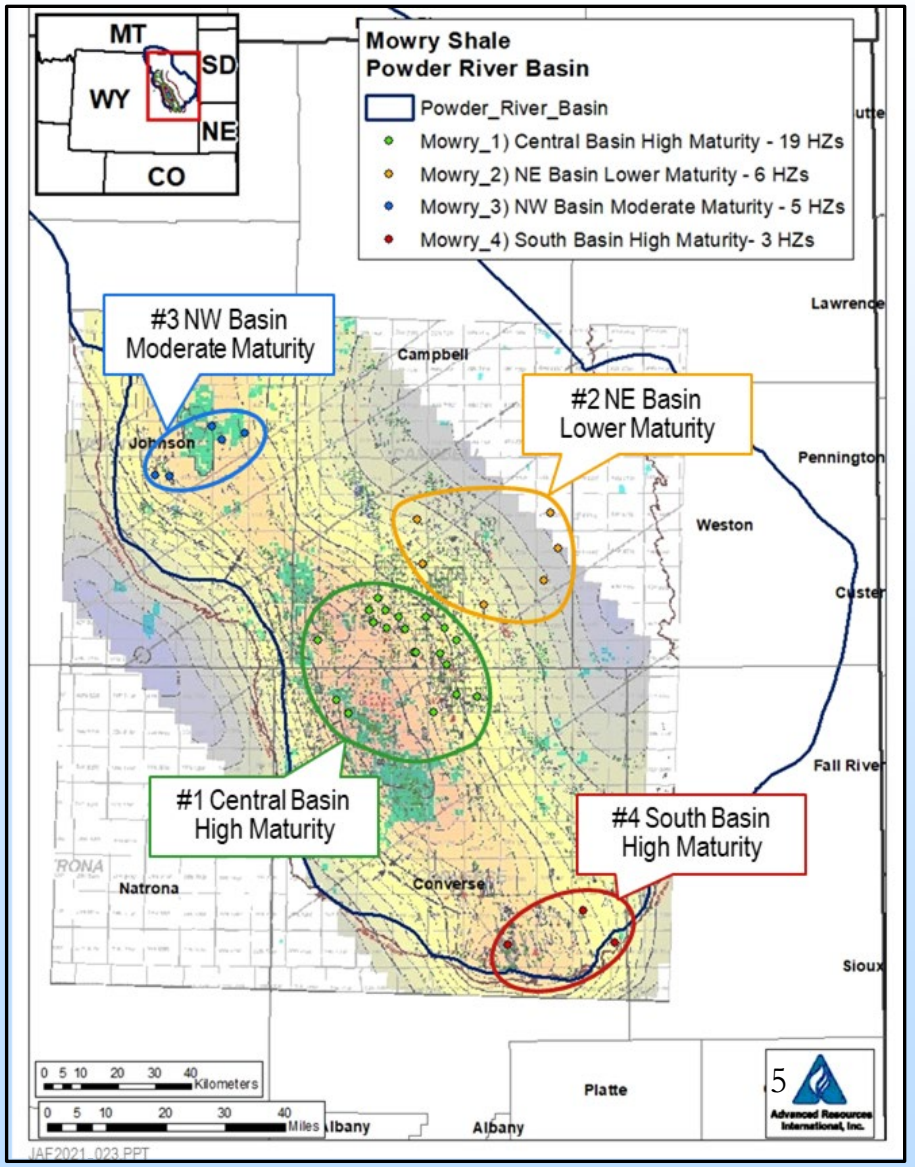




* Lawrence O. Anna and Troy A. Cook, 2008, "Assessment of the Mowry Shale and Niobrara Formation as Continuous Hydrocarbon Systems, Powder River Basin, Montana and Wyoming,"

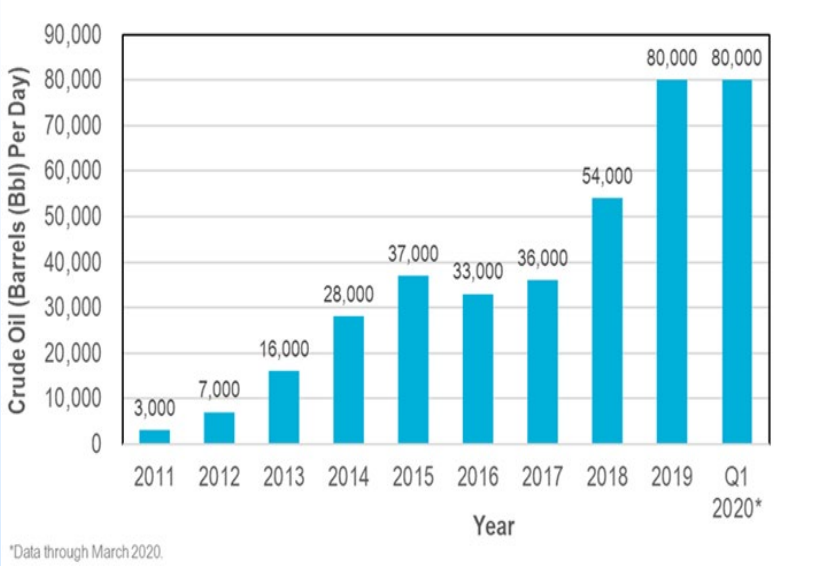
Background – PRB Unconventional Plays

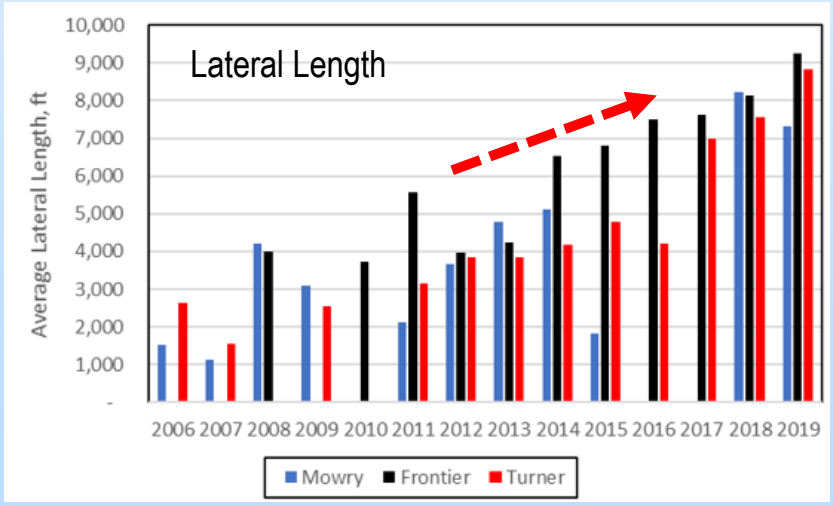
- Development of unconventional production in the Powder River Basin has lagged the Permian and other basins
- Identify difficulties with geology and the rock that might impact development of the Mowry, Turner, and Niobrara emerging plays

