Received Shelton Award for best paper presented in Search and Discovery 2011.

Characterization of the Bakken System of the Williston Basin from Pores to Production; The Power of a Source Rock/Unconventional Reservoir Couplet*

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Abstract

The Williston Basin Bakken system development in the last five years has become the largest field in the Continental USA with 3.8 billion barrels recoverable (USGS). The Devonian aged Middle Bakken Carbonate interval and the Three Forks dolomites comprise the reservoirs of this highly economic sequence, and the world class source rocks include the upper and lower Bakken shales.

The reservoir rocks of both the Middle Bakken and the Three Forks formations are considered tight and unconventional, with average porosities of 4-8% and permeability in the microdarcy range. It is the close vertical juxtaposition of these reservoirs with the world class source rock shales that create an ideal target for stratified oil-saturated reservoir targets perfect for horizontal drilling. Multistage stimulation techniques bring the state-of-the-art completion technology necessary for effectively stimulating these tight reservoirs and producing highly economic volumes of oil.

The Bakken reservoir rocks are highly complicated and variable. There are many stratigraphic targets and sweet spots for lateral drilling around the basin. Variables such as thermal maturity and facies distribution are primary controls on the distribution of the overall play. Natural fracturing of the reservoir is also key to success, and ranges from microfracturing, diagenetically-enhanced fracturing, hydraulic fracturing due to hydrocarbon generation, and tectonic fracturing of brittle rock types. Facies controlled lithologies and subsequent diagenesis also play a role in reservoir quality. Finally, reservoir pressure and water saturation play a role in the ultimate recoveries. Understandably, these variables yield a wide range of reservoir

targets and production characteristics around the Williston Basin. Case studies from several of these areas will be presented. The Bakken System at Elm Coulee, Parshall Field, and the Nesson Anticline will be presented, showing how each of these areas varies in terms of reservoir specifics and recoveries.

Characterization of the Bakken System of the Williston Basin from Pores to Production; The Power of a Source Rock/Unconventional Reservoir Couplet

ANNE GRAU – FIDELITY EXPLORATION AND PRODUCTION CO.
ROBERT STERLING – CIRQUE RESOURCES LP

AAPG ICE
MILAN, ITALY
2011

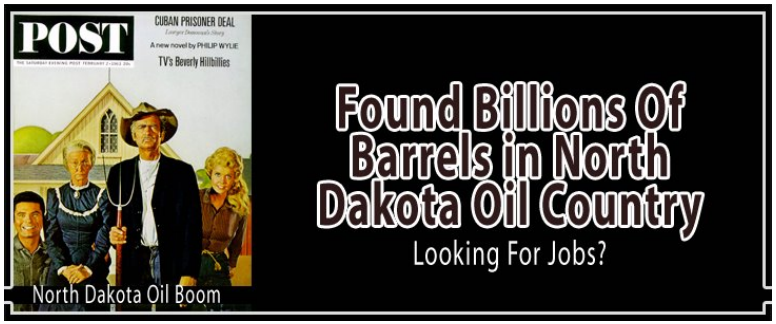
OUTLINE

Going Back to the Beginning

- A brief history of the Bakken Play evolution in the Williston Basin

Parshall Field Attributes

- High EURS and rates of production



Parshall Play Type

- Unique Middle Bakken Reservoir
- Unique Stratigraphic Trap
- Unique Maturity Setting
- Unique pressuring
- Oil Wet: High Oil Saturation

Implications

- Multiple Play Types within Bakken System
- Multidisciplinary Technical Approach Necessary
- Completion Approach Critical!

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LOCATION

Source: U.S. Energy Information Administration based on data from various published studies. Canada and Mexico plays from ARI.
Updated: May 9, 2011

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SIGNIFICANCE

Top 18 Giant Fields

Field Name	Country	Discovery year	Range of URR [GB]
Ghawar	Saudi Arabia	1948	66-100
Burgan Greater	Kuwait	1938	32-60
Safaniya	Saudi Arabia	1951	21-36
Bolivar Coastal	Venezuela	1917	14-36
Berri	Saudi Arabia	1964	10-25
Rumalia N&S	Iraq	1953	22
Zakum	Abu Dhabi	1964	17-21
Cantarell Complex	Mexico	1976	11-20
Manifa	Saudi Arabia	1957	17
Kirkuk	Iraq	1927	16
Gashsaran	Iran	1928	12-15
Abqaiq	Saudi Arabia	1941	10-15
Ahwaz	Iran	1958	13-15
Marun	Iran	1963	12-14
Samotlor	Russia	1961	6-14
Agha Jari	Iran	1937	6-14
Zuluf	Saudi Arabia	1965	12-14
Prudhoe Bay	Alaska	1969	13

