

# Evaluation of ROZ in the Tensleep Formation, Northeastern Bighorn Basin, Wyoming

*Nick Jones – Manager, Conventional  
Resources*



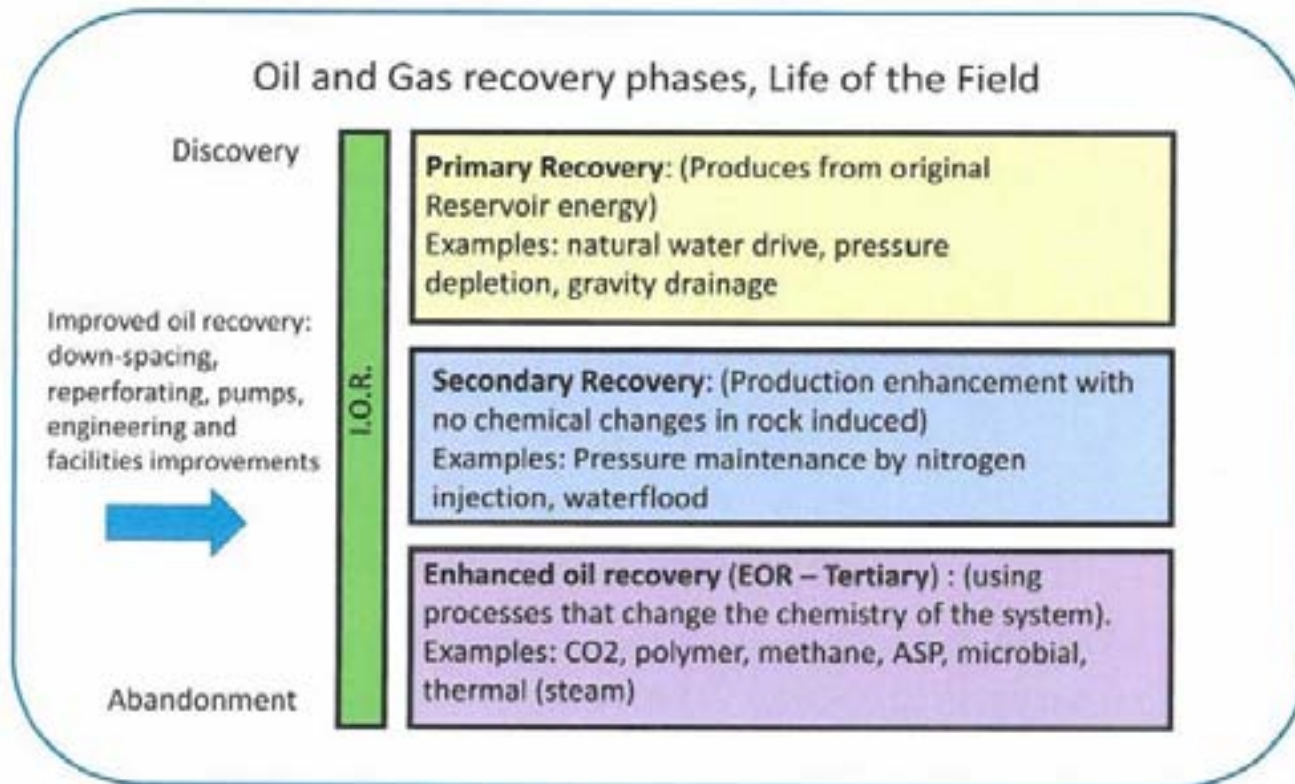
*November 3, 2016*



# EORI – Mission

***The mission of EORI is to facilitate a meaningful and measurable increase in recoverable reserves and production of oil and natural gas in Wyoming that may otherwise not be realized. Key to this is the effective and efficient transfer of relevant technology, information and knowledge to Wyoming producers. EORI believes that its mission is being met when producers consider EORI as a vital source of relevant technology, information, expertise and knowledge for Wyoming fields.***

# Enhanced and Improved Oil Recovery



Freyberger, S. and Jones, N. EORI 2015

- CO<sub>2</sub>-EOR
  - CO<sub>2</sub> to mobilize residual oil
  - Miscible – single phase fluid
  - Immobile oil in the rock matrix
- Reasons for immobile oil
  - Relative permeability
  - Wettability
  - Primary Strata (Micro Strat Traps)
  - Fractures (Open vs Closed)

# EORI Tensleep ROZ Study 2011-2012

## Apply Permian Basin idea to Bighorn Basin.

Importance of ROZ.

Recovered oil from ROZ.

## Data collection.

Cores, cuttings, well logs, PI cards, completion, workover, operator communications.

Create database to organize the data.

## Recognition & Mechanisms.

HC shows below and around MPZ.

Information provided by reservoir geologists and engineers.

Oil migration and accumulation history.

## Methodology.

Select Frannie-Sage Creek-Homestead region as an example.

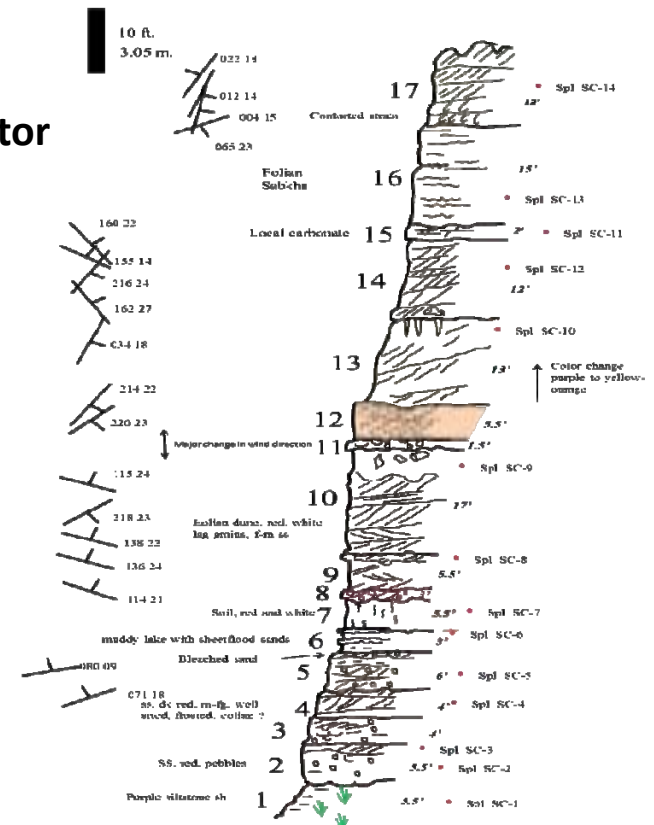
From data collection to potential ROZ reserve.

## Tensleep Potential ROZ reserves in Bighorn Basin.

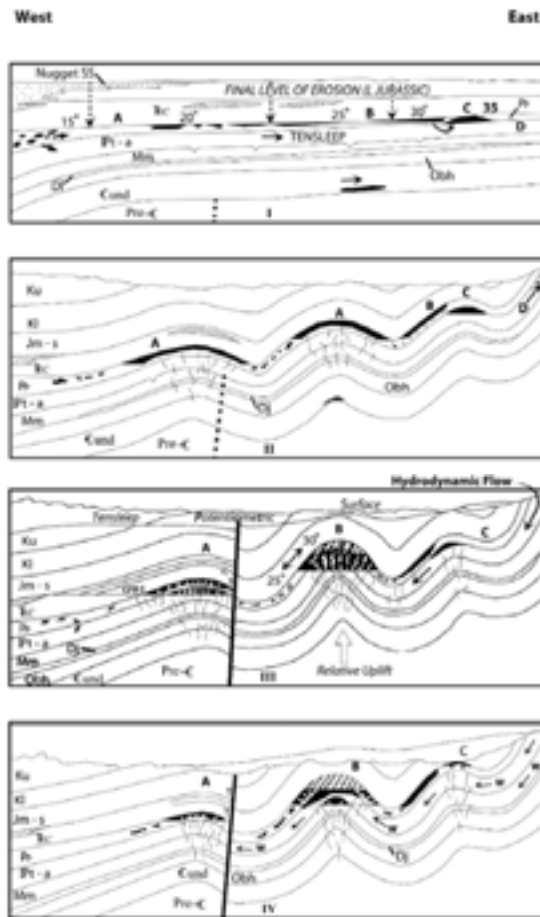
Potential Tensleep ROZ reserve.