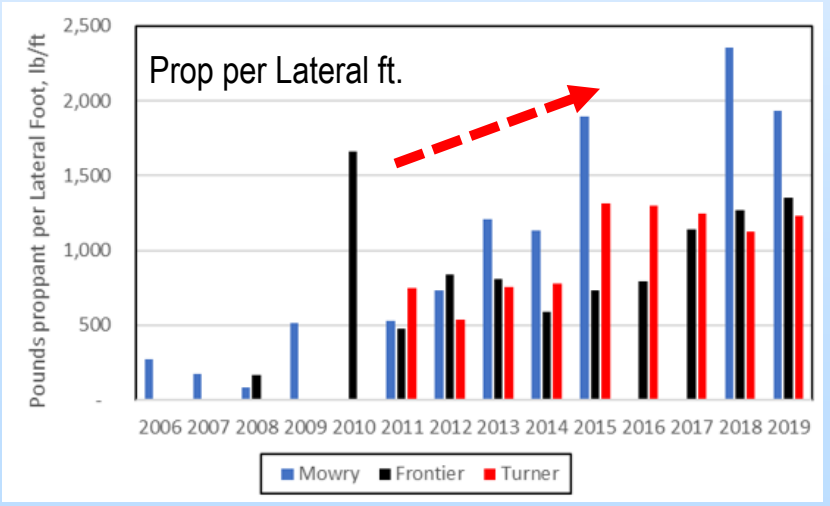


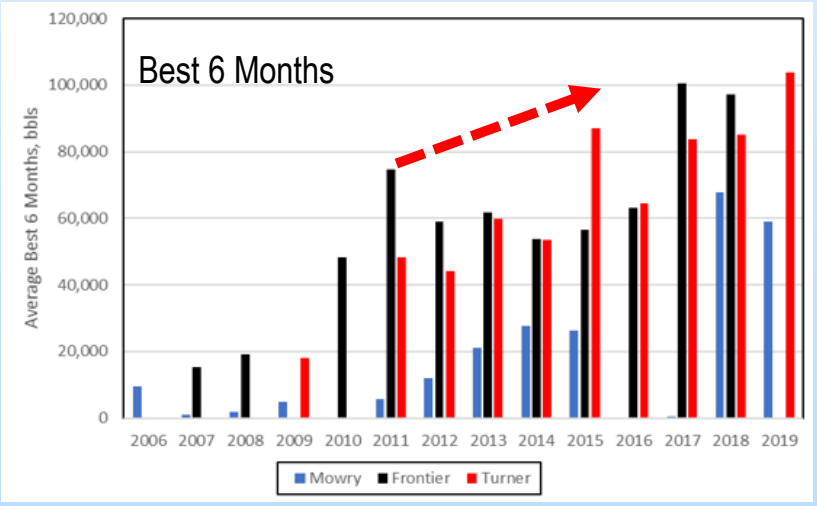
Background – Well Completion Trends

- Crude oil production from the Powder River Basin's tight oil formations has grown rapidly.
  - From 3,000 B/D to over 80,000 B/D in 2019/2020.
  - Turner Formation – 67,000 B/D (2019)
  - Frontier Formation – 10,000 B/D (2019)
  - Mowry Shale – 3,000 B/D (2019)
- From 2006 – 2019, completion and production trends in the PRB indicate increases in average lateral length and proppant per foot made better wells.





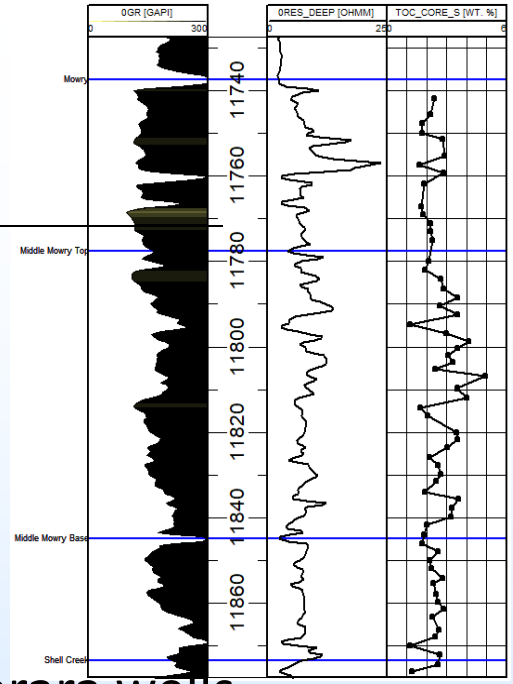




Establishing a Field Laboratory

- Oxy drilled and completed
  - 1 vertical well
  - 2 horizontal Niobrara wells
  - 1 horizontal Turner well
- Collected well logs and cores
  - Oxy donated Turner and Niobrara core
  - Collected 191 ft of Mowry core from vertical pilot hole drilled in Dec 2021 through Jan 2022

Project Scope



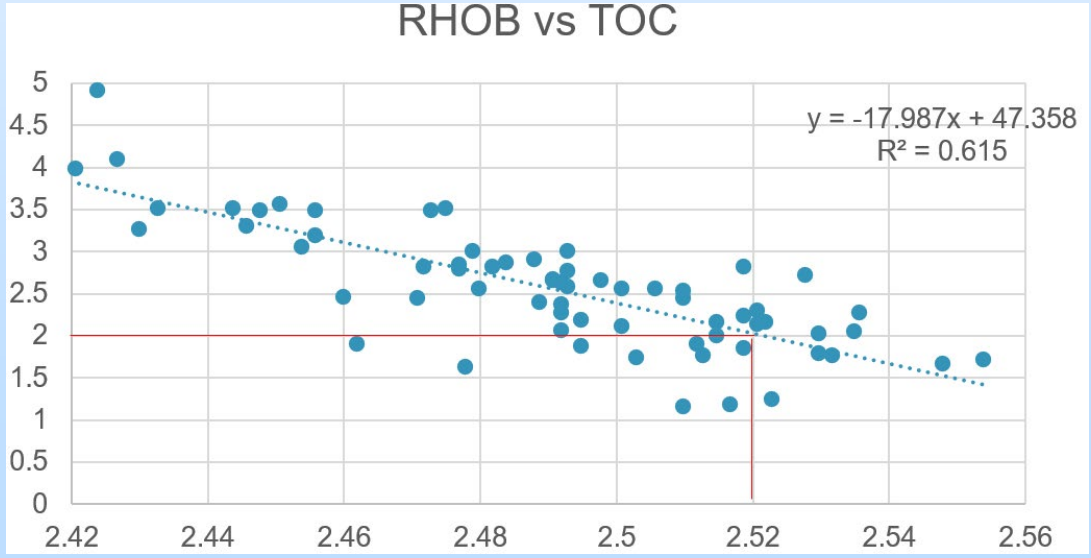
- Start with Field Laboratory area
  - Drill Pilot hole
  - Describe core and geology
  - Core testing (RCA, SCA, Geomechanical testing, flow experiments)
  - Stimulation fluid compatibility testing
  - Install microseismic receivers to monitor completions of Turner and Niobrara wells
  - Install permanent fiber optic cable in Niobrara horizontal well
  - Testing of different completion designs (microseismic and FO cable) using a DoE process
  - Apply learnings to geologic and numerical models
- Then take to regional PRB
  - Understand regional geology
  - Apply learnings and publish results

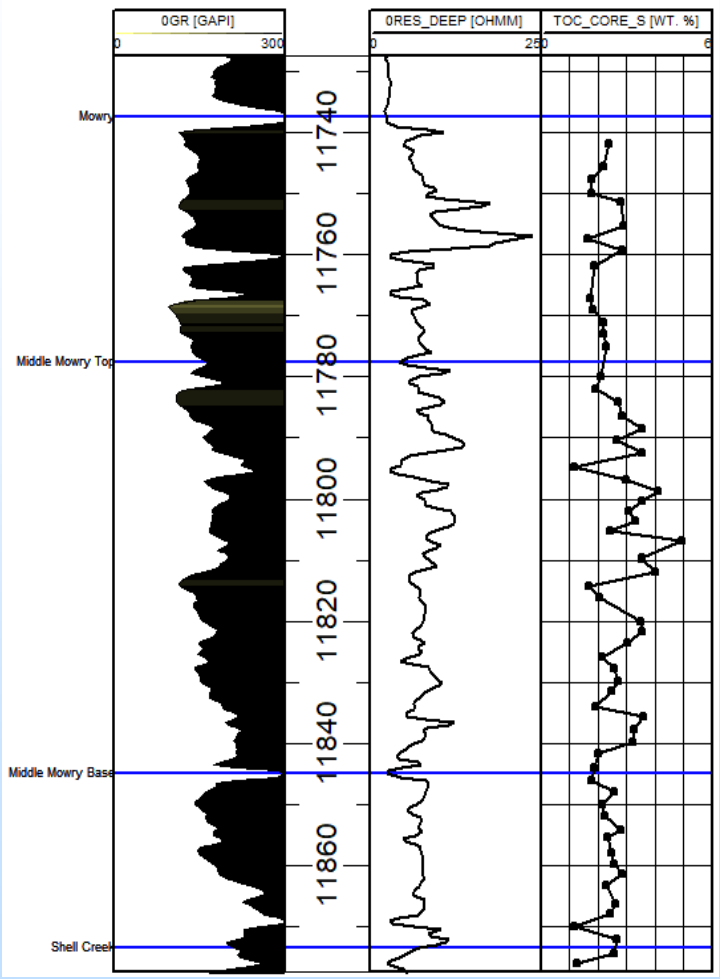
Project Schedule/Status

- Core/Laboratory work is mostly completed
- Geomechanical testing is complete, but finishing up some fracture modeling
- Stimulation fluid / rock interaction testing is complete
- Testing of different completion designs completed
  - Turner monitored using microseismic
  - Niobrara testing using Design of Experiment (DoE) technique
- Numerical modeling of production and completions
  - Initial modeling completed
  - Feedback loop is ongoing and dependent on completion of lab work
- Regional geology mostly completed
- Basin-wide development strategy plan in the works