Source: AAPG, OGJ, EIA

Eagleford Texas 2006 2-45 URR GB

Bakken North Dakota 2006 3.2-24 URR GB

Technology driven gas and liquid rich shale plays have transformed the US energy industry and supply outlook!

GB = Giga barrel = 10^9 Barrels = Billion Barrels
URR = Ultimate Recoverable Reserves

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Bakken Exploration In the Williston Basin

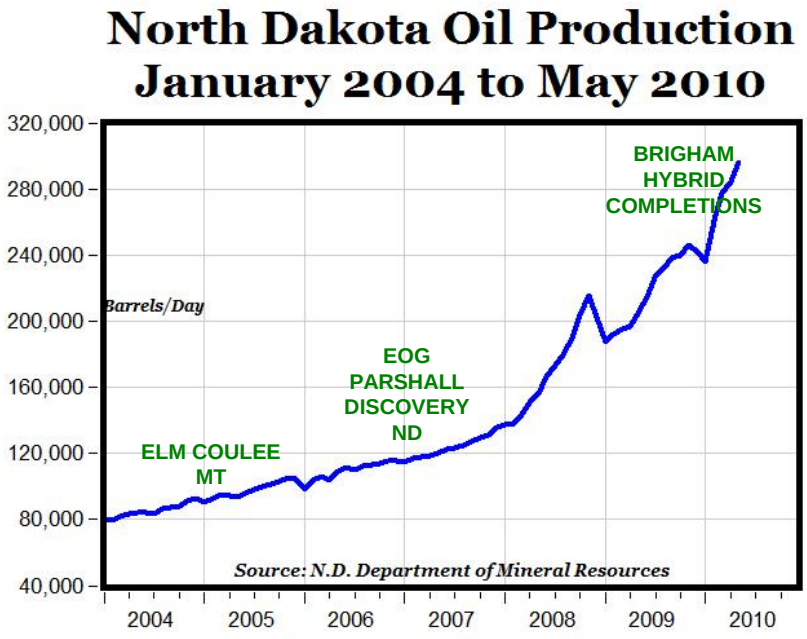
1990's:Vertical Well Production Fractured Shale along Depositional Boundaries

Horizontal Wells in Middle Bakken Reservoir:

1. Early 2000's Elm Coulee, MT
   - Unstimulated or Hail-Mary Frac's
   - Shorter laterals 320's/640's

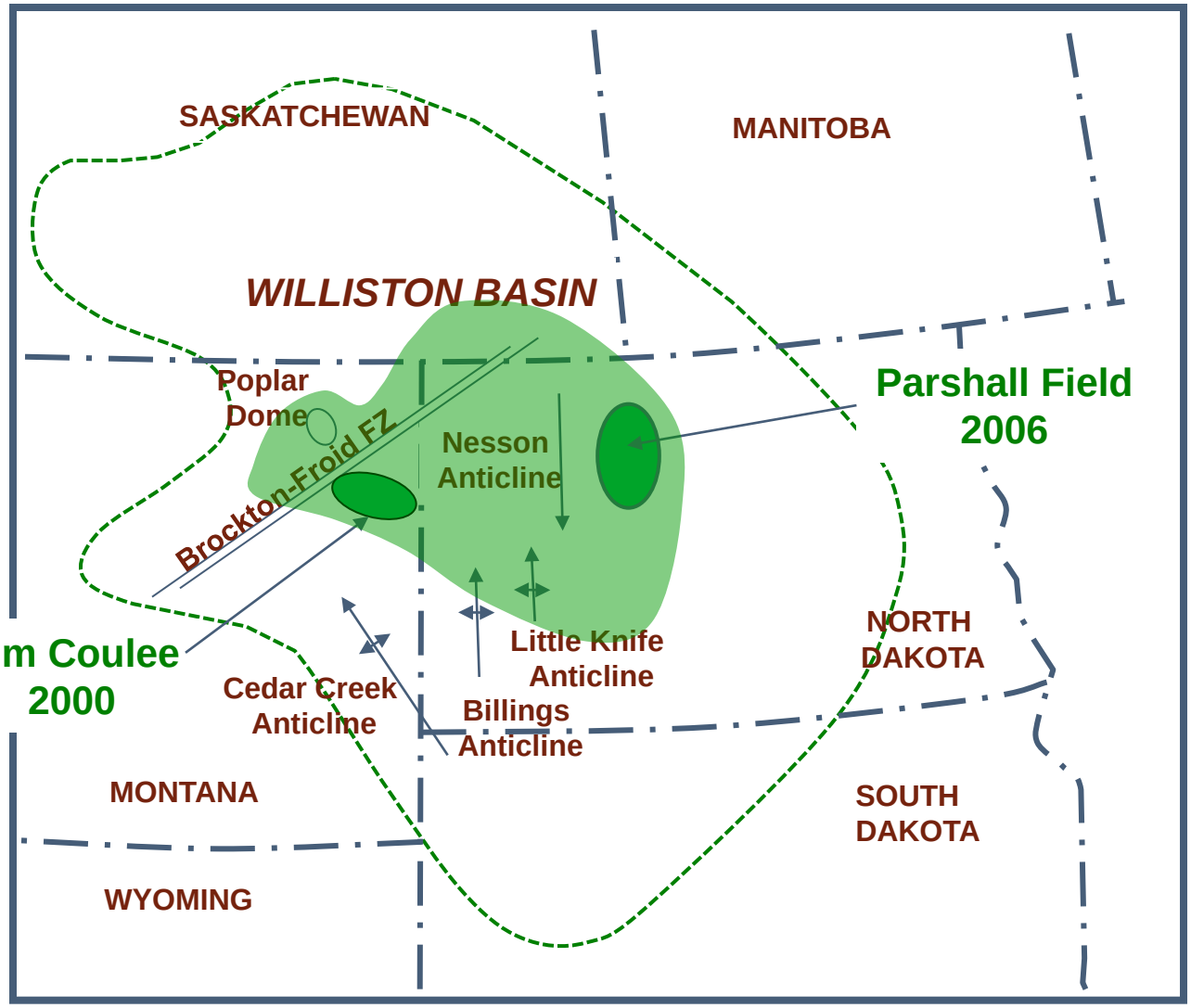
2. 2005-2009: Parshall and North Dakota
   - Staged Completions (5-12),
   - Longer laterals 640's and 1280's

3. 2009+
   - Hybrid Completions with Extensive Multi-Staged Fracs ("Brigham"-style) 30+
   - Longer Laterals 1280's+



http://www.theoildrum.com/node/3868

Middle Bakken: Large Area, Variable Deposition Patterns (Multiple Play types, Multiple Reservoir Targets)



Parshall Field Discovery 2006: Bakken Horizontal Drilling in North Dakota

From Wikipedia: “Bakken”

The greatest Bakken oil production comes from Elm Coulee Oil Field, Richland County, Montana, where production began in 2000 and is expected to ultimately total 270 million barrels. In 2007, production from Elm Coulee averaged 53,000 barrels per day (8,400 m^3/d) — more than the entire state of Montana a few years earlier.[12]

New interest developed in 2007 when EOG Resources out of Houston, Texas reported that a single well it had drilled into an oil-rich layer of shale below Parshall, North Dakota was anticipated to produce 700,000 barrels (111,000 m^3) of oil.[13] This, combined with other factors, including an oil-drilling tax break enacted by the state of North Dakota in 2007,[14] shifted attention in the Bakken from Montana to the North Dakota side.[*citation needed*] The number of wells drilled in the North Dakota Bakken jumped from 300 in 2006[15] to 457 in 2007.[16] Those same sources show oil production in the North Dakota Bakken increasing 229%, from 2.2 million barrels (350,000 m^3) in 2006 to 7.4 million barrels (1,180,000 m^3) in 2007.