ROZ fairway.

**Measured section: Tensleep (Casper) Formation  
Sand Creek, Albany County Wyoming  
Fryberger, Jones, Johnson  
Section complete except for upper 30 feet of Tensleep**



# Deformation, Migration, and Accumulation



Modified from Stone, 1967

## Early Mesozoic – Oil begins migrating into stratigraphic traps

Note: The uppermost sequence of the Tensleep Formation has already been eroded prior to deposition of the overlying Phosphoria Formation creating an erosional unconformity.

## Late Mesozoic– Structural traps begin developing and charging

Regional dip is down to the southwest (present day) allowing migration to proceed up gradient, as migration occurs connate formation water is displaced and reduced to residual saturation.

## Early Tertiary – Fracturing, faulting and compartmentalization?

Developing thrust faults begin to compartmentalize anticlinal structures affecting continued migration and accumulation of oil. Early stages of meteoric influx begin to degrade updip oil accumulations resulting in low API gravity oil and in some places result in tar layers at the OWC.

## Late Tertiary– Hydrodynamic charging flushes existing oil accumulations?

Over time cementation of crestal fractures degrades fluid movement resulting in the majority of accumulations of oil to occur down dip of the fault plane and crest of the anticline. Water influx and tilted OWC's need to be reevaluated with respect to initial reported production and drainage of off structure fractures.

# Why is it different in Wyoming?

## Lessons from early development in the Bighorn Basin .

Water wet below the Main Pay Zone (MPZ) – Noneconomic!

## Source rocks are younger than reservoir rocks.

Deposition, deformation, and erosion of upper Tensleep Permian facies (deep marine shales to shallow marine carbonates)

## Severity and timing of structural deformation.

Encroachment of the Antler Arc

Impact of the Sonoma, Nevadan, and Sevier Orogenies

Impact of Greybull Arch (Permian)

Affect of the Laramide Orogeny

Regional Uplift and Rotation (Colorado Plateau)

## Uplift, timing and erosional exposure.

Laramide (~50-100 mya) Upper Cretaceous – Early Tertiary

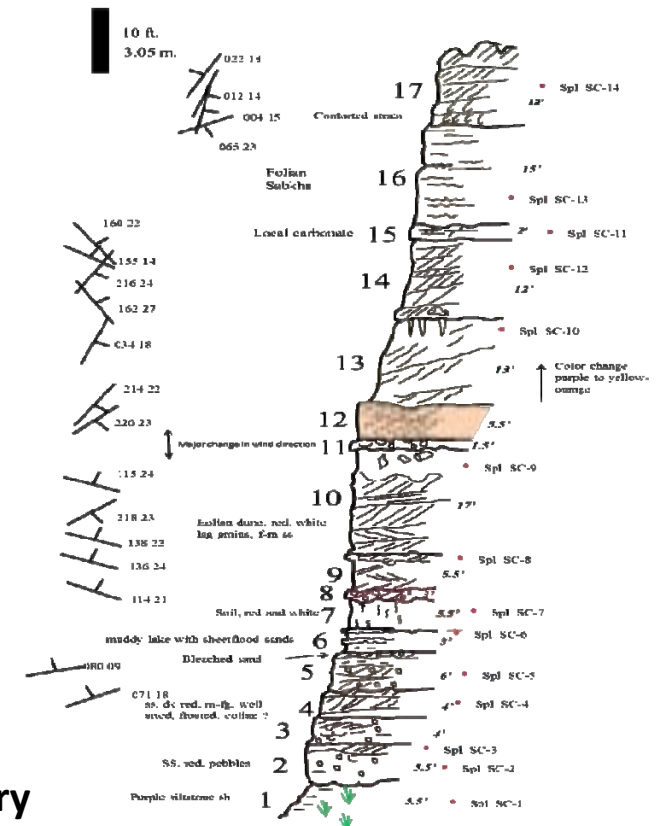
Exacerbated structural deformation in Tertiary Paleocene Time

## A different perspective on opportunities

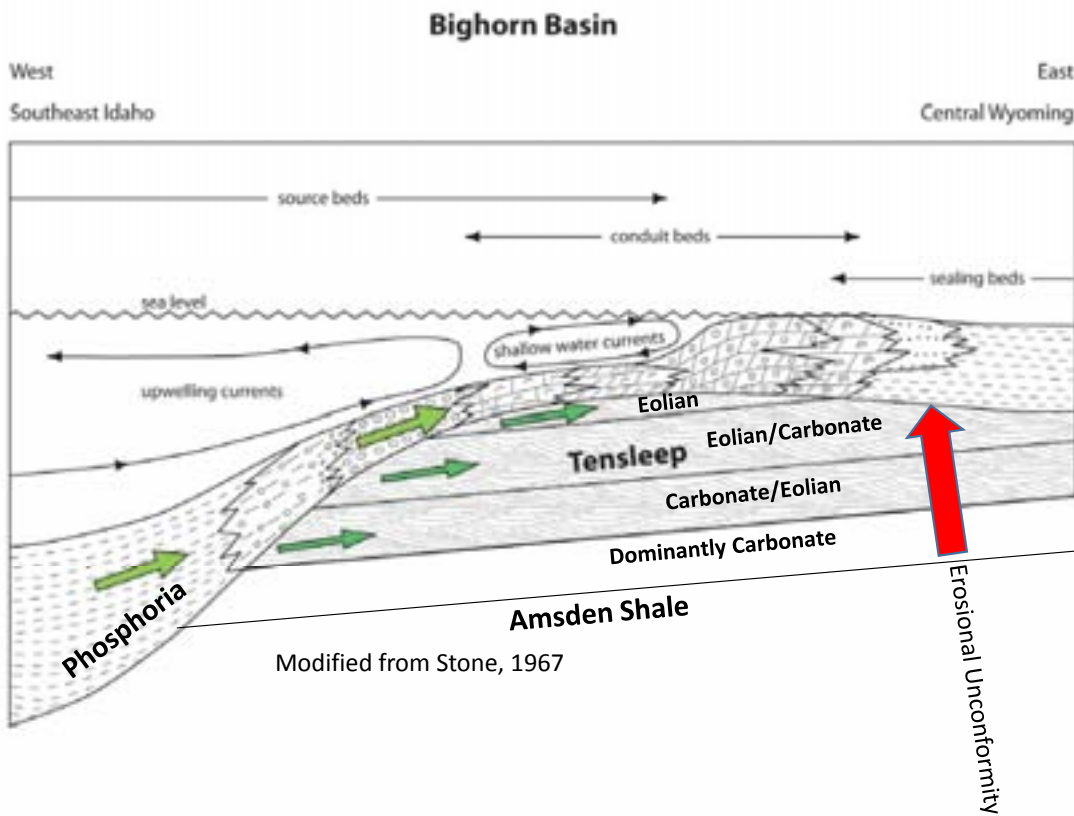
Main Pay zone only represents a small percentage of rock volume