Accomplishments – Lab Work

- Described core and identified facies
- Mowry: 5 subtidal sheet facies, but largely a homogeneous shale with thick bentonite beds
  - Facies not sensitive to TOC, S_{HC}, or ϕ
  - Middle member has highest average TOC (2.9%) and highest S_{HC}

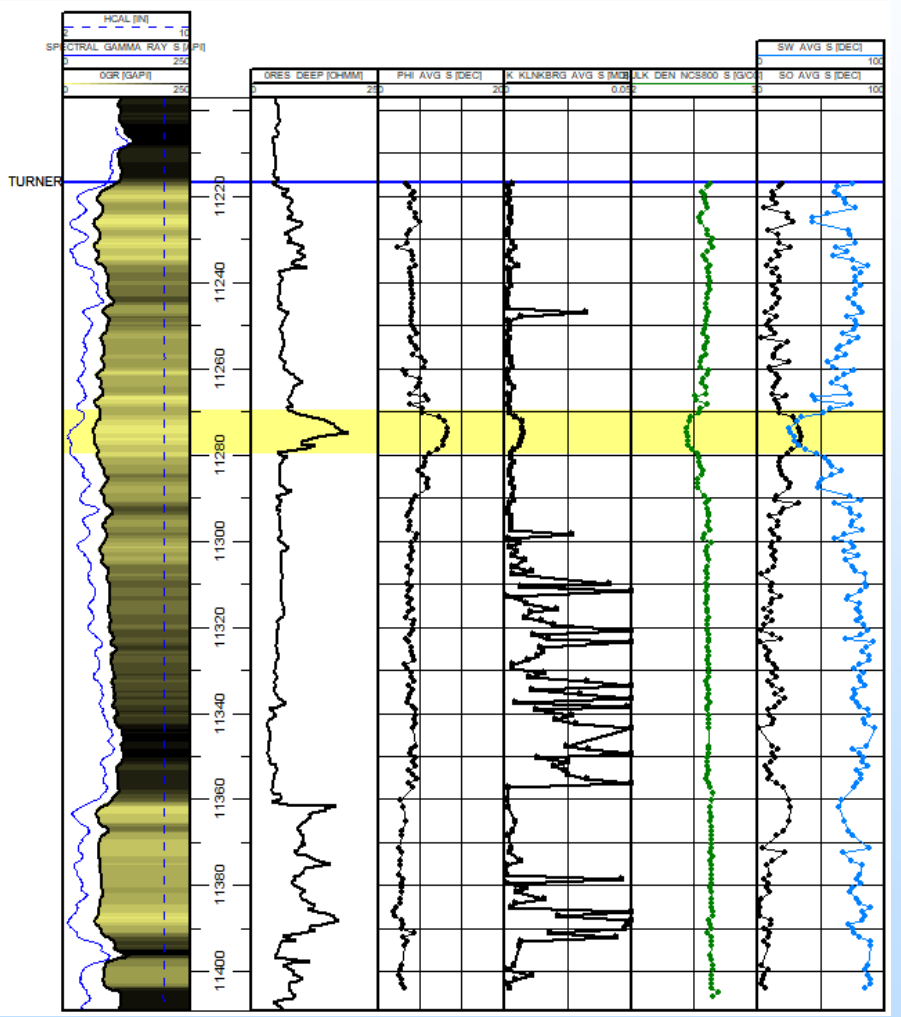


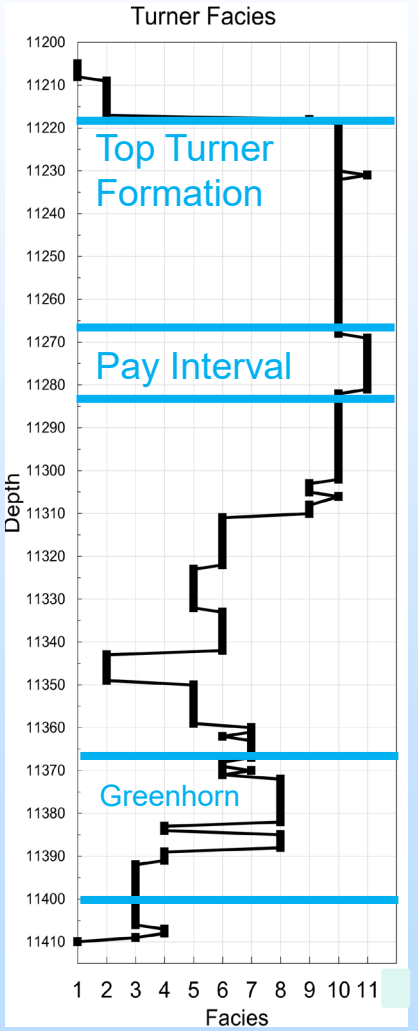


Turner Core and Geologic Model

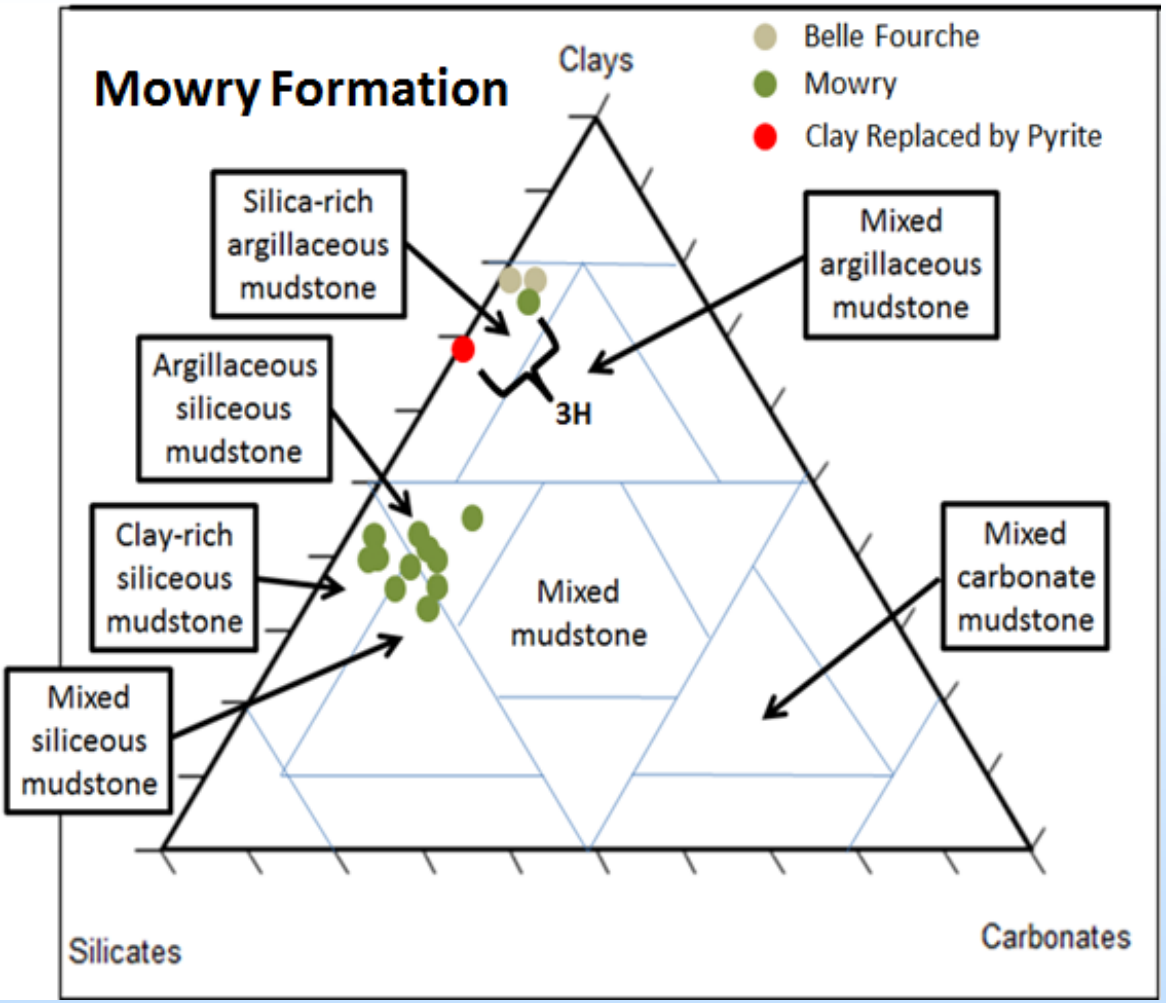
- Described the Turner core
- Assign geologic facies to each foot of core
  - Defined 11 different facies
  - Facies 11 (the clean sandstone) correlates with the interval with higher porosity and higher oil saturation

