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Critical Challenges. Practical Solutions.

IDENTIFICATION OF RESIDUAL OIL ZONES (ROZs) IN THE WILLISTON AND POWDER RIVER BASINS

DE-FE0024453

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Energy & Environmental Research Center

U.S. Department of Energy

National Energy Technology Laboratory

Mastering the Subsurface Through Technology Innovation, Partnerships and Collaboration:
Carbon Storage and Oil and Natural Gas Technologies Review Meeting

August 1–3, 2017

Critical Challenges. Practical Solutions.

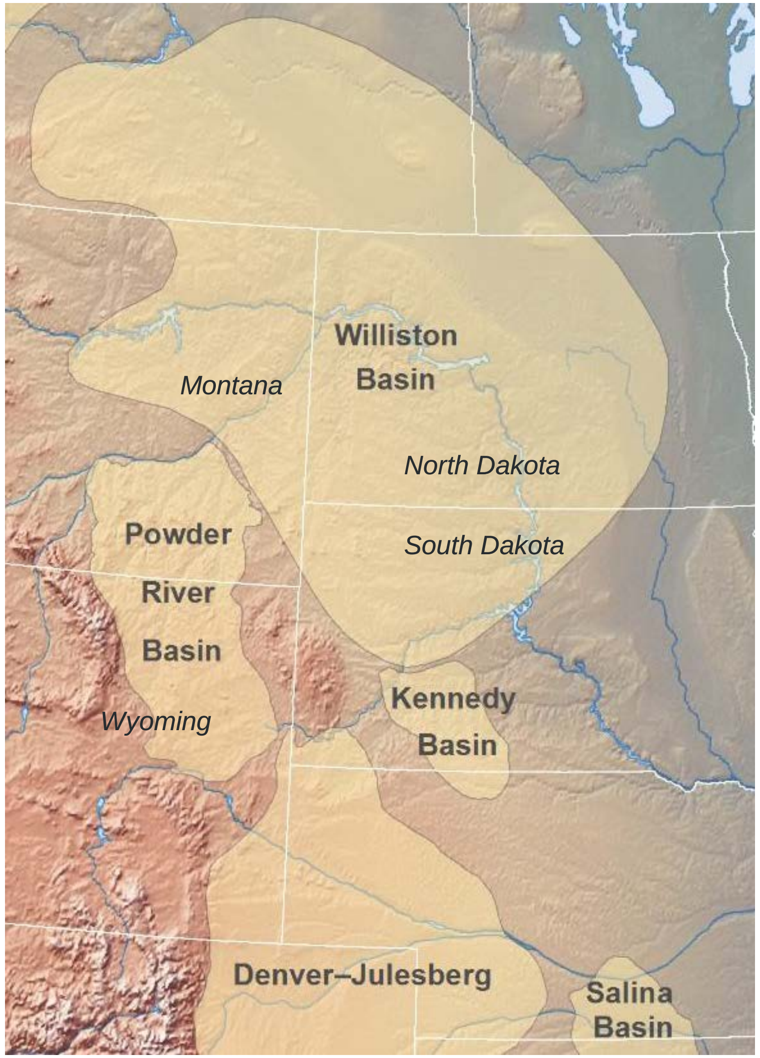
PRESENTATION OUTLINE

- Technical Status
  - ROZ Definition
  - Basin Evolution Modeling
  - ROZ Exploration
    - ♦ PetroMod Saturation
    - ♦ Hydrocarbon Mass History
    - ♦ PetroMod+Sulfur
    - ♦ Structural Surface Transformation Modeling
- Project Summary
- Synergy Opportunities
- Accomplishments to Date
- Appendix

PROJECT OVERVIEW – GOALS AND OBJECTIVES

Objectives:

- Use basin modeling to identify potential for residual oil zones (ROZs) in the Williston and Powder River Basins.
- Estimate residual oil in place and CO_2 storage potential.
- Determine potential for CO_2 enhanced oil recovery (EOR) in identified ROZs.
- Develop repeatable methodology for sedimentary basins to be included in a best practices manual (BPM).

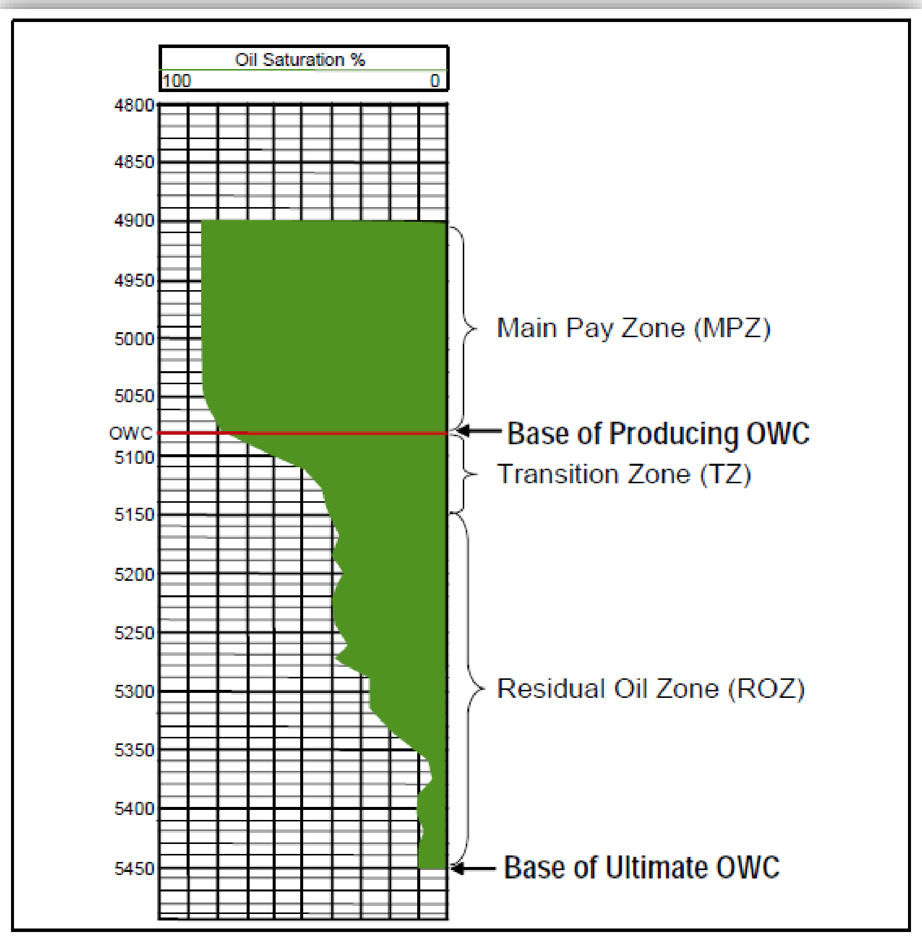


Critical Challenges. Practical Solutions.

WHAT IS A ROZ?

Residual Oil Zones

- “Mother Nature’s waterflood.”
- Oil zones have already been swept:
  - Oil shows but does not produce (20%–40% S_o).
  - Waterflood will not extract additional oil.
  - Skip to tertiary recovery (CO_2 flood).
- We’re looking for ROZs formed under hydrodynamic conditions caused by structural uplift of (primarily) the Big Horn Mountains.
  - Type 3 ROZs.