Economic limits – Wettability – Primary Strata – Reservoir Geometry

**Measured section: Tensleep (Casper) Formation  
Sand Creek, Albany County Wyoming  
Fryberger, Jones, Johnson  
Section complete except for upper 30 feet of Tensleep**



# Tensleep-Phosphoria Depositional System



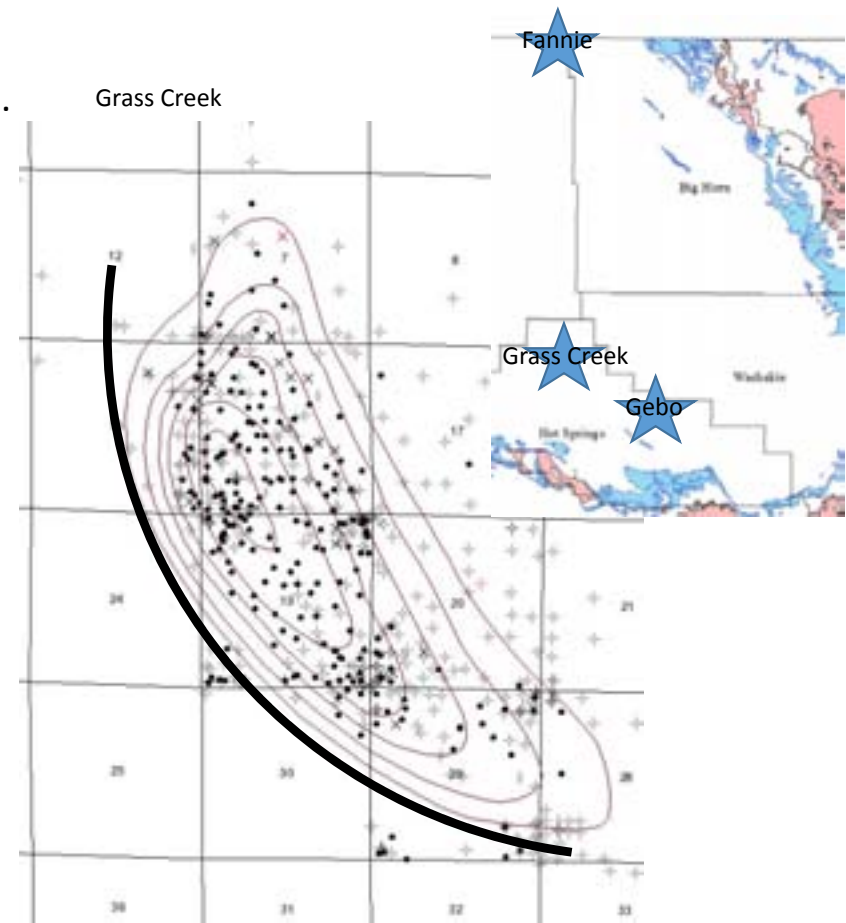
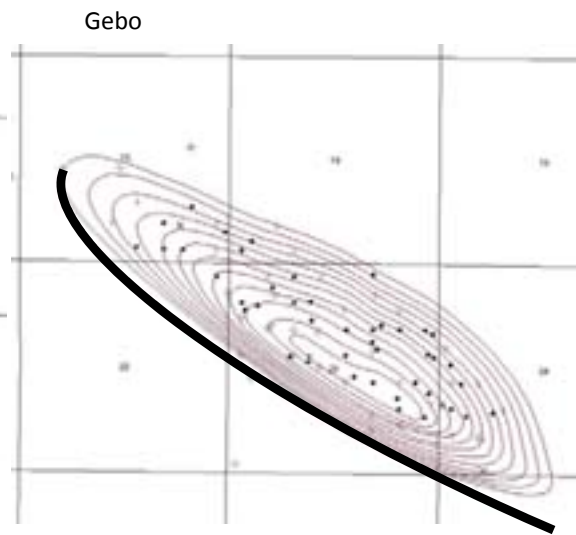
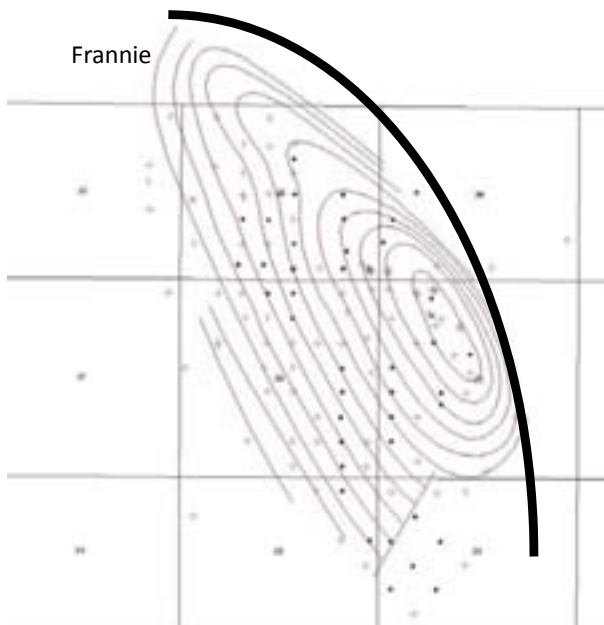
Permo-Pennsylvanian Paleotopographic depositional setting

R. Blakey – Northern Arizona University

# Diversity of well distribution on structures in the BHB

As fractures form at the crest of structures early cementation occurs.

Depending on the timing of migration, the fracture network can prevent fluid flow into the crest.



Cooper, S. – Consultant  
Lorenz, J. - Consultant  
Freyberger, S. - Shell  
Hennings, P. - ConocoPhillips



# Fracture Form & Fill?



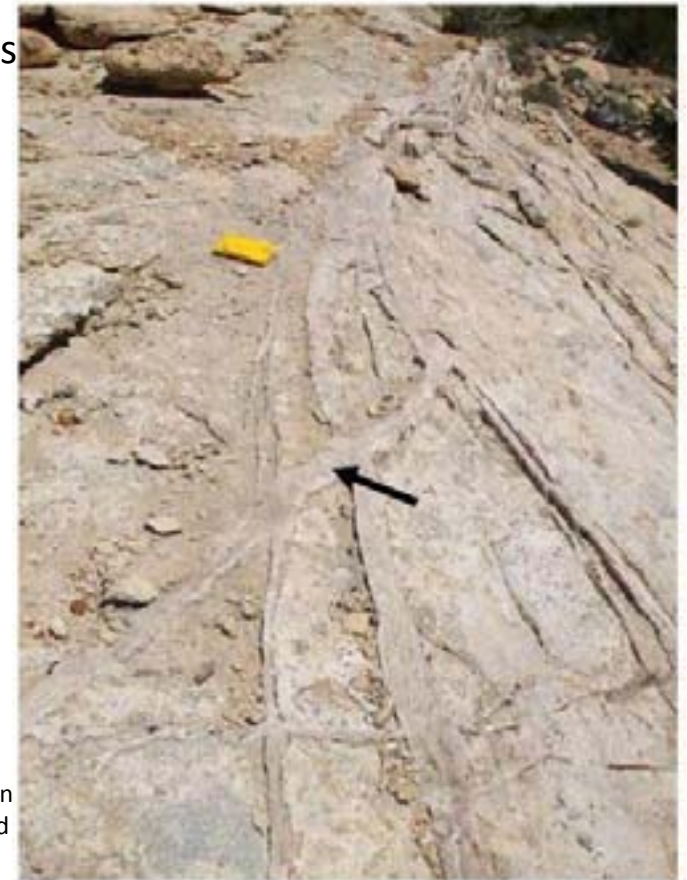
Cemented fractures at Pine Butte

Examples of extensional fractures common in Tensleep structures noted in outcrop and core.