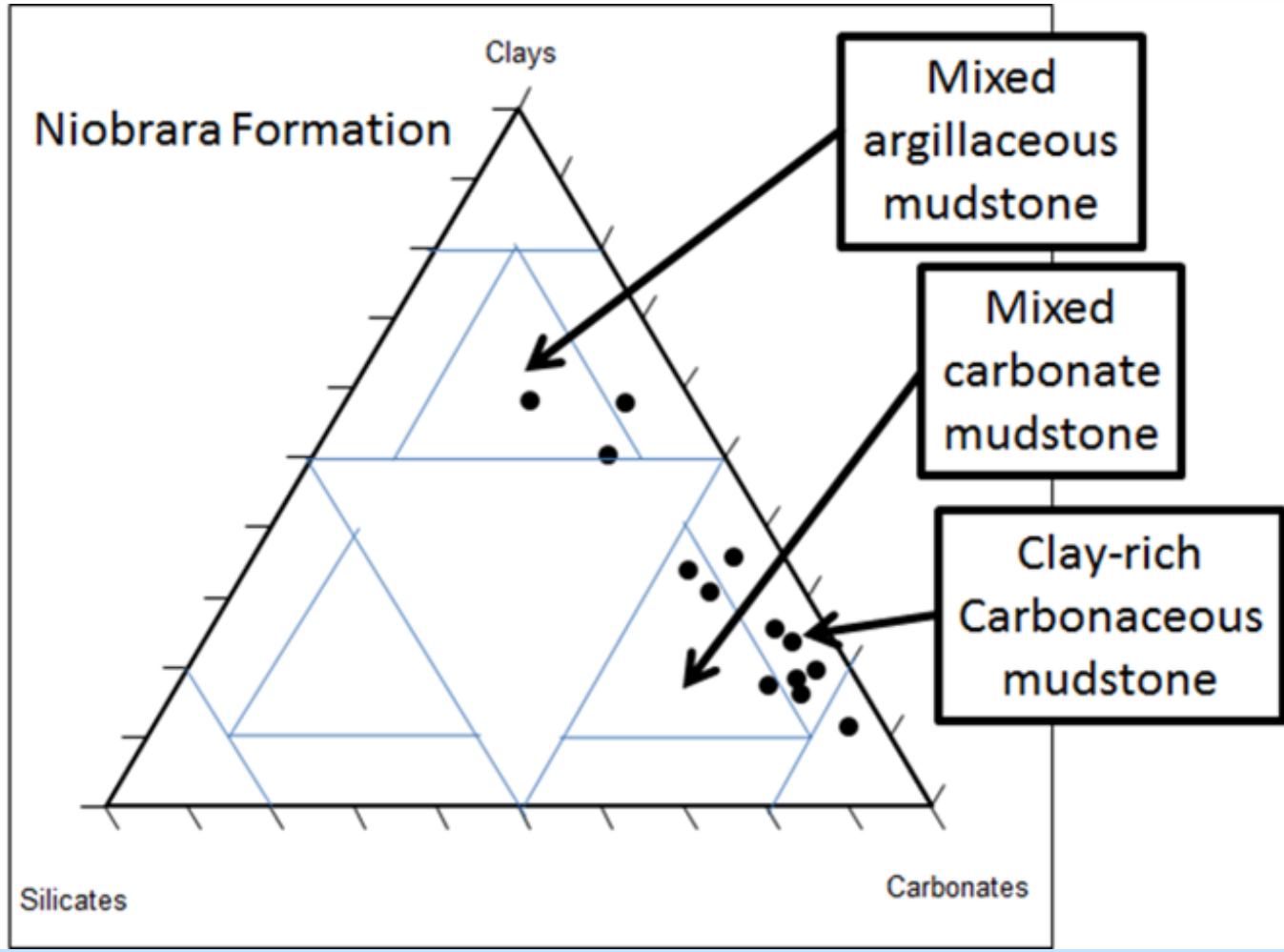
Facies #	Facies Name	Average Bioturbation Level	Frequency (ft)
1	Massive to faintly bedded mudstone	1.6	7
2	Sandy/Silty Mudstone	1.9	16
3	Calcareous Sandy/Silty Mudstone (Limestone)	3.7	16
4	Calcareous Laminated Mudstone, Siltstone, Sandstone (Limestone)	1.9	8
5	Laminated Mudstone, Siltstone, Sandstone	1.7	20
6	Bioturbated Heterolithic Silty/Sandy Mudstone	2.8	27
7	Burrow Mottled Heterolithic Mudstone	3.7	7
8	Bioturbated Heterolithic Calcareous Silty/Sandy Mudstone (Limestone)	3.1	14
9	Bioturbated Argillaceous Sandstone	3.6	8
10	Burrow Mottled Argillaceous Sandstone	3.8	70
11	Clean Sandstone	3.4	14





Mowry & Niobrara Formations: Ternary Diagrams





Nitro Federal 3569-19-T1H

Trinity State 3569-16-T31H

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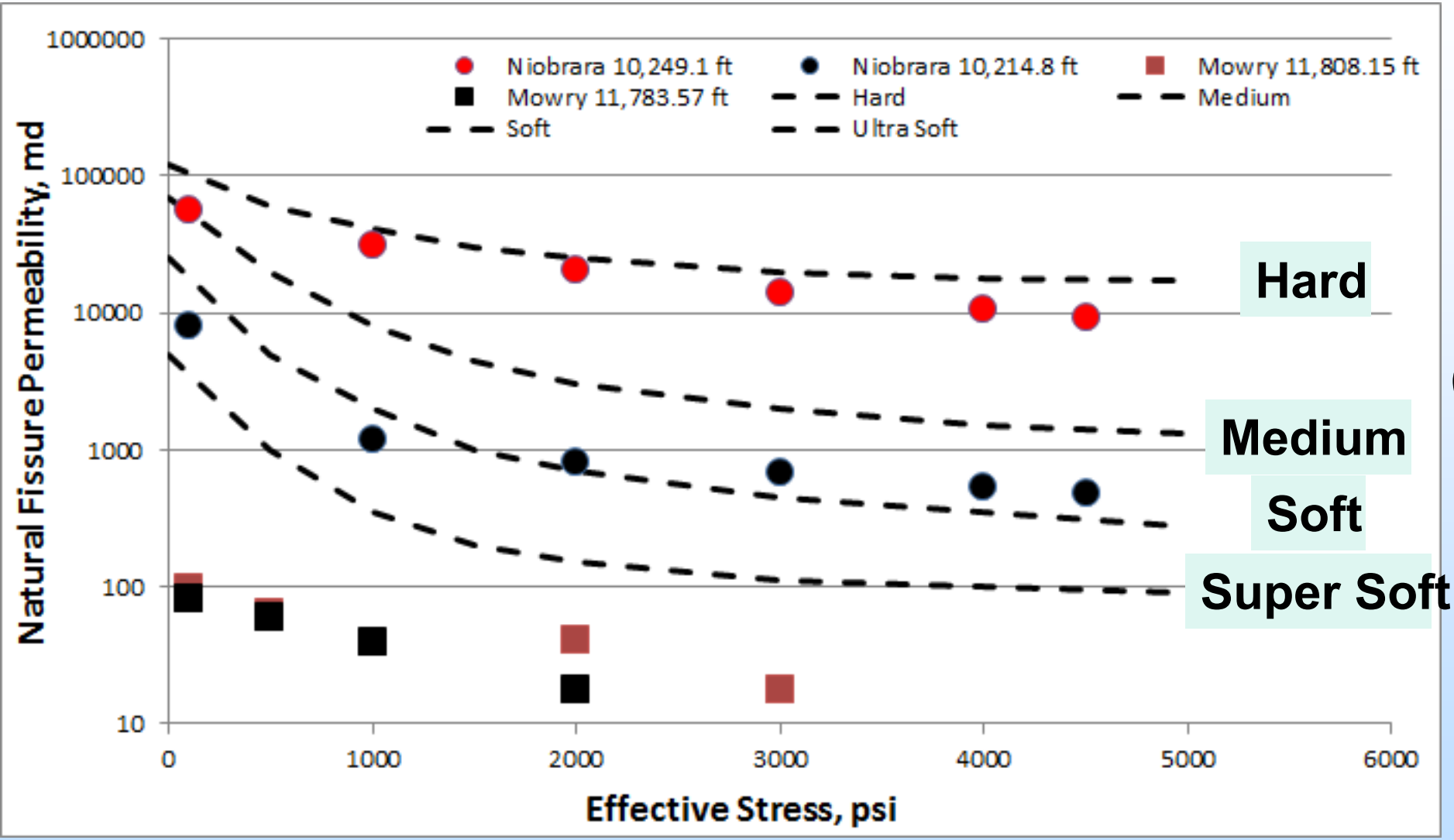
Mowry & Niobrara Formations: Un-Propped Crack Tests