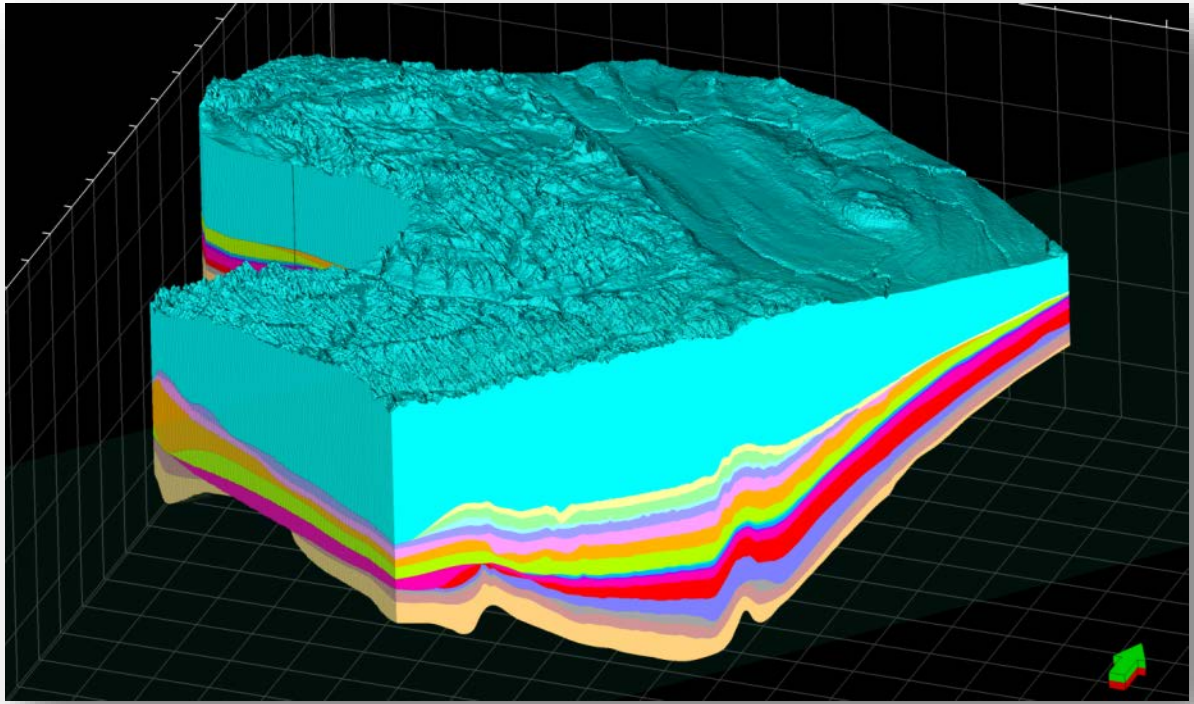


Koperna and Kuuskraa (2006)

BASIN EVOLUTION MODELING

Provides a complete record of the evolution of a petroleum system, including:

- Deposition and erosion
- Pressure and compaction
- Heat flow analysis
- Petroleum generation
- Fluid pressure, volume, temperature analysis
- Reservoir volumetrics
- Structural evolution
- Migration, and accumulation of hydrocarbons



BASIN EVOLUTION MODELING

- We simulate basin evolution models to mimic hydrocarbon:
  - Generation
  - Migration
  - Accumulation

Exploration!

Multiple methods from which to choose

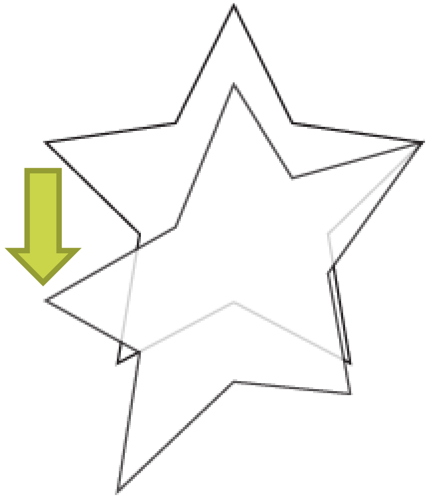
PetroMod: Identify ROZs by saturation values	PetroMod: External analysis of simulation outputs	PetroMod + Additional Data: External analysis of simulation outputs combined with other ROZ indicators	Static Models: Identify ROZs with pressure and structural data	Old School: Identify ROZs one well at a time

PetroMod

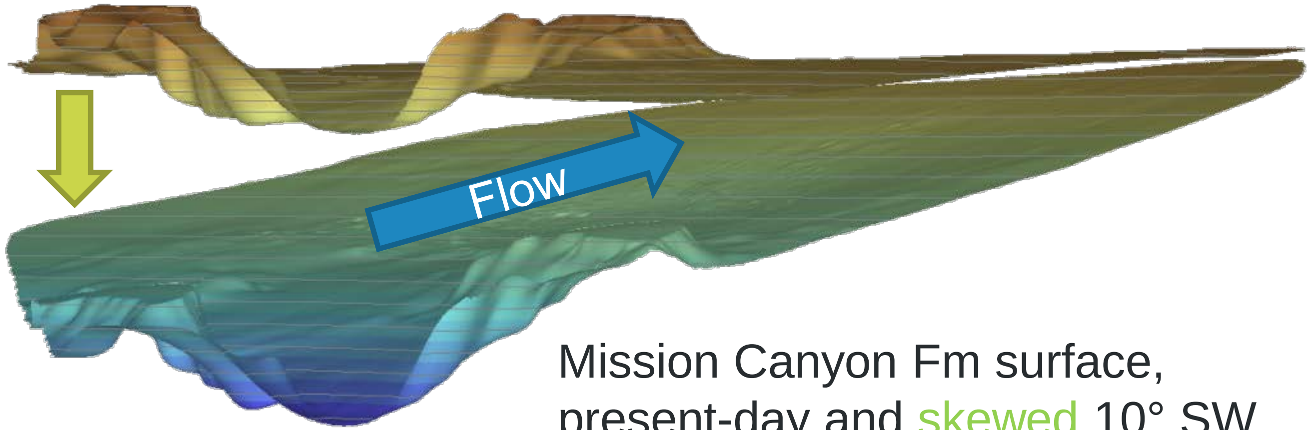
Spectrum of Methods

BASIN EVOLUTION MODELING

- For all methods using PetroMod:
  - Model is skewed before simulation to mimic hydrodynamic effects.
  - Calibration: If the model can predict known oil pools, assume the migration pathways are relatively accurate.
  - Outputs are useful for ROZ exploration, but for best results, either need to include very detailed (localized) input data (and diminishing returns) or marry to external data.



Structural surfaces were skewed to mimic hydrodynamic forces.