Consider the timing of:

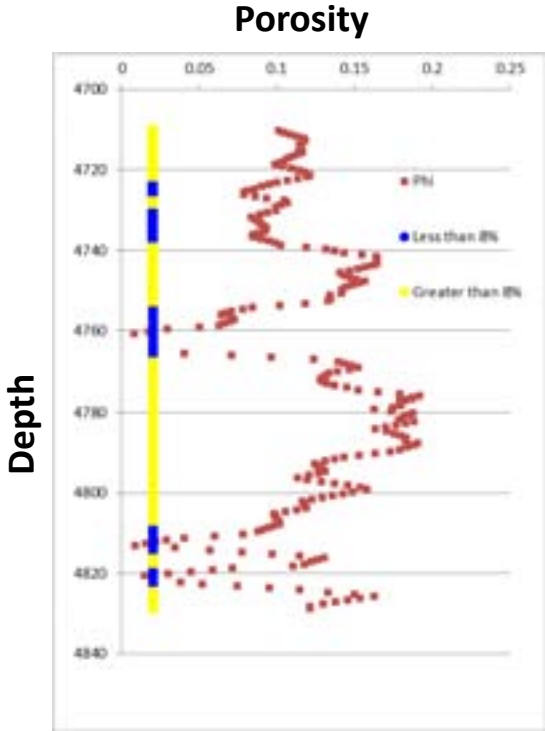
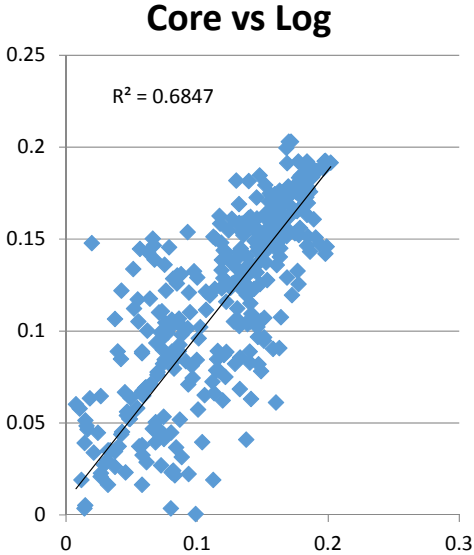
- Fluid migration
  - Fluid type
- Mineral dissolution
- Structural deformation
- Precipitation/cementation

Cooper, S.P. and Lorenz, J.C., 2011. Tensleep Formation Fracture Study Compendium. Prepared for and funded by the Enhanced Oil Recovery Institute.

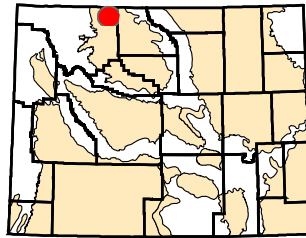
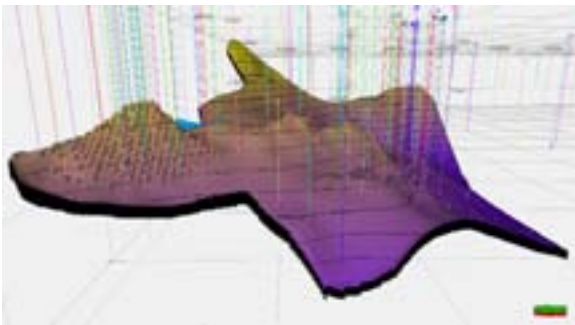


Cemented fractures at Flat Top

# The Model



# EORI ROZ Study Area



## Correlation Data

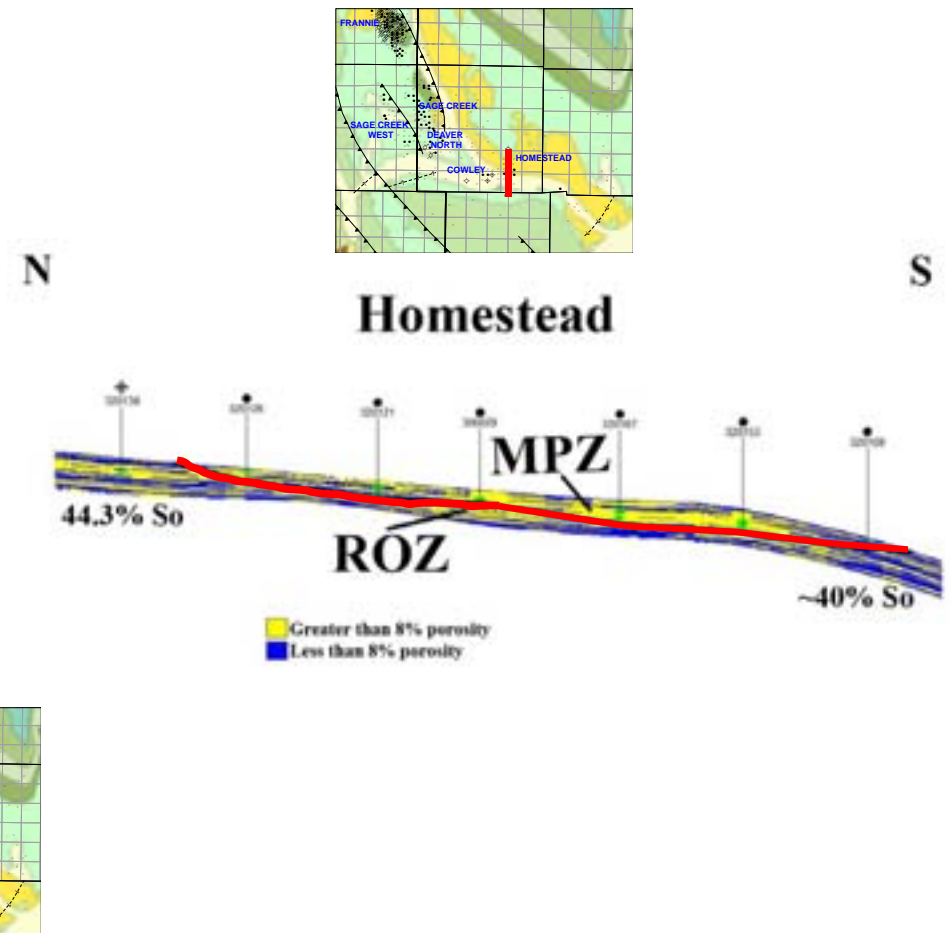
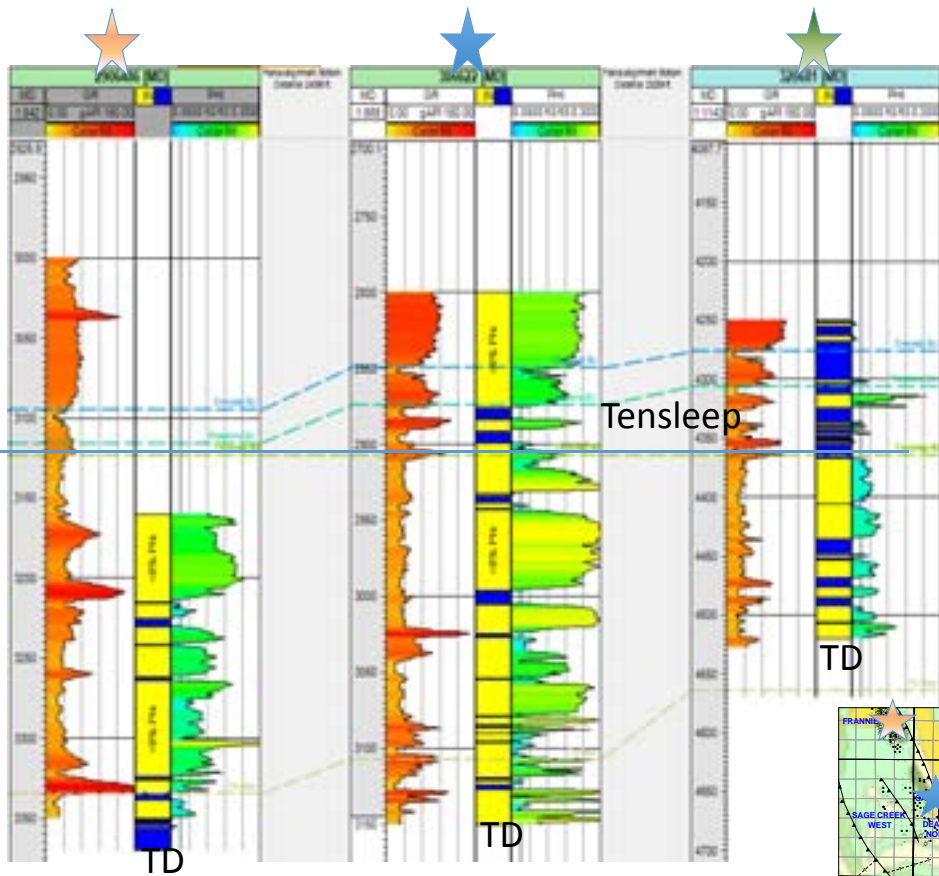
Wells	
85	Wildcats
192	Frannie
83	Sage Creek
12	Sage Creek West
19	Deaver
10	Deaver North
21	Homestead
15	Cowley