The Niobrara Formation Is A Medium to Hard (i.e, Brittle) Formation

The Mowry Formation Is A Super Soft (i.e, Ductile) Formation

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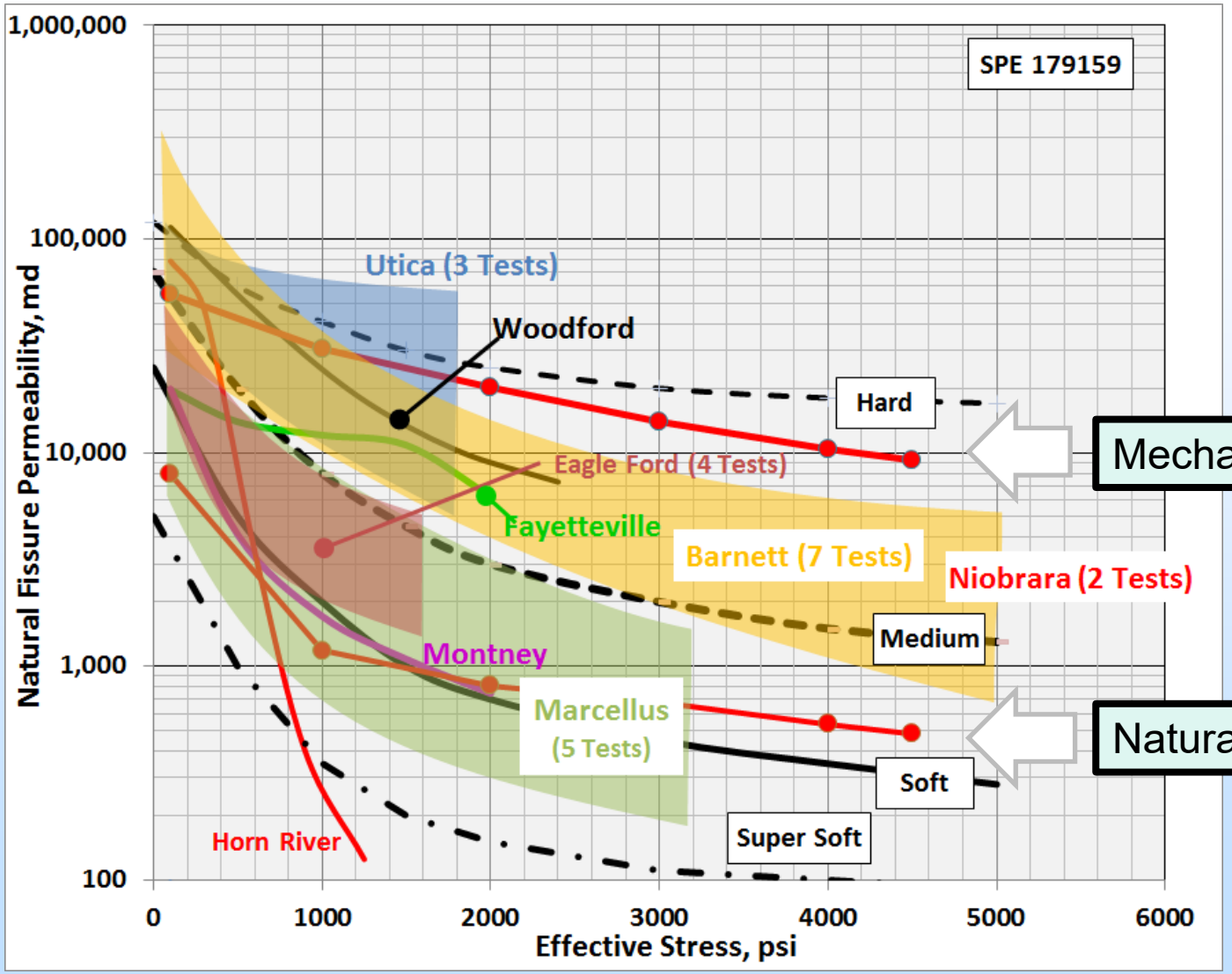
Mowry & Niobrara Formation: Un-Propped Crack Tests



The Niobrara Un-Propped Crack Tests Show The Formation To Be Moderate To Hard (i.e, Brittle) And Comparable To Other Shales

Mechanically Fractured

Naturally Fractured

The Mowry Un-Propped Crack Tests (not shown here) indicates the formation is very ductile

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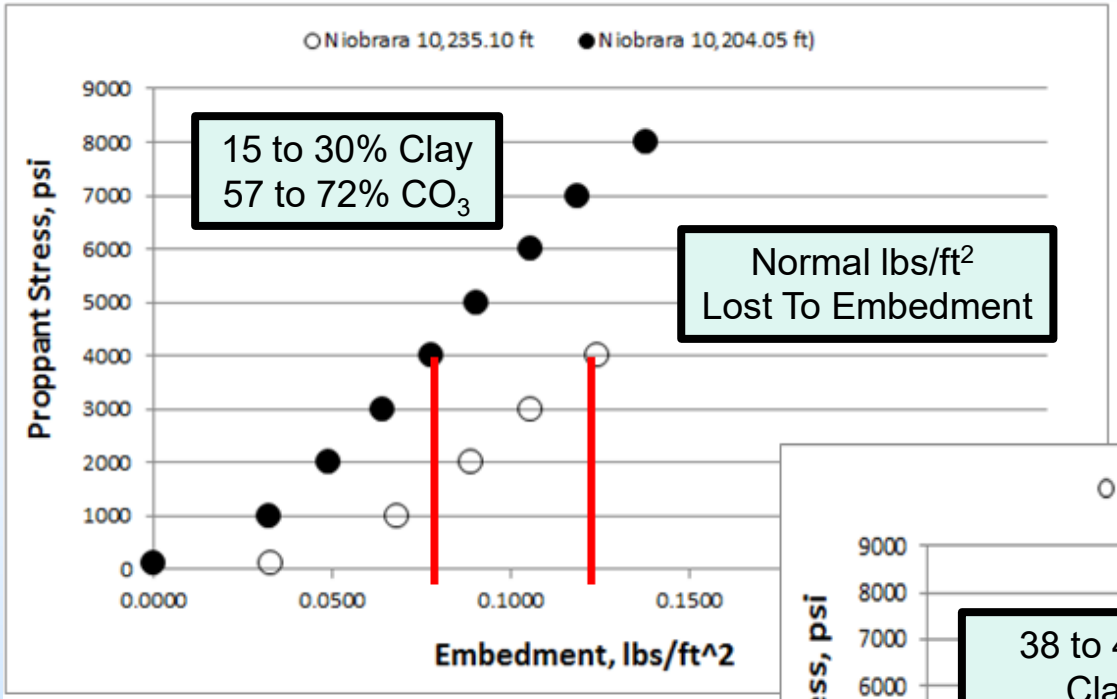
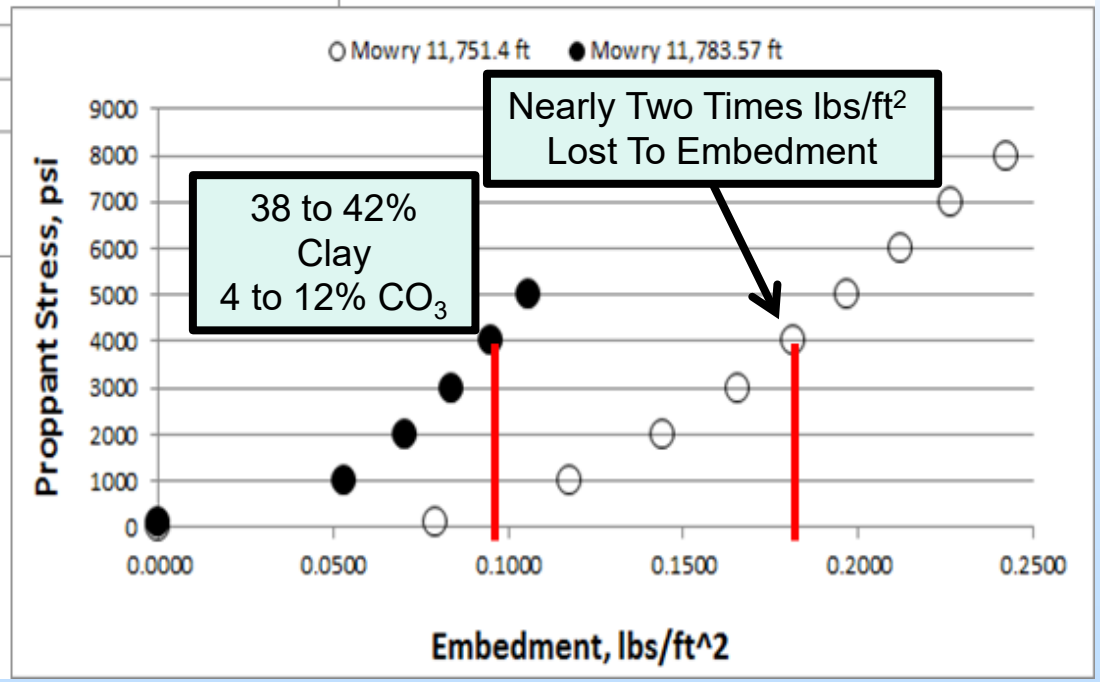
Mowry & Niobrara: Embedment Tests