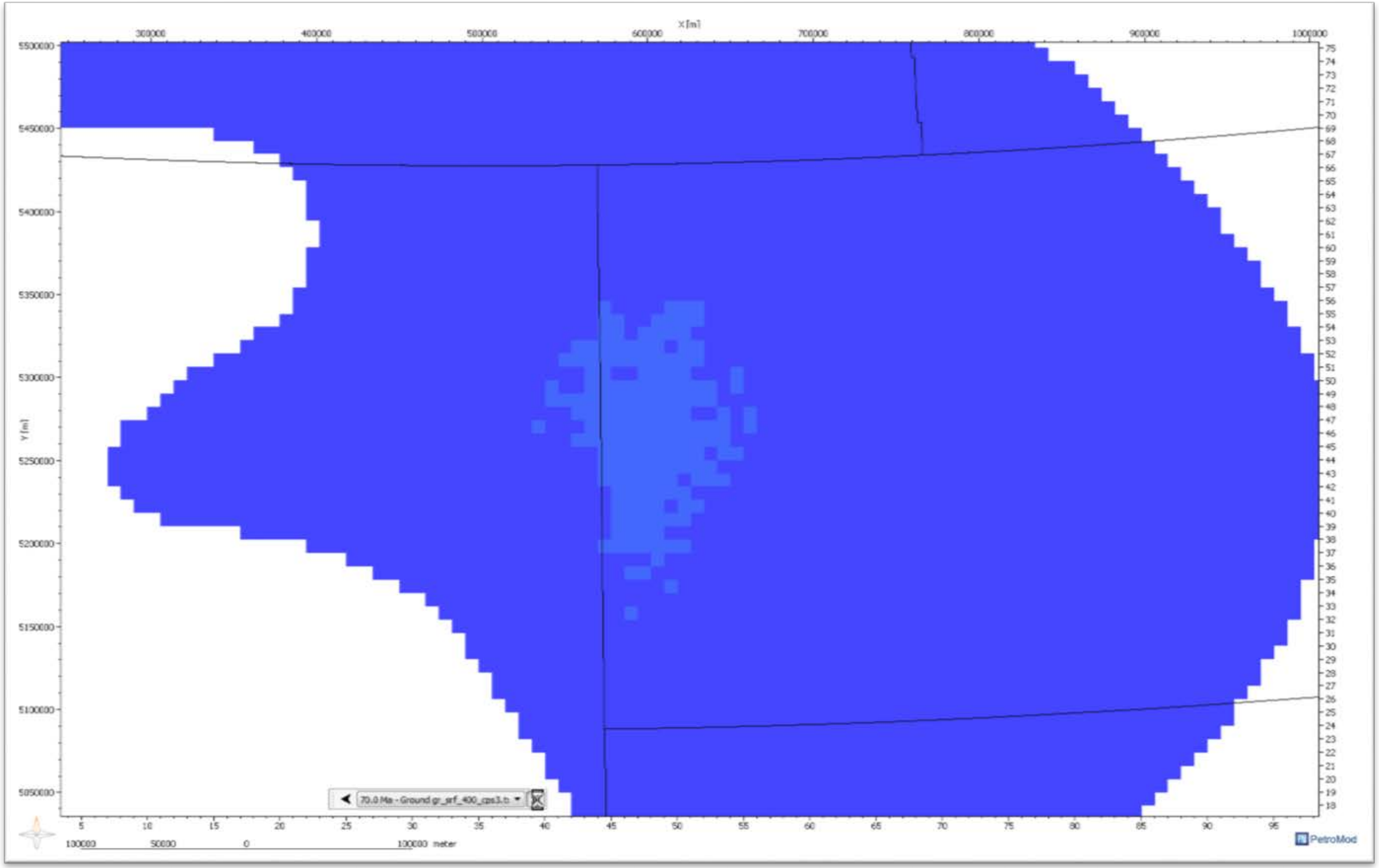


Mission Canyon Fm surface, present-day and skewed 10° SW (view from S, WB+PRB_1000_tilt02_change14)

BASIN EVOLUTION MODELING

- Animation of oil saturation in the Mission Canyon Fm from ~70 Ma to 0 Ma.

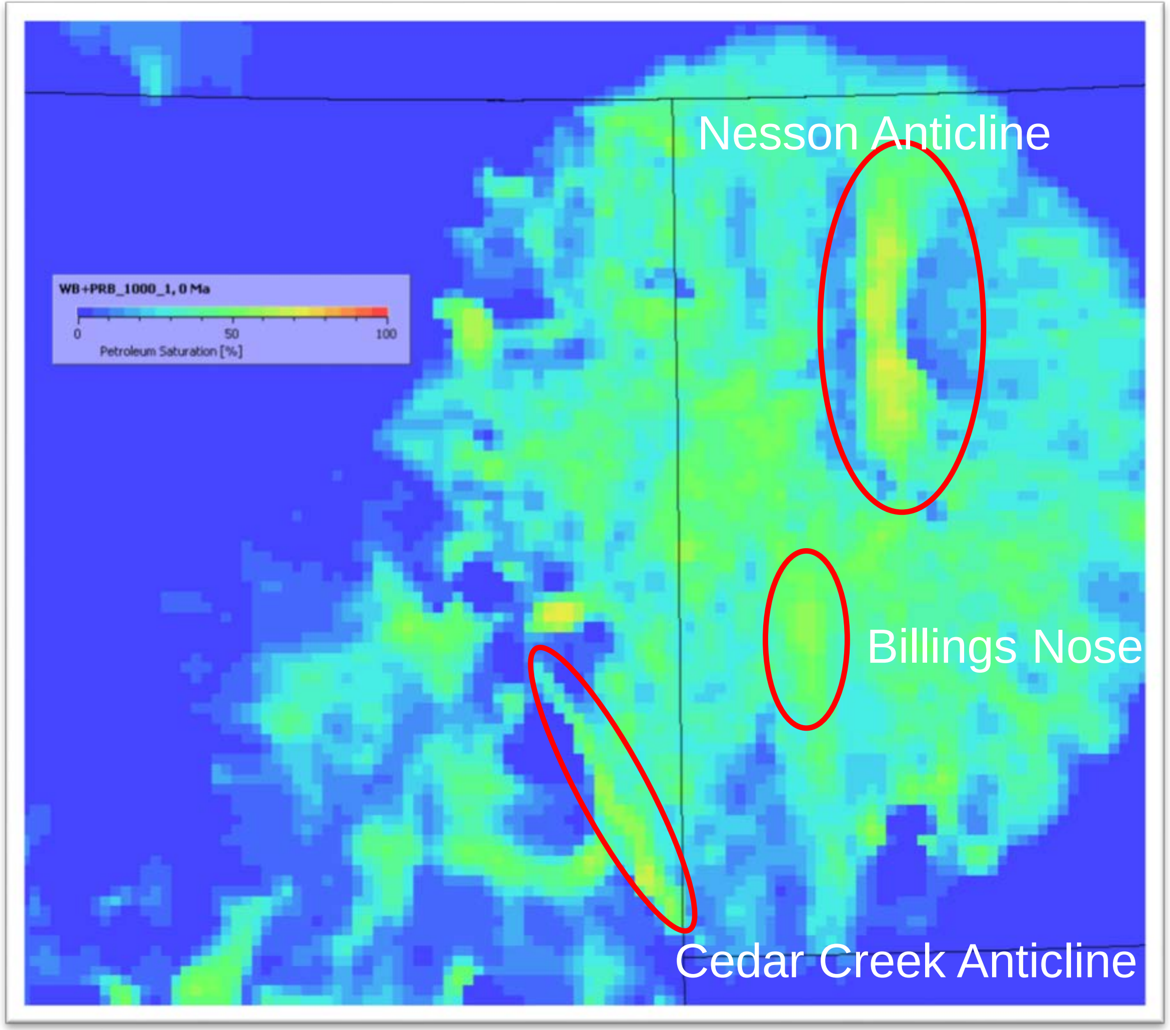
- At 35 Ma, the model starts to skew, coincident with the end of the Laramide Orogeny.



Mission Canyon, WB+PRB_1000_tilt02_change10_AOI004

ROZ EXPLORATION – PETROMOD SATURATION

- Oil saturation is a key descriptor when identifying ROZs.
- Also very dependent on small-scale lithologic, structure, generation (organic components, heat flow), and migration (pressure) variability.
- Modeling of large rock volumes requires large cells in order to simulate efficiently—which masks small-scale variability.
  - Notably vertical change in So: all oil migrates to top of reservoir, rather than being distributed vertically.
- Oil saturation outputs are useful qualitative products during model calibration.