## Porosity Data

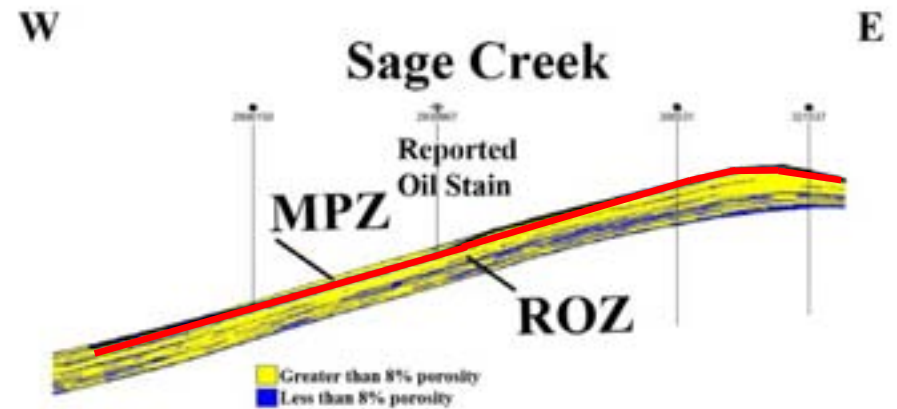
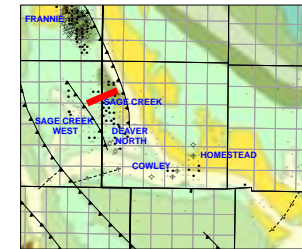
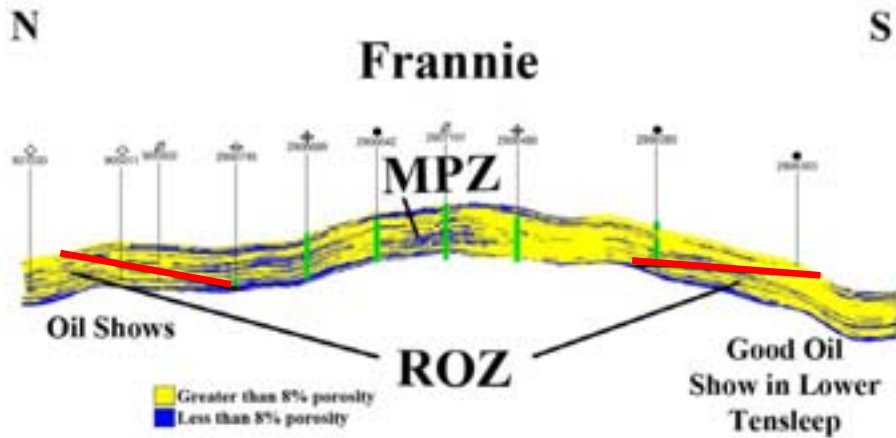
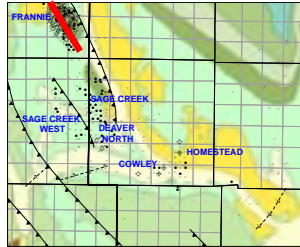
Phi logs		Core	
66	DT	55	
9	DPHI	15	Core/DT
37	DPHI-NPHI	8	Core/NPHI-DPHI
9	SPHI		
<b>Total</b>		<b>131</b>	

