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THE MOWRY SHALE OF THE POWDER RIVER BASIN: A MULTISCALE RE-EVALUATION OF A SUPER BASIN SOURCE ROCK AND EMERGING UNCONVENTIONAL PLAY

Mowry Shale Petroleum System



Oil Seeps in 1899 – Plunkett Anticline, Wind River Basin



"The oil emerges with small amounts of water and gas. It is a light volatile oil, very different from the dark heavy high sulfur oils described at most of the other sites, and has very little accumulation of tarry residue" Photos modified from Love, 1978

Mowry Shale Play History

30000

28000

2019

2018

Emerging Play:

- Mowry accounts for ~2% of all hz wells in PRB
- <40 Mowry wells; results improving w/ time
- How can we repeat or improve upon current results?



Normalized Hz Mowry Shale Production Results

Mowry Shale Background





- Light gray siliceous shale with abundant radiolarian tests, fish scales & other fish debris, marine organic matter, & bentonites + varying detrital silt
- Deposited during a major transgression (late Albian-early Cenomanian)
 Low-angle ramp (<0.01°) in an elongate seaway with cool Boreal waters
 - (not connected southward to warm Tethyan sea)

Belle Fourche Sh	Gross Thickness	130-250' (PRB)
	тос	<1-8 wt% ave 2-3 wt%
Thermopolis	Porosity	5-9% ave 7%
THURSE STATES	Permeability	200-300 nD
	Sw	>50% often >90% in upper Mowry
Devil's Kitchen (N. Greybull), WY	Kerogen	mixed Type II/Type III

Powder River Basin Mowry Shale



Structure (TVD), CI 1000'

Gross Thickness, CI 12.5'



Components: Radiolaria





Images courtesy J. May

20 µm

Components: Fish Scales, Bones, and Teeth





Components: Bentonite Beds and Laminae





Components: Marine Organic Matter and Clay



Organo-minerallic aggregates (OMAs) = "marine snow" or "carbon rain"



Components: Detrital Silt









Research Dataset



- Petra project across Big Horn, Wind River, and Powder River Basins
- Eight+ Mowry outcrops
- Seven cores with near complete Mowry Shale intervals
 - **191 XRD samples**
 - 206 crush rock samples (GRI/SRP)
 - 209 Rock Eval samples

Major Facies – Shades of Gray

MUDTOC **Extrabasinal/Detrital** Intrabasinal/Biogenic **Big Horn Powder River Bioturbated Bioturbated** Ash & & cross-lam **Microcrystalline** Siliceous mudstone with varying silty interlaminated muddy quartz-rich proportions of silt laminae mudstone mudstone ash & clay siltstone & sandstone

Mowry Systems Tracts and Sequence Boundaries

HST



- low-gradient ramp (<0.01°)
- no lowstand fans (no lowstand systems tract)
- transgressive systems tracts are thin to nonexistent basinward
- sequence boundary is a correlative conformity ("maximum regressive surface")



continental sandstone & mudstone

shallow-marine sandstone

mfs/cs

HST





Existing Sequence Stratigraphic Model





- Outcrop description from Cottonwood Creek
- Mowry consists of
 - Latest portion of transgressive systems tract
 - Early highstand systems tract
 - Condensed section in the middle with a maximum flooding surface
- Is there another way to interpret the Mowry within a sequence stratigraphic framework?



Mowry Parasequences



Mowry Systems Tracts & Sequence Boundaries



J. May

Updated Model and Regional Correlations





Lower-Middle-Upper Gross Thickness





*Note colorbar change

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Lower-Middle-Upper TOC





Lower-Middle-Upper Water Saturation

Lower-Middle-Upper Permeability



Lateral Target Selection



Target uppermost siliceous parasequences in the most regressive HST (middle Mowry) where:

- TOC is high
- Better perm
- Favorable geomech





Temperature and Maturity





Maturity Trends – Core Scale



- Lower mixed I/S
- Lower Sw
- Increased porosity
- Enhanced permeability





Maturity Trends – Pore Scale

MINES



Improved Well Performance



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Increased Lateral Length



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MUDTOC

Completion Metrics Over Time





- Higher fluid concentrations, ~50gal/ft
- Higher proppant concentrations, ~2,750'lbs/ft
- Increase in stage count
- Decrease in stage length, ~150'-200'



Key Takeaways



- recrystallized radiolaria dominate
- variable detrital overprint
- highest average Shc (though not the target zone)
- High-frequency Sequences
 - multiple thin parasequences with upward increasing silt & bioturbation
 - arranged into 3 regressive (highstand) systems tracts

• Sweet-spot Identification

- hotspot identification is key
- increased maturity samples have decreased mixed illite/smectite, lower Sw, higher porosity, & higher permeability (+ "goldilocks" GOR)

Reservoir Quality

- organic & clay content, + silica diagenesis, influence pore development
- coarser grained facies have increased extrabasinal silica, higher porosity, & higher permeability,
 <u>BUT</u> lower TOC and higher Sw
- middle Mowry has highest TOC & Shc
- optimal target is the upper middle Mowry (near top of HST)



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STRATUM

Mike Johnson & Associates

GEOMARK

LOGS





Major Mudstone Facies – Powder River Basin

 Facies 1:

 Bioturb Sandy

 Mudst

 Finity Lam

 Silty Mudst

Extrabasinal



Intrabasinal

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