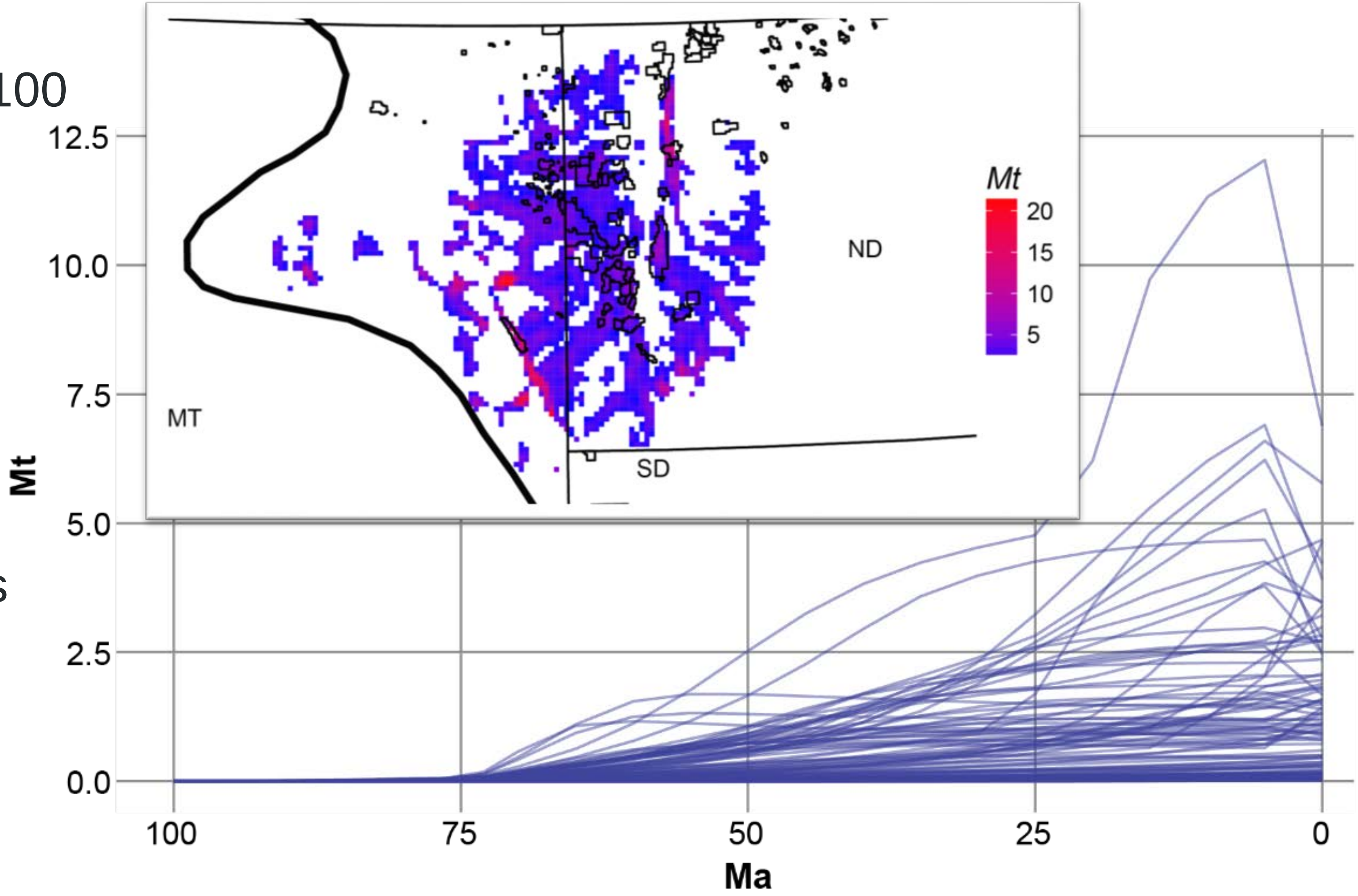


Mission Canyon, WB+PRB_1000_1

Early unskewed model showing large amounts of oil in known structural traps.

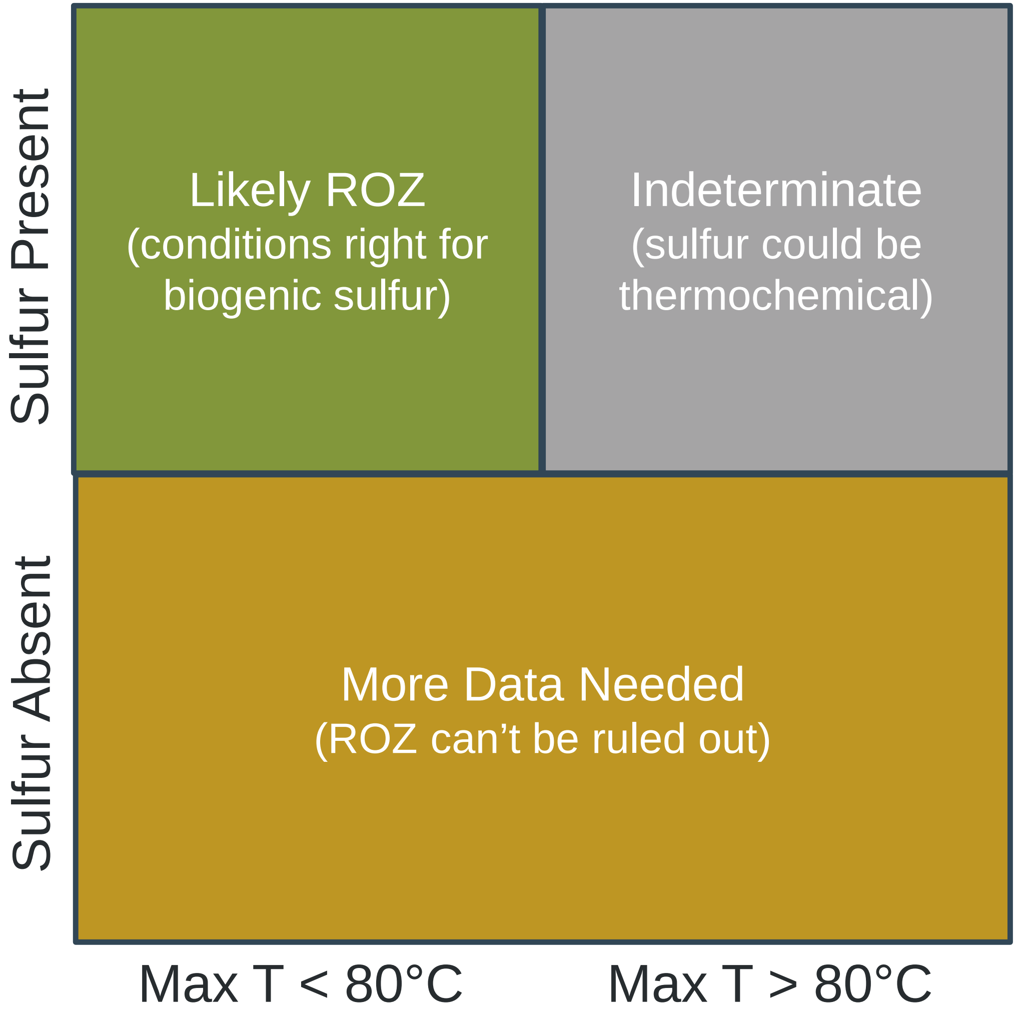
ROZ EXPLORATION – HYDROCARBON MASS HISTORY

- Oil “traffic” history through 100 random model cells in the upper Mission Canyon Formation.
- Derived by tracking oil generation and migration through the model.
- Areas with high total mass may not be recognizable as ROZs at the basin scale.
- Indicate potential areas for local grid refinement.