ROZ = Residual oil zone    MPZ = Main pay zone

# Porosity evaluation and pay identification



# Further examples of porosity distribution

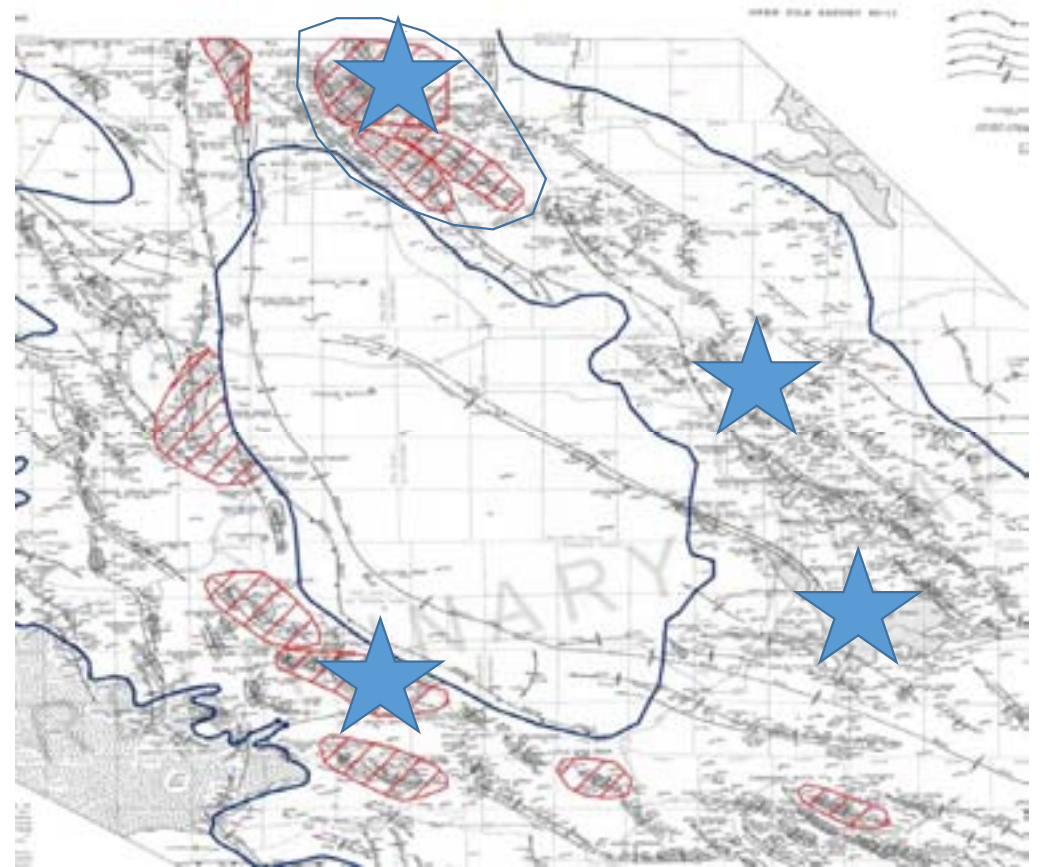
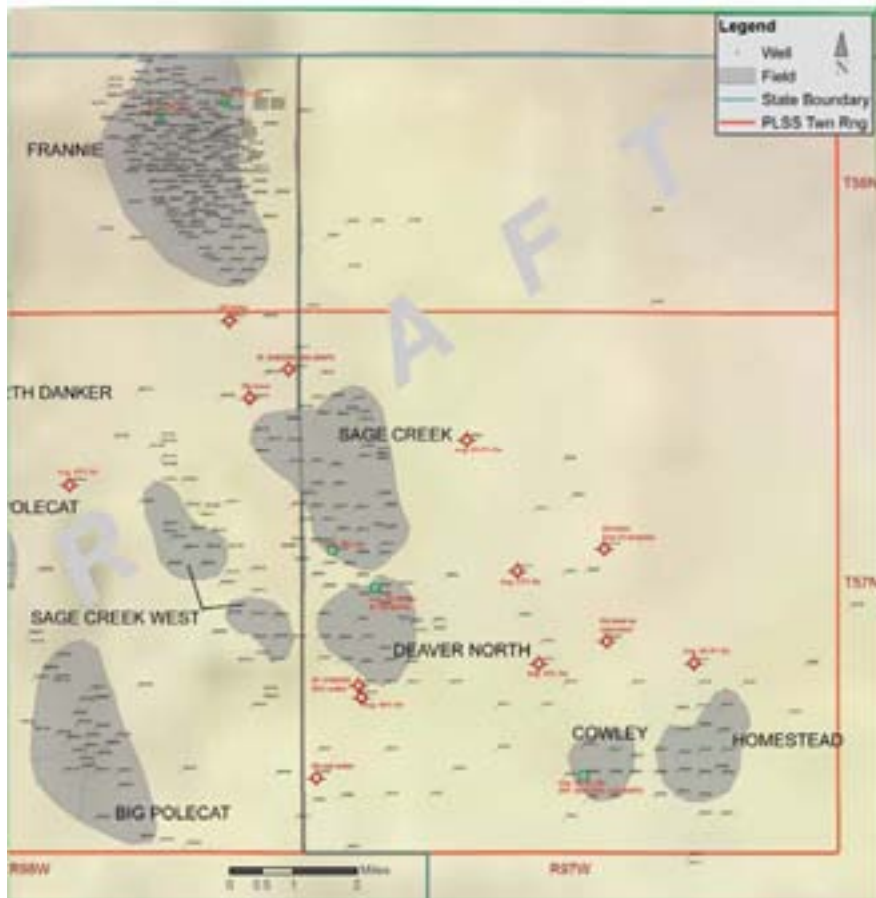