The Mowry Appears To Be A Better Frac Candidate For Gelled Fluids?

The Niobrara Appears To Be A Good Water-Frac Candidate!



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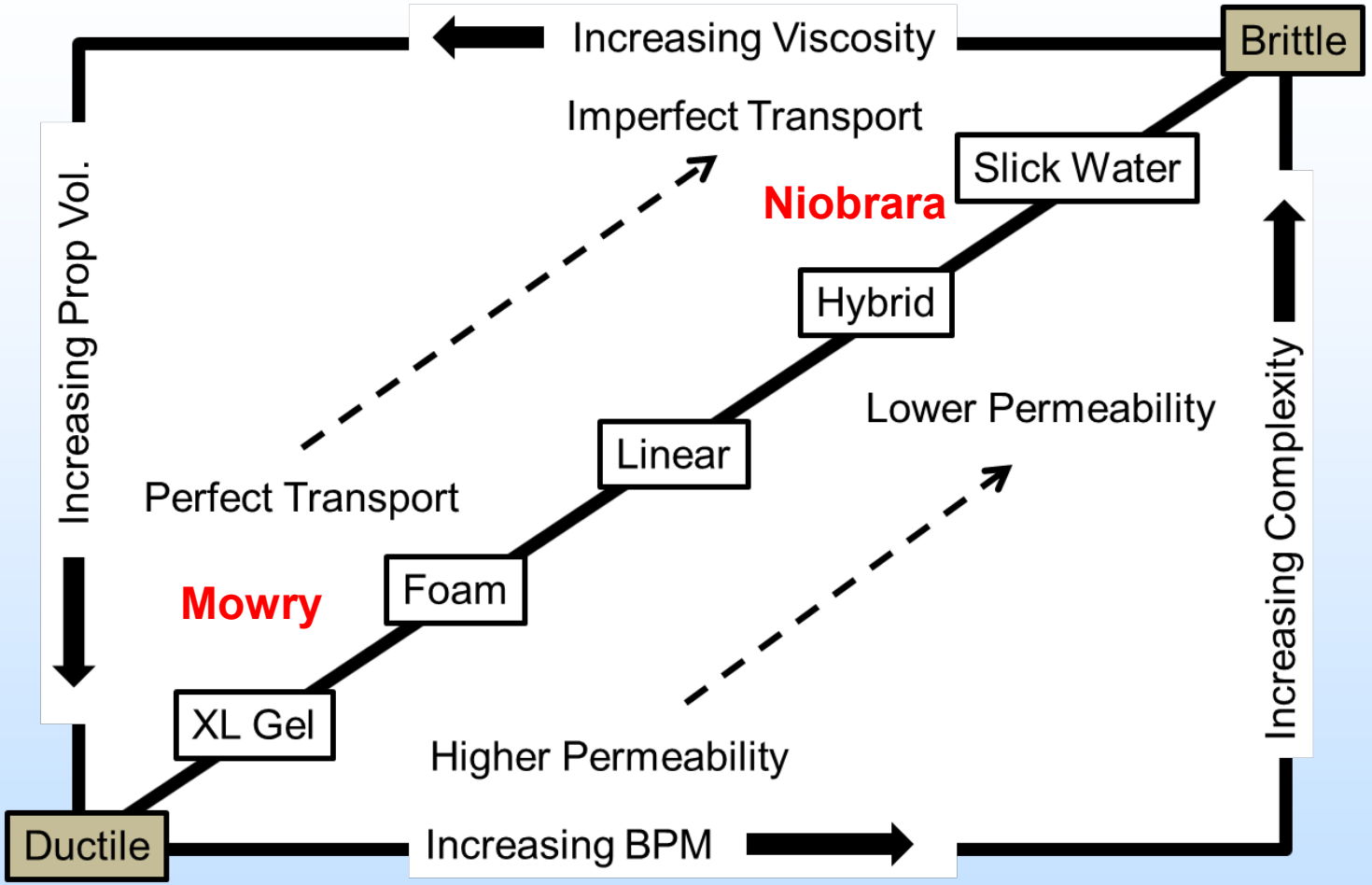
Mowry & Niobrara: Frac Design Schematic



The Niobrara Formation Has A Much Higher Young's Modulus Than The Mowry Formation & Appears More "Brittle" Than The Mowry Formation!