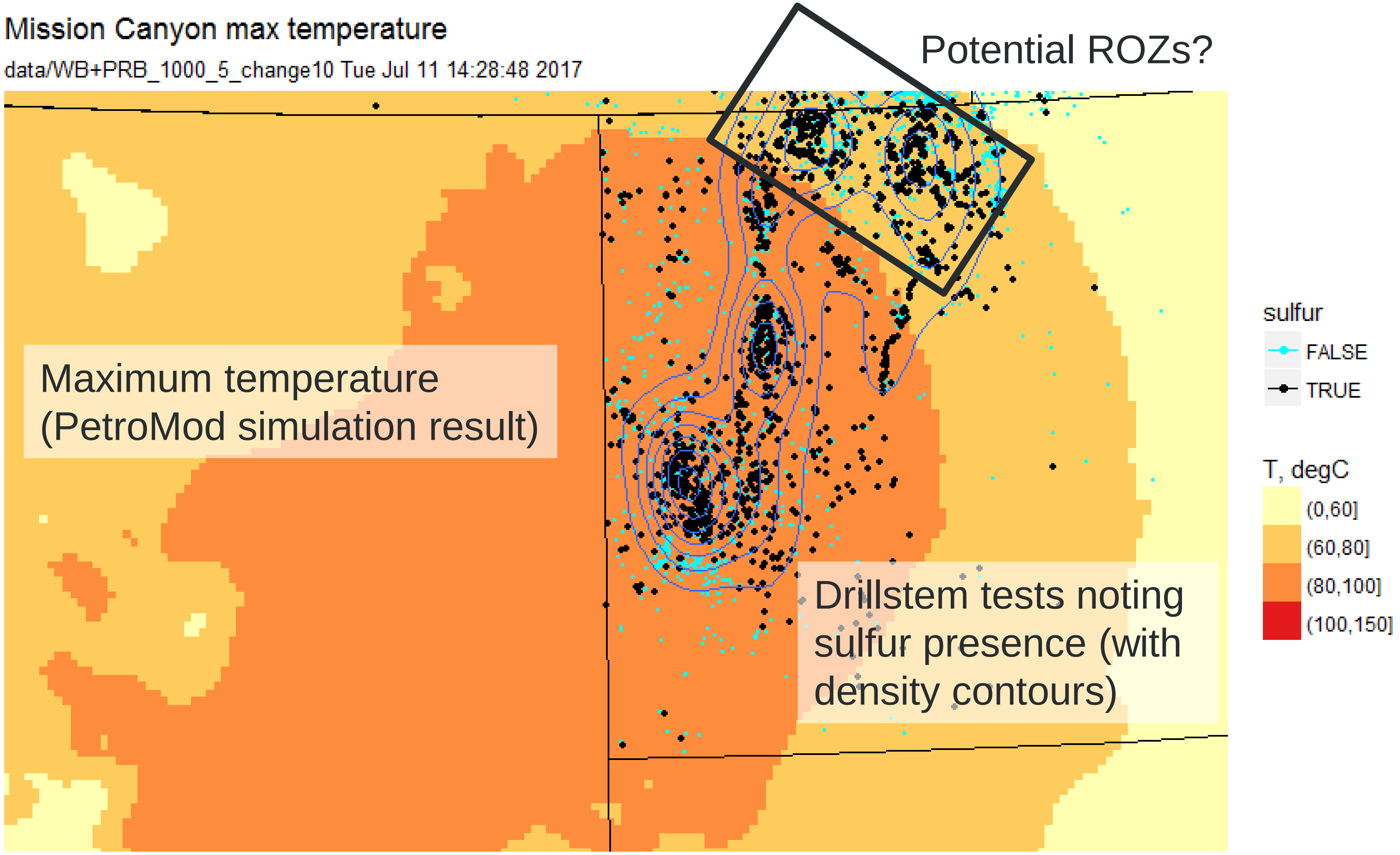
ROZ EXPLORATION – SULFUR

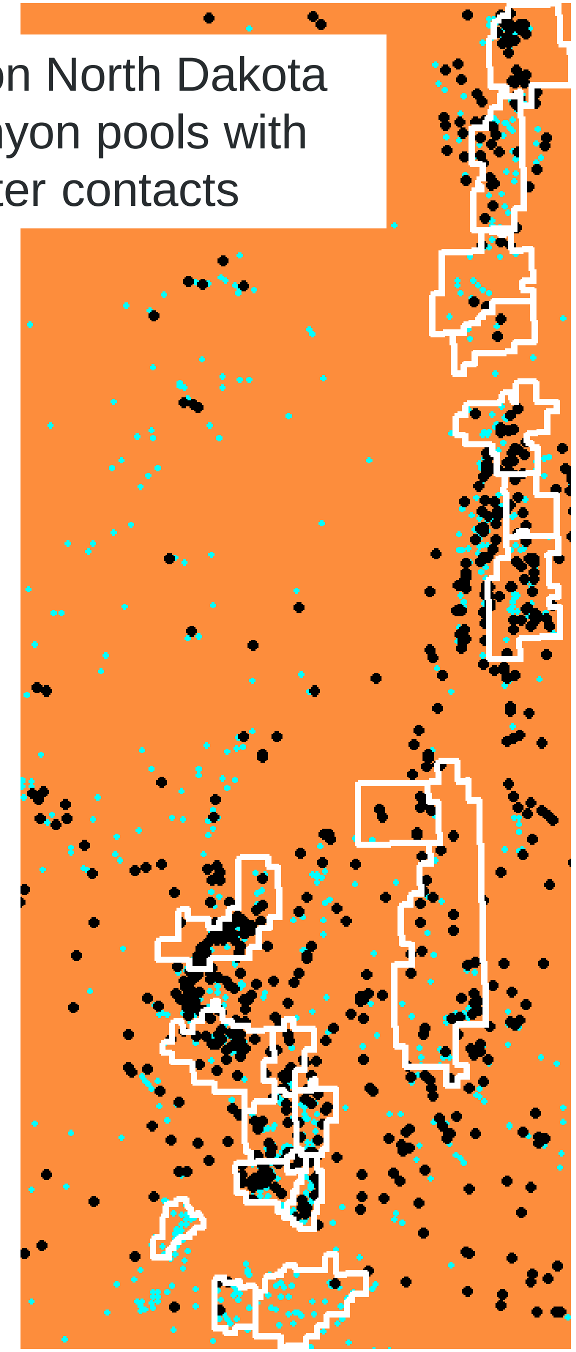
- Sulfur is one indicator of potential ROZs
- Why sulfur?
  - Sulfur can be produced by either thermochemical reactions or biological activity.
  - Biogenic sulfur can only be formed where bacteria can survive; specifically in a mix of oil and water ("eat oil and live in water").
  - Although biogenic sulfur cannot be distinguished from thermochemical sulfur, we can use the temperature limits (0°–80°C) of sulfate-reducing bacteria to estimate areas where each type of sulfate reduction occurred.