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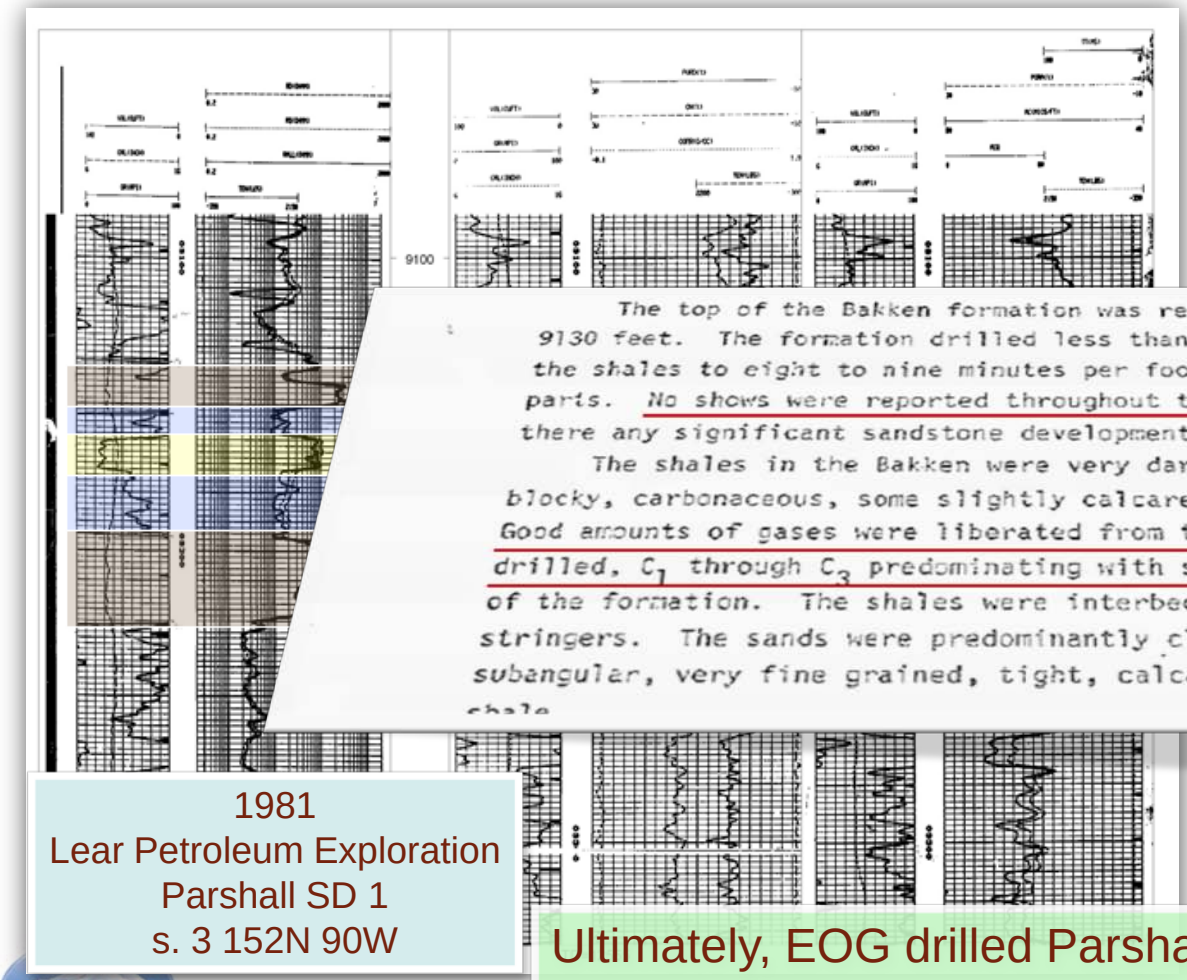
Evolution of Parshall Field Area: Lear Well