Extrapolation

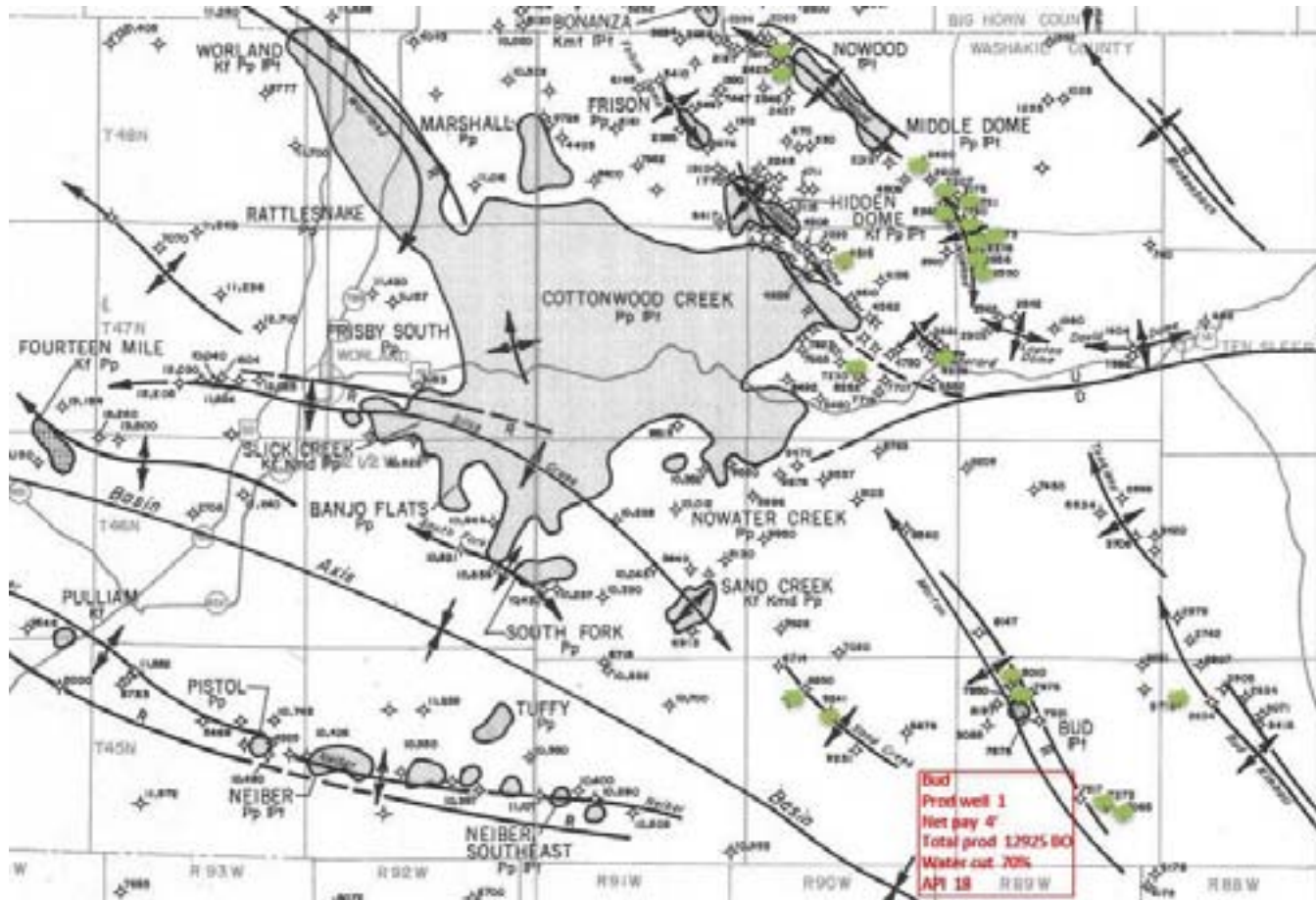
---

# Porosity + Oil Shows (The Big Picture)



Compiled by Peigui Yin – Senior Geologist EORI - Retired

# South East Bighorn Basin oil shows



Compiled by Peigui Yin – Senior Geologist EORI - Retired

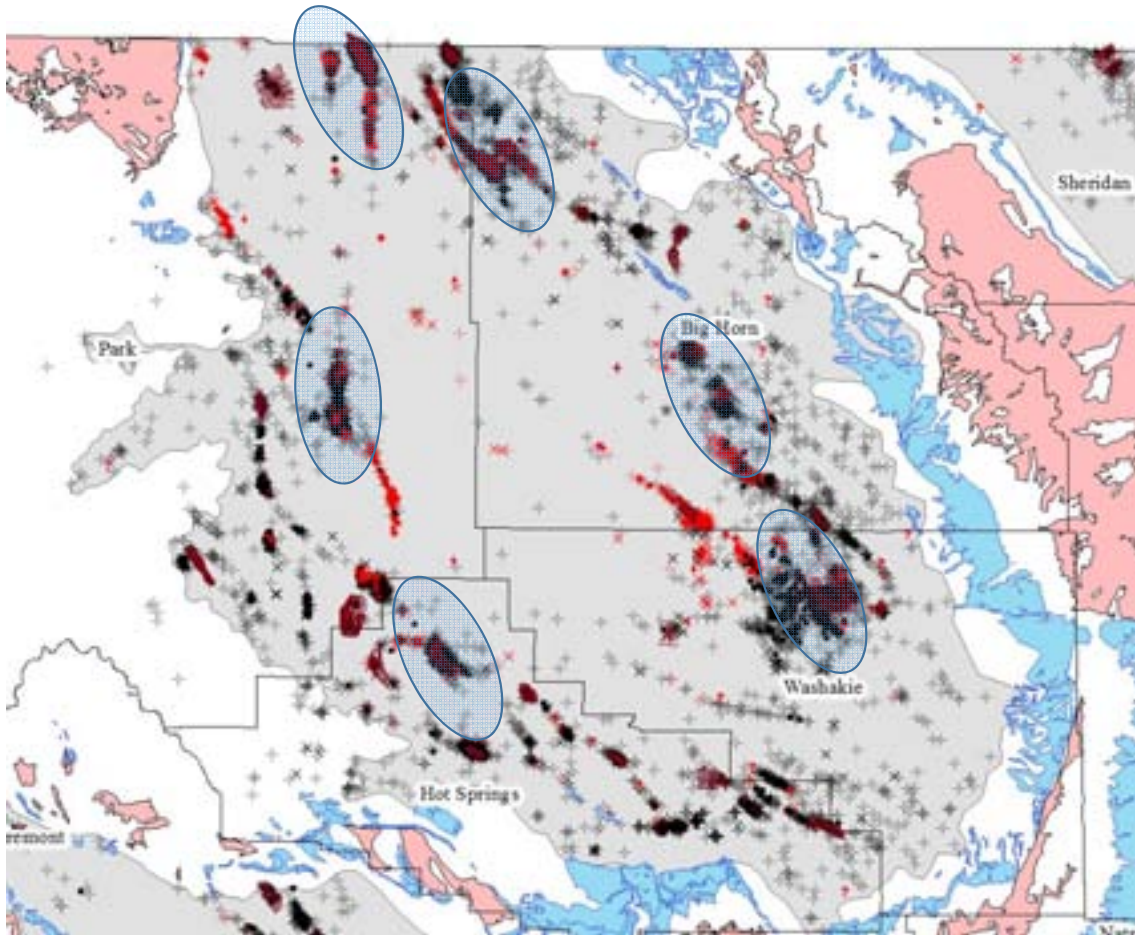


# West Central Bighorn Basin Shows



Compiled by Peigui Yin – Senior Geologist EORI - Retired

# Bighorn Basin Opportunities



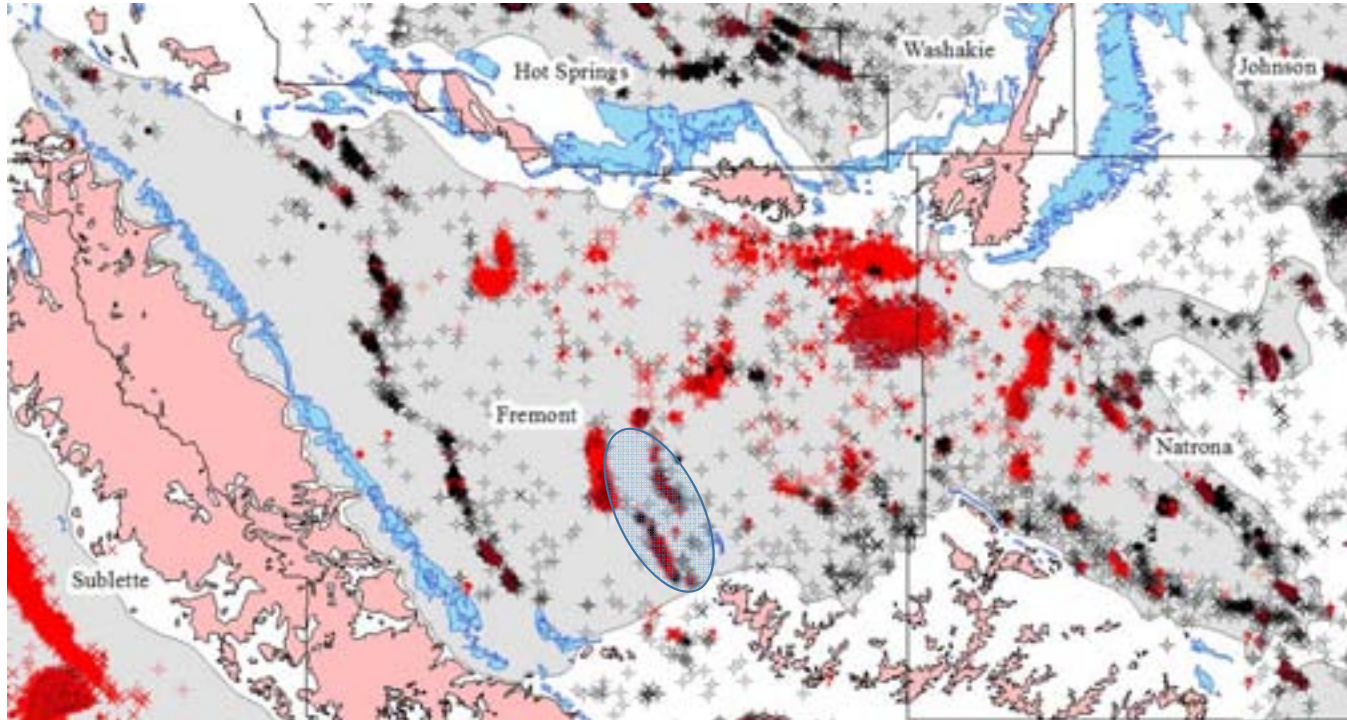
Phosphoria  
Tensleep

Frannie – Sage Creek

Cottonwood Creek

Lamb - Greybull

# Wind River Basin Opportunities



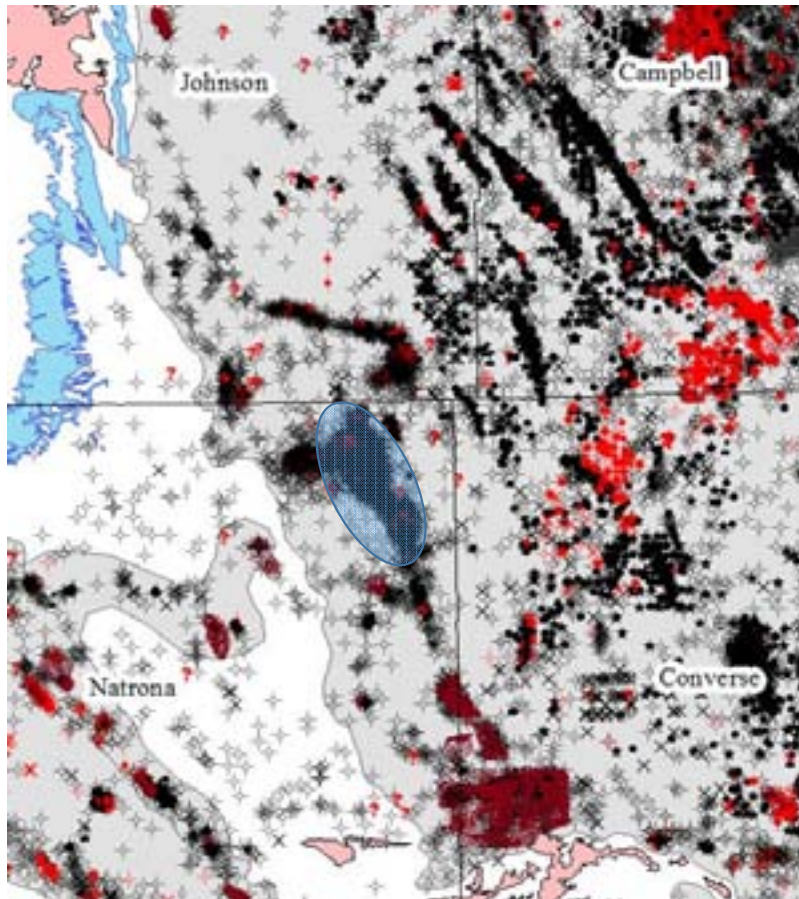
Phosphoria  
Tensleep  
Madison

Big Sand Draw

Beaver Creek

Other?

# Casper Arch (Powder River Basin) Opportunities



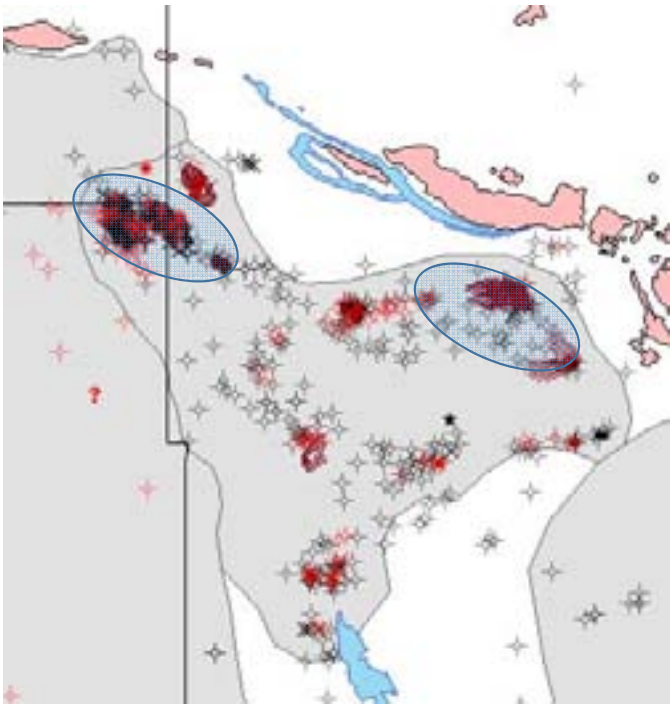
Cody  
Frontier  
Tensleep

Salt Creek

Teapot Dome

Other Casper Arch?

# Sand Wash Basin Opportunities



Frontier  
Tensleep  
Madison

Lost Soldier

Wertz

Mahoney Dome?

# Current CO2 Infrastructure



Pipeline data from the Wyoming Pipeline Authority

Sources:

## Lost Cabin

ConocoPhillips  
50 MMcf/day

## Shute Creek

ExxonMobile (LaBarge)  
365 MMcf/day

## Riley Ridge

Denbury  
? MMcf/day

Estimated CO2 costs  
1-2% of oil price

Potential incremental recovery  
1-2.5 bbls oil per ton CO2

Field Name	Year Started	Mcf CO2 Injected	Tons CO2
Salt Creek	2003	1,855,915,086	106,155,413
Patrick Draw	2003	759,035,446	43,415,629
Lost Soldier	1989	266,210,362	15,226,812
Beaver Creek	2008	161,263,510	9,224,018
Wertz	1986	68,818,359	3,936,301
Big Sand Draw	2013	35,720,452	2,043,153
Grieve	2012	33,240,232	1,901,289
Crooks Gap	2002	1,103,331	63,109
Sussex	2004	253,641	14,508
Glenrock South	2011	27,460	1,571