SULFUR

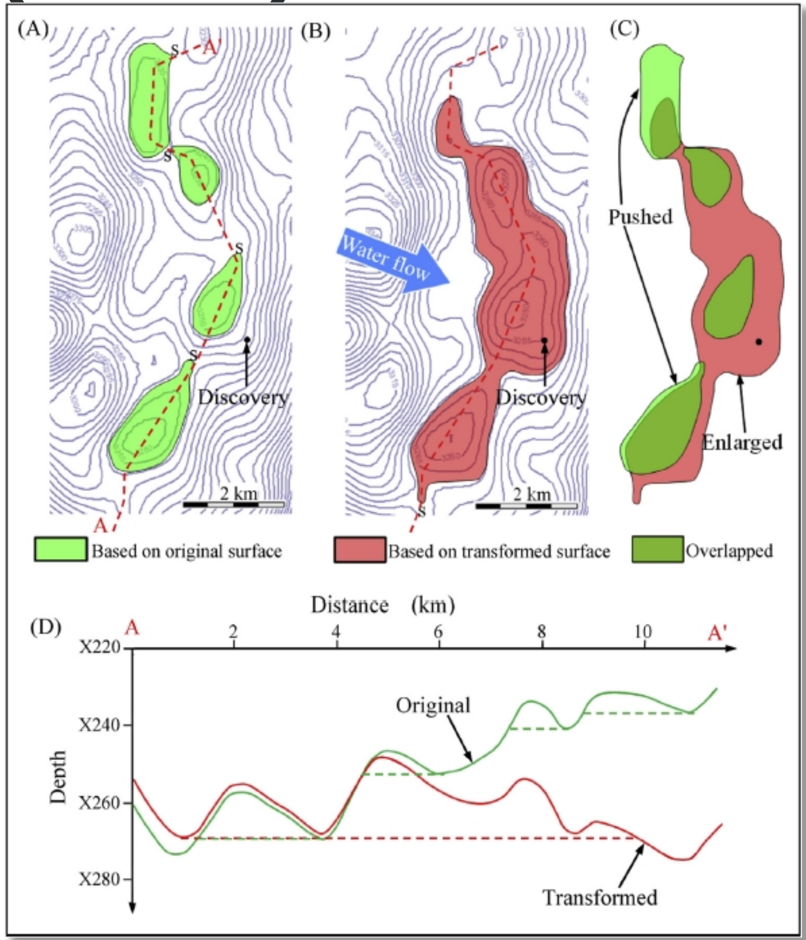
Map zoom on North Dakota Mission Canyon pools with tilted oil–water contacts





ROZ EXPLORATION: STRUCTURAL SURFACE TRANSFORMATION MODELING (SSTM)

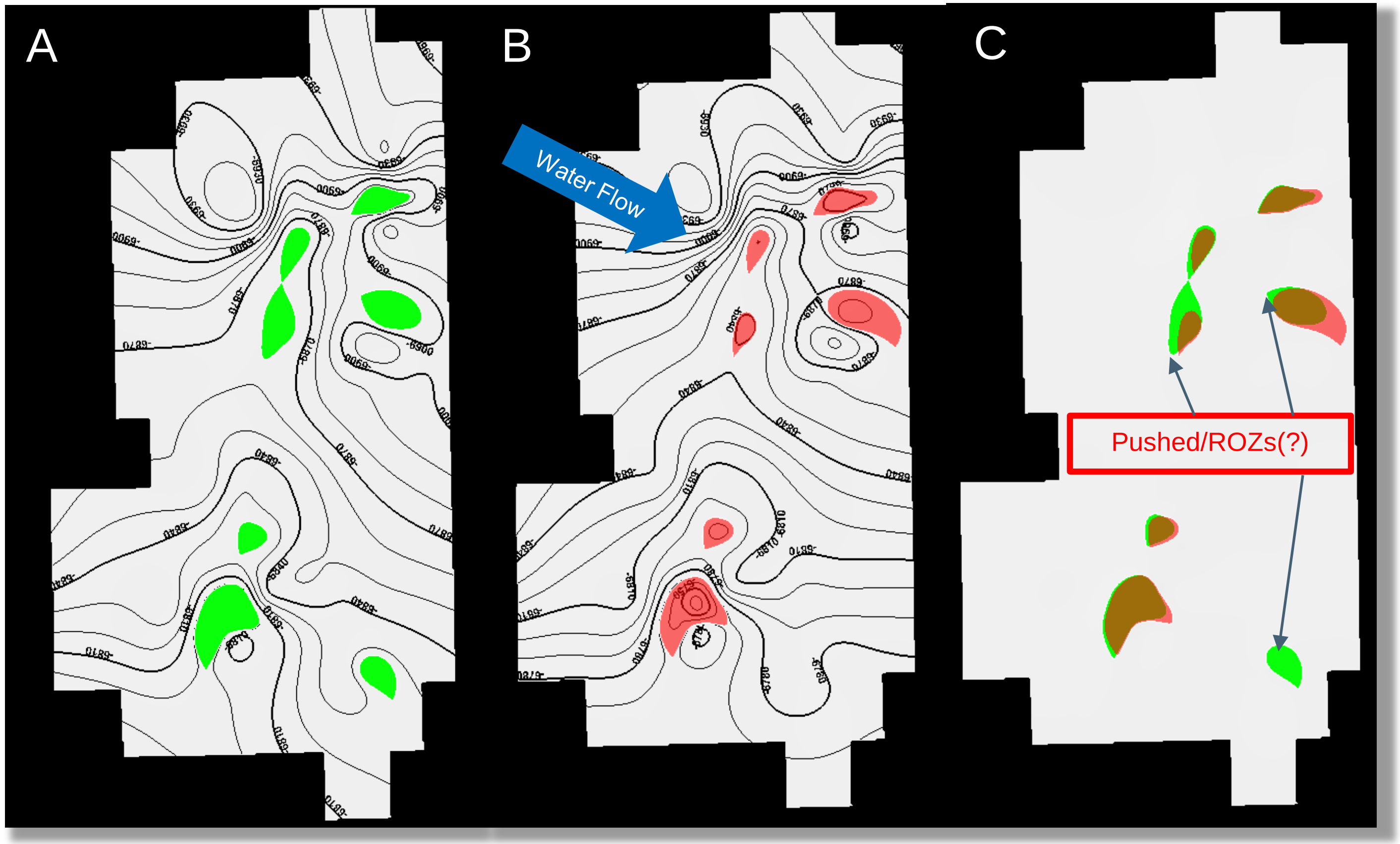
- A look into modeling hydrodynamic traps refers us to the work of Yang and Mahmoud (2016).
- Their work defines structural oil traps under original hydrostatic and hydrodynamic conditions and uses the difference to see where oil accumulations may have moved under current hydrodynamic conditions.
- These areas, defined as “pushed zones,” could potentially be considered ROZs.



Yang and Mahmoud (2016) Equation for defining hydrodynamic oil-water contact surface and an alternative approach, “ structure surface transformation” for mapping hydrodynamic traps.

SSTM – APPLICATION

- The method was applied to the Mission Canyon's Fryburg Interval, the MPZ, in the Billings Nose structure in the T.R. and Big Stick Fields, North Dakota.
- A hydraulic head plane was created from drillstem tests (DSTs). Its gradient was used to create a transformed structural surface.
- Oil traps were mapped on both surfaces and compared, showing pushed zones of oil accumulation.