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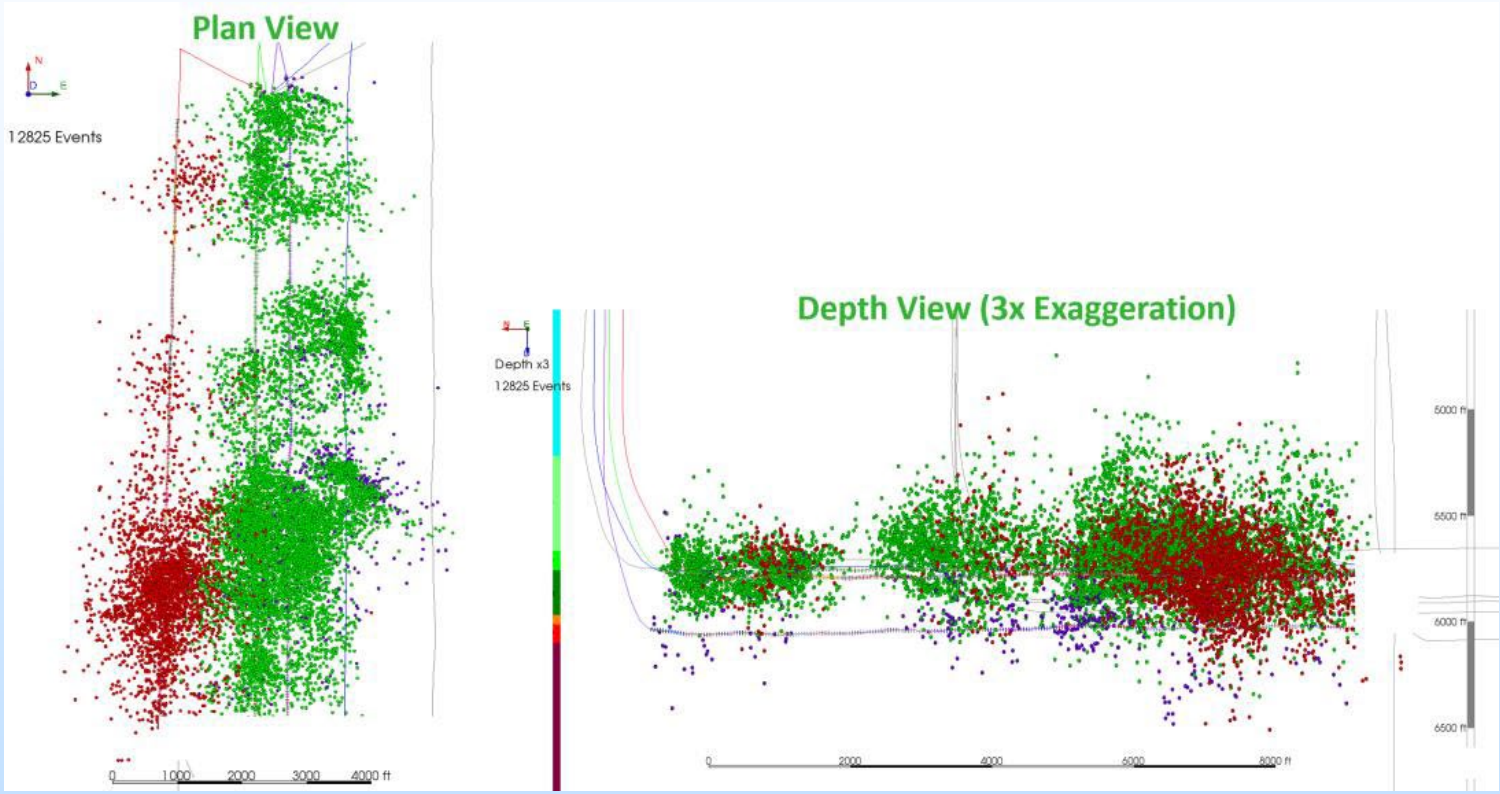
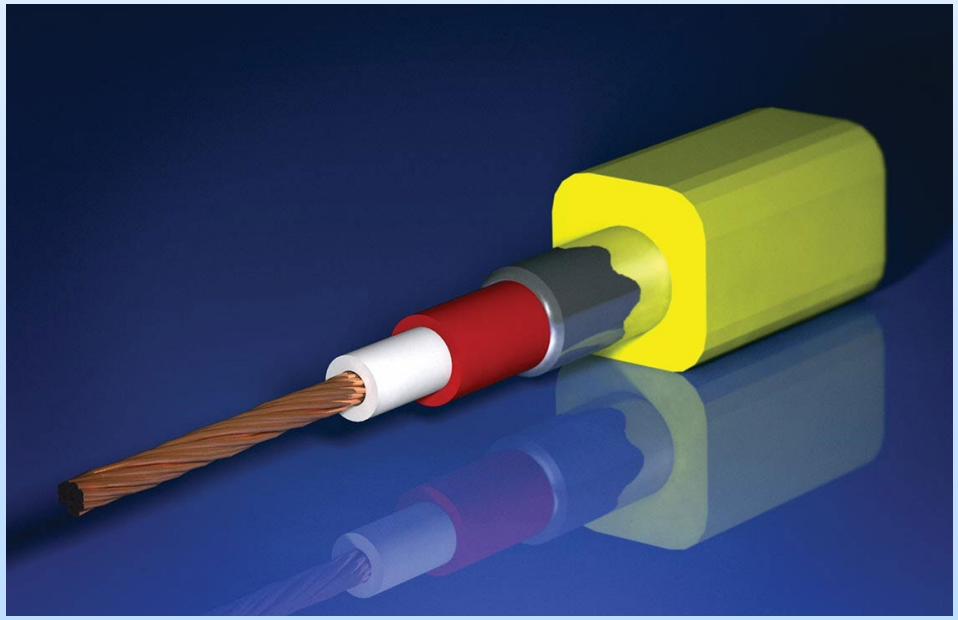
MicroSeismic Monitoring of Turner and Nio Completions

- Define the stimulated reservoir volume dimensions
  - Is there room to increase well spacing in DSU?
- Identify asymmetric fracture growth – both vertically and horizontally
- Identify interaction between faults and hydraulic fractures
- Identify potential communication between the Turner and the overlying Niobrara through the thin Sage Breaks Shale

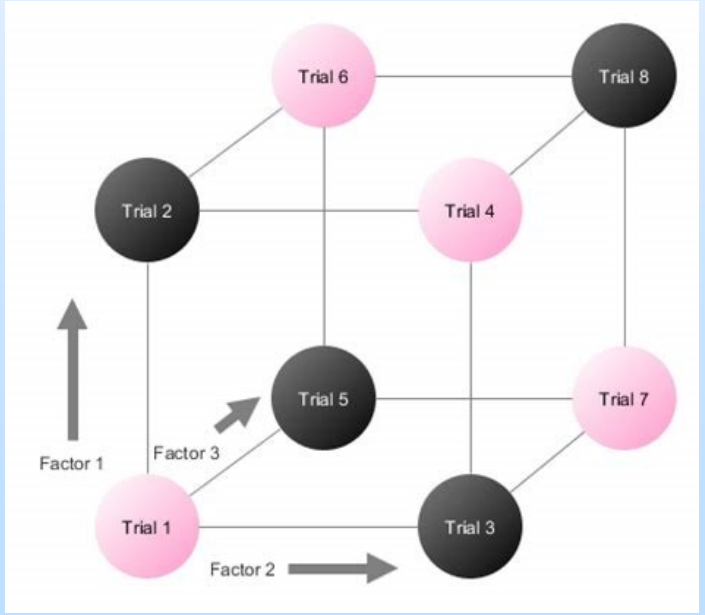


Stage-Level Completions Data

- Fiber optic cable permanently placed in 10,000-ft Niobrara lateral
- Design of Experiments (DoE) to optimize stage parameters



Courtesy of Schlumberger



Key Learnings from DoE on Niobrara Well

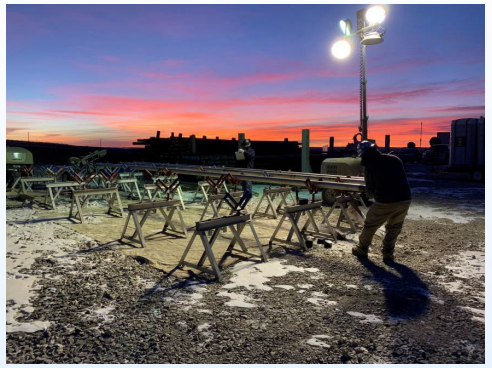
- The DoE tested 7 completion designs, uniformly repeated across horizontal length of well
  - Variables: stage length, clusters/stage, perfs/cluster, perf diameter, proppant/stage

Completion Parameter	M	A	C	D	G	H	I
Treatment Rate (bpm)	96	96	96	96	96	96	96
Clusters per Stage (#)	6	8	10	10	12	12	13
Cluster Spacing (ft)	31.25	31.25	31.25	31.25	31.25	31.25	31.25
Stage Length (ft)	188	250	313	313	375	375	406
Perfs per Cluster (#)	4	3	3	1	2	1	2
Perfs per Stage (#)	24	24	30	10	24	12	26
Perf Diameter (in)	0.45	0.45	0.45	0.62	0.45	0.62	0.45
Perf Scheme	Geometric	Geometric	Geometric	Geometric	Geometric	Geometric	Geometric
Proppant per Foot (ppf)	2,250	2,250	2,250	2,250	2,250	2,250	2,250
Proppant per Stage (lbm)	421,875	562,500	703,125	703,125	843,750	843,750	914,063
Proppant per Cluster (lbm/cluster)	70,313	70,313	70,313	70,313	70,313	70,313	70,313
Fluid per Foot (bpf)	45	45	45	45	45	45	45
Fluid per Stage (bbl)	8,438	11,250	14,063	14,063	16,875	16,875	18,281
Fluid per Cluster (bbl/cluster)	1,406	1,406	1,406	1,406	1,406	1,406	1,406
Rate per Cluster (bpm/cluster)	16.0	12.0	9.6	9.6	8.0	8.0	7.4
Rate per Perf (bpm/perf)	4.0	4.0	3.2	9.6	4.0	8.0	3.7
Initial Perf Friction (psi)	2,140	2,140	1,370	3,421	2,140	2,375	1,823
Target Stage Count (#)	5	5	5	5	5	4	4