Pitchfork	2011	1,390	80

Injection data from the Wyoming Oil and Gas Conservation Commission

# Conclusions

## Lessons from early development in the Bighorn Basin

Early on pay was defined based on economic saturations and porosity

Drilling costs and water handling were key factors

Undeveloped zone (ROZ) volumes far exceed developed pay volumes

(Undeveloped zone oil saturations range from 30-50% from evaluation of Frannie-Sage Creek area)

## Geologic Setting

Rocky Mountain tectonics vs Permian Basin tectonics

System source rocks – Just not there anymore!

Closed vs Open fracture networks

Timing and style of migration

Isolated and compartmentalized structures

## Fractures

Form and Fill?

## Opportunities & Challenges for CO2-EOR in Wyoming

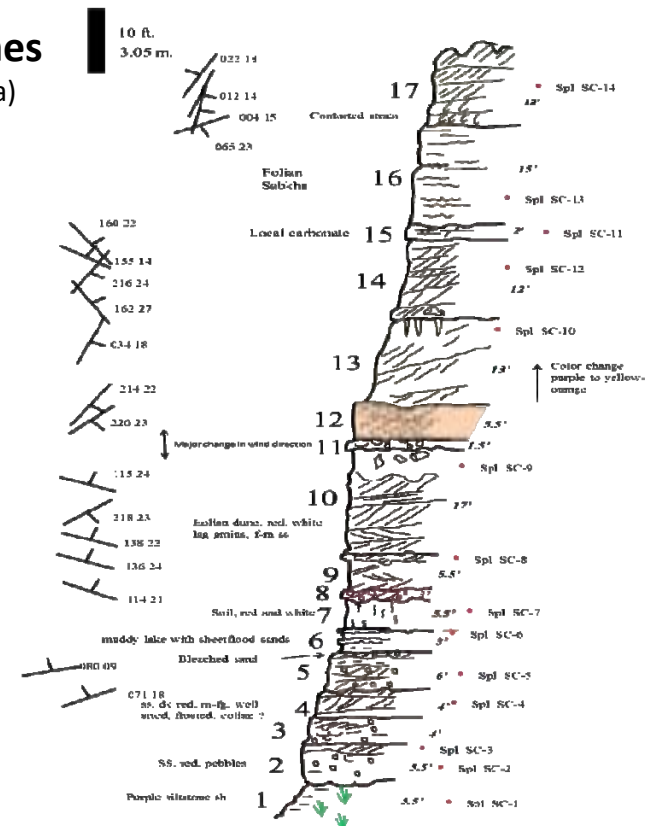
Bighorn Basin – Needs pipelines

Wind River Basin – Active work by Denbury

Casper Arch – Active Fleur De Lis

Sand Wash Basin – Active Memorial Resources

Measured section: Tensleep (Casper) Formation  
Sand Creek, Albany County Wyoming  
Fryberger, Jones, Johnson  
Section complete except for upper 30 feet of Tensleep



# Enhanced and Improved Oil Recovery



## Acknowledgements and Credits

- Enhanced Oil Recovery Commission
- Wyoming Oil & Gas Conservation Commission
- Wyoming Geological Association
- Wyoming Pipeline Authority
- University of Wyoming School of Energy Resources



## Special thanks and credit to:

Peigui Yin  
Matt Johnson  
Steve Fryberger





# Thank You or Questions, Comments, Concerns

Nick Jones- Manager, Conventional Resources

[NJones@uwyo.edu](mailto:NJones@uwyo.edu)

Office 307-761-3284

[www.uwyo.edu/eori](http://www.uwyo.edu/eori)



# Notes