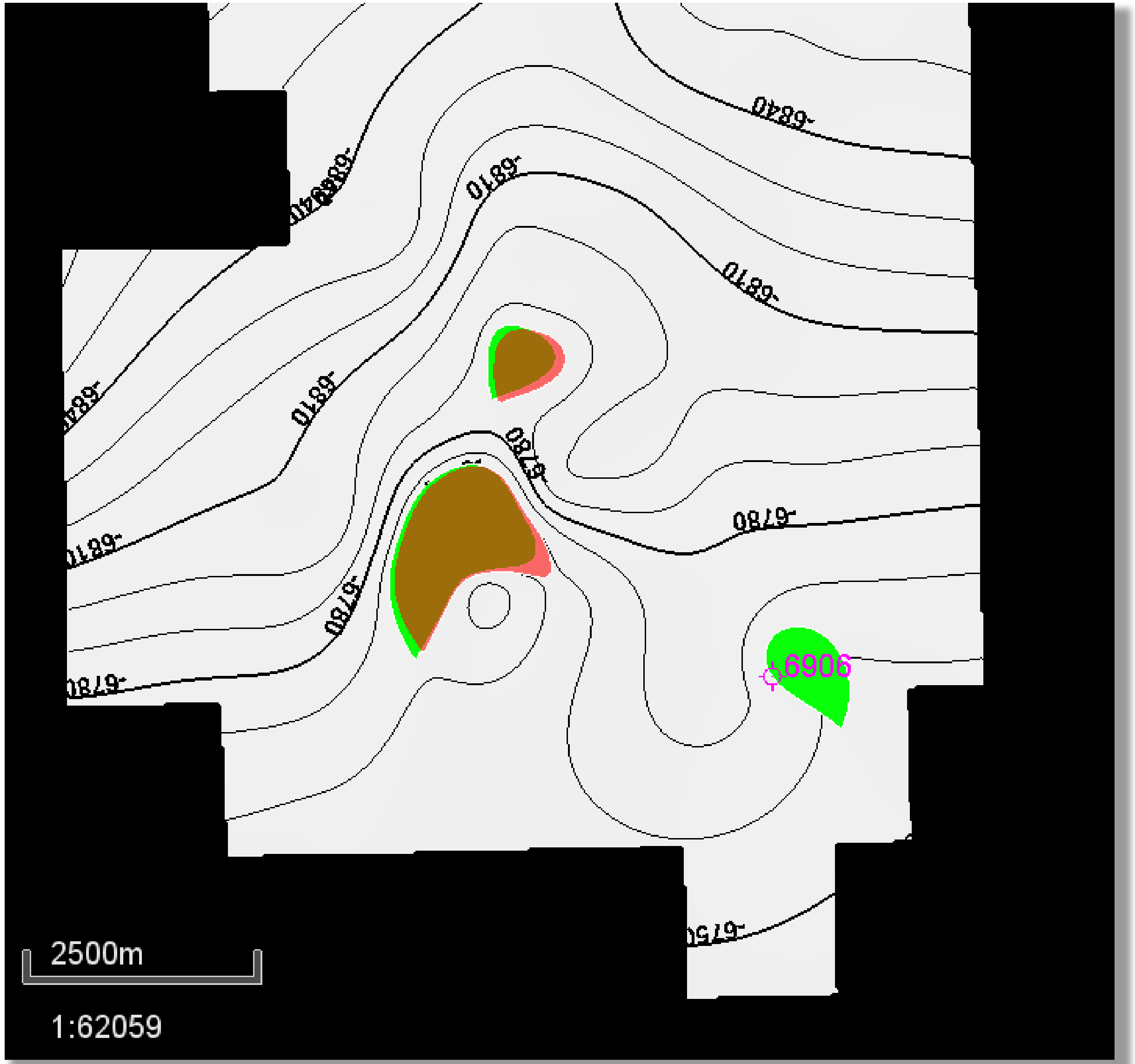


(A) The original structure with traps (green areas).(B) Transformed structure surface with traps (red areas). (C) Traps from the transformed surface overlaying the traps from the original surface showing difference in trap location and the potential for ROZs in pushed areas.

SSTM – RESULTS

- A dry well, located in the SE of the TR Field, is inside the modeled pushed zone and has a DST in the Fryburg showing only trace oil with a large recovery of “black sulfur water” which may indicate a potential ROZ.

- The combined evidence of the DST and the model showing a hydrodynamic trap suggests a possible ROZ.



PROJECT SUMMARY

- Key findings
  - Current PetroMod models predict hydrocarbon accumulations that largely agree with known pools.
- Lessons learned
  - There is a spectrum of semiautomated methods that may point in the direction of a potential ROZ.
  - Basin-scale models are the first step in manual additional exploration activities.
- Next steps
  - Lock down the best simulations, and crosscheck potential ROZ locations against well data.
  - Solidify estimated fairways based on hydrocarbon mass history.

SYNERGY OPPORTUNITIES

Associated Storage (EOR)

- Basin evolution modeling could be used to identify future unconventional or conventional targets.
- Collaboration between projects investigating CO_2 EOR in unconventional reservoirs and ROZs will help further the understanding of CO_2 storage associated with EOR.

ACCOMPLISHMENTS TO DATE

- Literature review completed.
- Several 1-D models have been completed, simulated, and calibrated as part of the PetroMod learning process.
- Several 2-D models have been extracted from the Williston Basin + Powder River Basin combined 3-D model and simulated.
- Calibration of lithologic properties and other input data based on 1-D and 2-D simulations is well under way.
- Reservoir simulation of T.R. and Big Stick Fields of North Dakota is complete.
- Collected pulsed-neutron logs in seven wells in the study area.
- Presented conference paper at GHGT-13, now in press.
- Project overview has been presented in multiple venues.

ACKNOWLEDGMENT

This material is based upon work supported by the U.S. Department of Energy National Energy Technology Laboratory under Award No. DE-FE0024453.

Disclaimer

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APPENDIX

BENEFIT TO THE PROGRAM

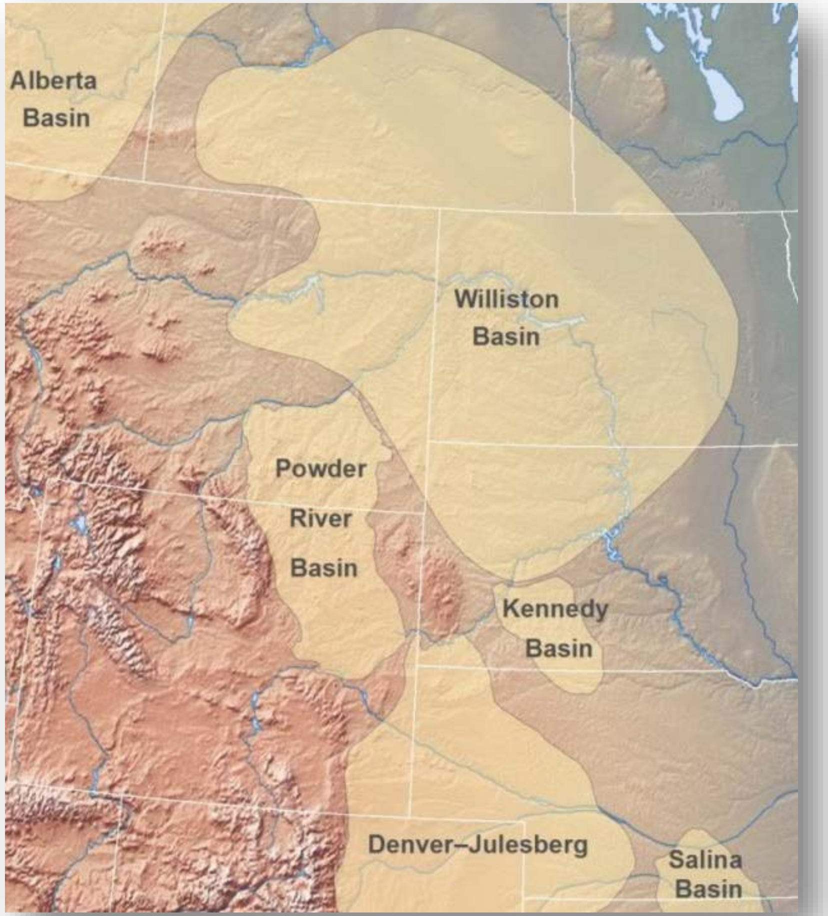
- Second and fourth goals of Carbon Storage Program:
  - Improve reservoir storage efficiency while ensuring containment effectiveness.
  - Develop best practices manuals (BPMs).