- Focused on stages that optimized the Stimulation Distribution Effectiveness (SDE) based on a previous project funded by DOE (HFTS-2)
- Fiber installed all they way to end of 10,000-ft lateral with only one wrap
- This well was easily in the top tier of Oxy's permanent fiber projects

Project Steps and Work Plan

- Completed
  - Current state of the art analysis
  - Drill pilot hole and collect vertical core
  - Complete horizontal wells
    - Complete two wells and monitor with microseismic
    - Drill and install fiber optic cable
    - Complete well according to the DoE and collect production data
    - Reduce and analyze data to optimize future completions
- Ongoing
  - Laboratory testing on Mowry, Turner, and Niobrara core
    - Perm changes with pressure
    - Mechanical properties and modeling
    - Fluid flow properties (matrix and propped fractures)
  - Refine geologic and numerical models
- Future
  - Extrapolate optimized completions model to whole area based on geologic model and core learnings
  - Deliver final report on best practices for well completions in these formations



Key Milestones

- Nov 2019 – Project kickoff
- Sep 2020 – Baseline geology, state of the art, completions database
- Nov 2021 – Oxy joins project
- Jan 2022 – Pilot well completed and Mowry core retrieved
- Jun 2023 – Horizontal wells completed and stimulation data logged
- Jul 2024 – Production modeling and completions optimization
- Sep 2024 – Complete laboratory flow experiments
- Jul 2025 – Project ends with best practices identified and final report submitted

Success Criteria and Risks/Mitigation

- Project success criteria
  - BP1: Selection of the Field Laboratory Site
  - BP2: Collect Logs/Core from Pilot Hole
  - BP3: Completion of Field Lab Horizontal Production Wells and the Field Laboratory Geologic Model
  - BP4: Finalize well completion designs and numerical and economic model. Incorporate all findings and issue a PRB Development Strategy Plan and Upload all data to EDX
- Remaining Project risks and mitigation strategies
  - Very tight matrix properties has stretched the project timeline
  - Mitigated by reducing the data collection (e.g., collect rel perm end points instead of a full curve)

Summary

- Lessons learned
  - Expect setbacks and be ready to pivot, if needed
  - Carefully planned wells drilled with vigilance results in very good Field Laboratory wells
- Future plans
  - Complete the laboratory phase of the work
  - Incorporate learnings from all phases of the project
  - Share results
- “Take-away” message
  - Although expensive, permanent fiber may offer a cheaper, faster way to optimize horizontal well completions
  - Regional geologic modeling combined with well completion optimization offers methodology to apply learnings to the whole southern Powder River Basin

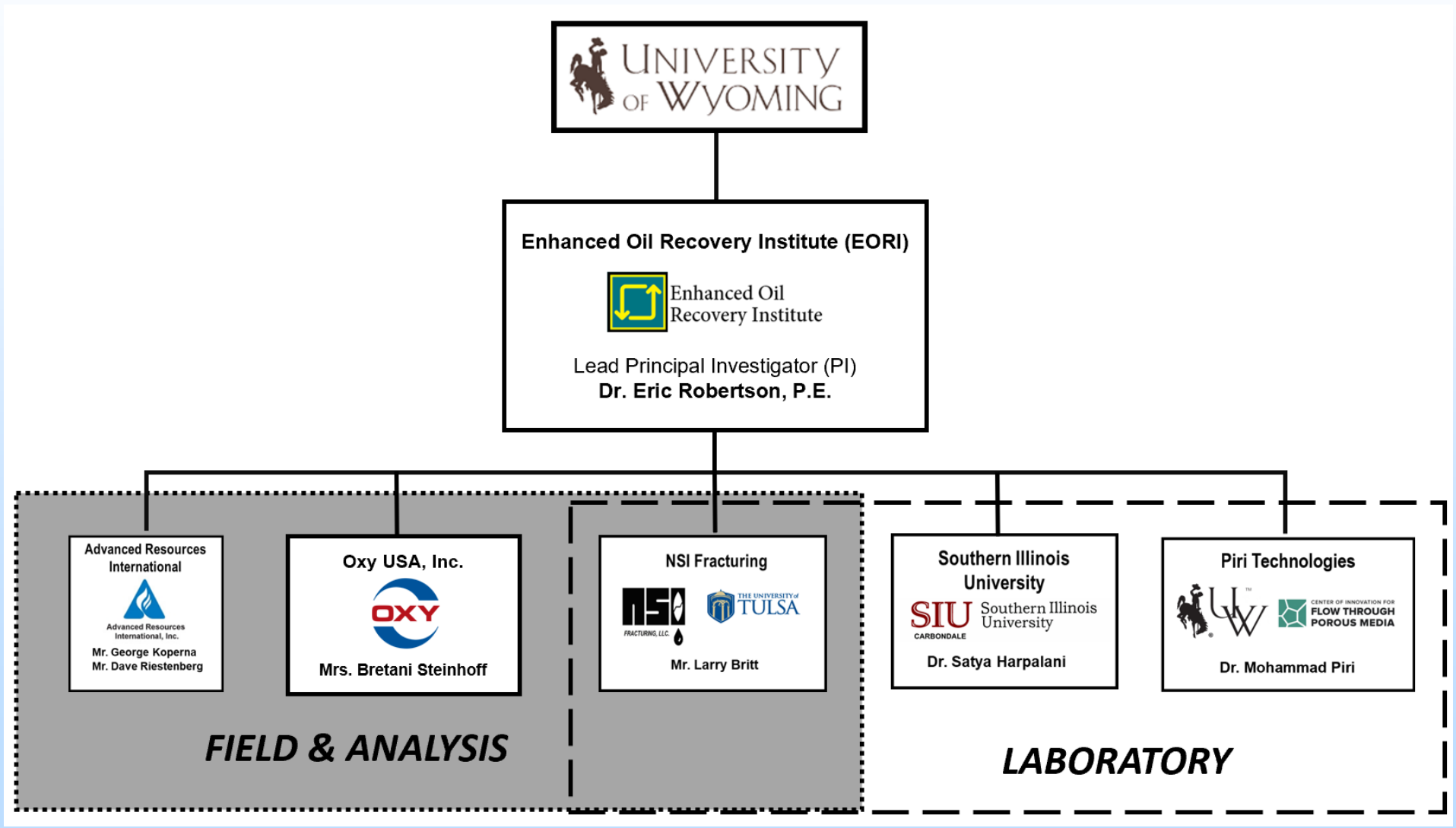
Thank You!

– Thanks to all the partners on this project, but especially to:
  - Oxy
  - All the project team members
  - DOE Project Manager, Eric Smistad
– Time for questions or comments
– Contact:
  - Dr. Eric Robertson, Project P.I.
  - eric.robertson@uwyo.edu

Appendix

– These slides will not be discussed during the presentation but are mandatory.

Organization Chart



Simplified Project Gantt Chart

Task Number	Task Name
1	Project Management & Planning
2	Workforce Readiness Plan
3	Baseline Data Gathering and Models
	Deliverable: PRB SOTA and Field Laboratory Site Selection
4	Develop Work Plans for Field Laboratory
	Deliverable: Pilot Hole Work Plan
	Go/No-Go Decision Point
	Deliverable: Field Laboratory Work Plan
5	Pilot Hole Well Drilling and Data Acquisition
	Deliverable: Pilot Hole Data Collection Summary
6	Laboratory Core Work
	Deliverable: Laboratory and Core Analysis Results
7	Feedback Loop - Geologic and Fracture Mechanics Results
	Deliverable: Site-specific Design Plan Update
8	Production well Drilling, Completion, Stimulation, and Monitoring Results
	Deliverable: Final Well Completion
9	Feedback Loop - Production Data and Advanced Core Analysis
	Deliverable: Final Well Completion and Stimulation Evaluation
10	PRB Development Strategy Plan
	Deliverable: PRB Development Strategy Plan