- Potential ROZs will be identified and evaluated for oil recovery and CO_2 storage resource potential.
  - CO_2 storage efficiency is improved through CO_2 enhanced oil recovery (EOR).
- A repeatable methodology will be developed and presented in a BPM.

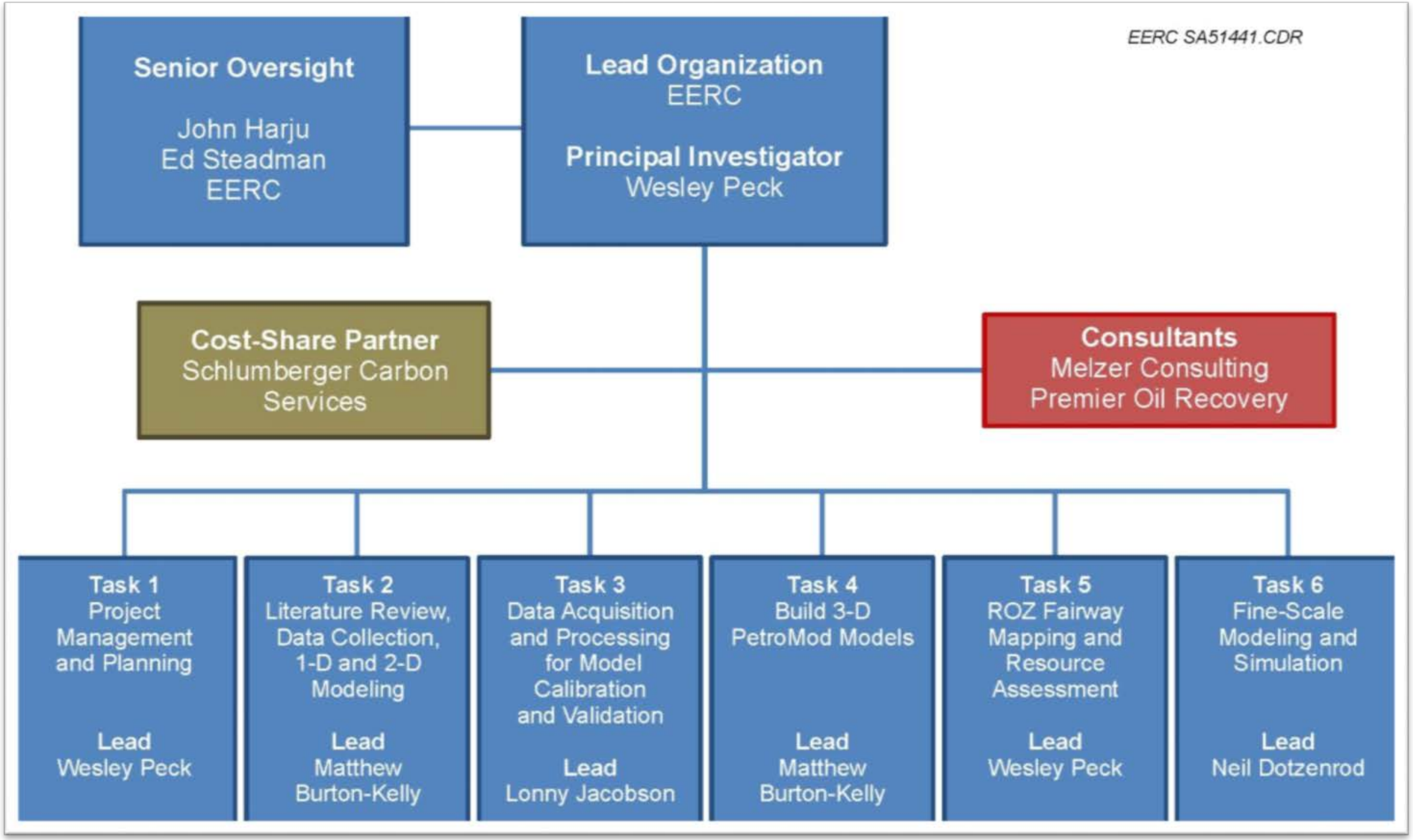
PROJECT OVERVIEW – GOALS AND OBJECTIVES

Objectives:

- Identify and characterize the presence and extent of potential ROZs in the Williston Basin (WB) and Powder River Basin (PRB).
- Estimate residual oil in place and CO_2 storage potential (Goal 2).
- Determine potential for CO_2 EOR in identified ROZs (Goal 2).
- Develop repeatable methodology for sedimentary basins to be included in a BPM (Goal 4).

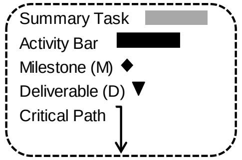


ORGANIZATION CHART



GANTT CHART

	Start Date	End Date
Task 1.0 – Project Management and Planning	**11/1/2014**	**10/31/2017**
1.1 – Perform Project Management	11/1/2014	10/31/2017
1.2 – Project Reporting	11/1/2014	10/31/2017
Task 2.0 – Literature Review, Data Collection, Compilation and Simulation of 1-D and 2-D PetroMod Models	**11/1/2014**	**12/31/2016**
2.1 – Literature Review and Data Collection	11/1/2014	12/31/2015
2.2 – Build Dynamic 1-D PetroMod Models	12/1/2014	9/30/2015
2.3 – Build Dynamic 2-D PetroMod Models	3/1/2015	9/30/2015
2.4 – Recalibrate, History-Match, and Simulate 2-D PetroMod Models Based on Field Logging Interpretations	12/1/2015	12/31/2016
Task 3.0 – Data Acquisition and Processing for Model Calibration and Validation	**6/1/2015**	**12/31/2016**
3.1 – Core Acquisition and Petrophysical Analysis	6/1/2015	10/31/2016
3.2 – Pulsed-Neutron and Temperature Logging	1/1/2016	12/31/2016
Task 4.0 – Build 3-D PetroMod Models	**5/1/2016**	**1/31/2017**
4.1 – Build, Calibrate, and Simulate 3-D PetroMod Models	5/1/2016	1/31/2017
4.2 – Select Submodels for Evaluation of Salt Movement, Hydrogen Sulfide Existence, and Free Sulfide Migration	7/1/2016	1/31/2017
4.3 – Perform Risk Analysis	12/1/2016	1/31/2017
Task 5.0 – ROZ Fairway Mapping, Volumetric Resource Estimates, and Preparation of Methodology to Be Used in Other Basins	**2/1/2017**	**6/30/2017**
5.1 – ROZ Fairway Mapping	2/1/2017	4/30/2017
5.2 – CO_2 EOR Feasibility Study	2/1/2017	6/30/2017
Task 6.0 – Fine-Scale Modeling and Simulation	**11/1/2015**	**9/30/2016**
6.1 – Build Fine-Scale Model(s)	11/1/2015	3/31/2016
6.2 – Conduct Simulation of Fine-Scale Model(s)	4/1/2016	9/30/2016



Key for Milestones (M) ◆	Key for Deliverables (D) ▼
M1 – Project Kickoff Meeting Held	D1 – Updated PMP
M2 – First Cross Section of 1-D Model Completed	D2 – Project Fact Sheet
M3 – Potential ROZ Identified	D3 – Data Submission to EDX
M4 – First Petrophysical Analysis Completed	D4 – Final Report
M5 – PNL Collection Completed	D5 – Literature Review Summary
M6 – Risk Analysis Completed	D6 – Conference Paper
M7 – Resource Assessment Completed	D7 – Peer-Reviewed Journal Article
M8 – Debriefing Meeting with Operators	D8 – Topical Report: Fine-Scale Modeling and Simulation Results

Rev. October 9, 2015

BIBLIOGRAPHY

- No peer-reviewed literature to date.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