2005: The hunt for Elm Coulee Analogs

- **Resistivity anomaly**
- **Very Subtle Shows**



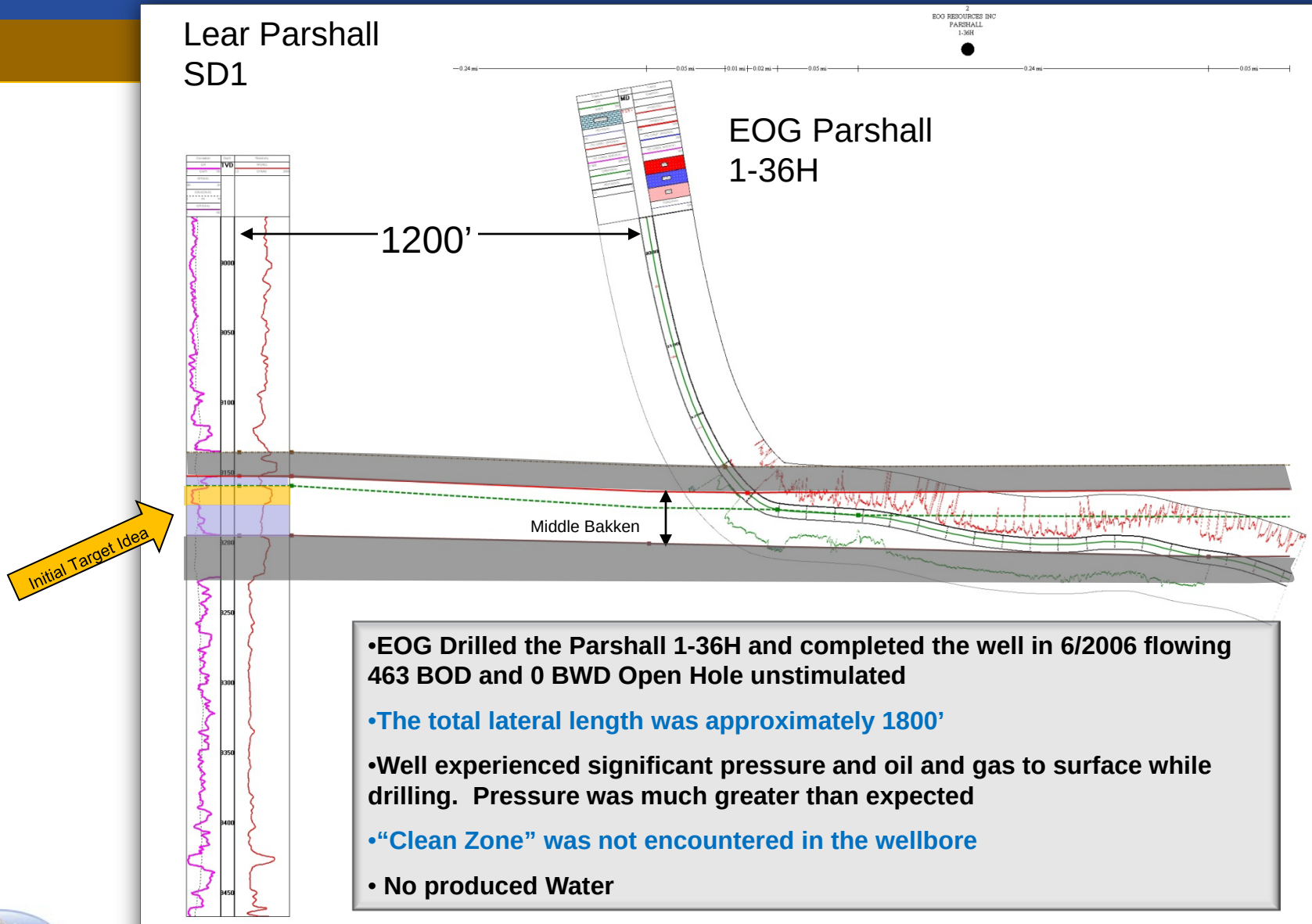
The top of the Bakken formation was reached at a drill depth of 9130 feet. The formation drilled less than five minutes per foot in the shales to eight to nine minutes per foot in the sandier, siltier parts. No shows were reported throughout the formation, nor was there any significant sandstone development.

The shales in the Bakken were very dark grey to dark brown, soft, blocky, carbonaceous, some slightly calcareous and pyritic in part. Good amounts of gases were liberated from the shales as they were drilled, C_1 through C_3 predominating with some C_4 seen at the very top of the formation. The shales were interbedded with thin sandstone stringers. The sands were predominantly clear to light grey coloured, subangular, very fine grained, tight, calcareous, silty grading into

1981
Lear Petroleum Exploration
Parshall SD 1
s. 3 152N 90W

Ultimately, EOG drilled Parshall 1-36H Discovery Well 1200’ away from this well

EOG Parshall 1-36 (Parshall Discovery Well)



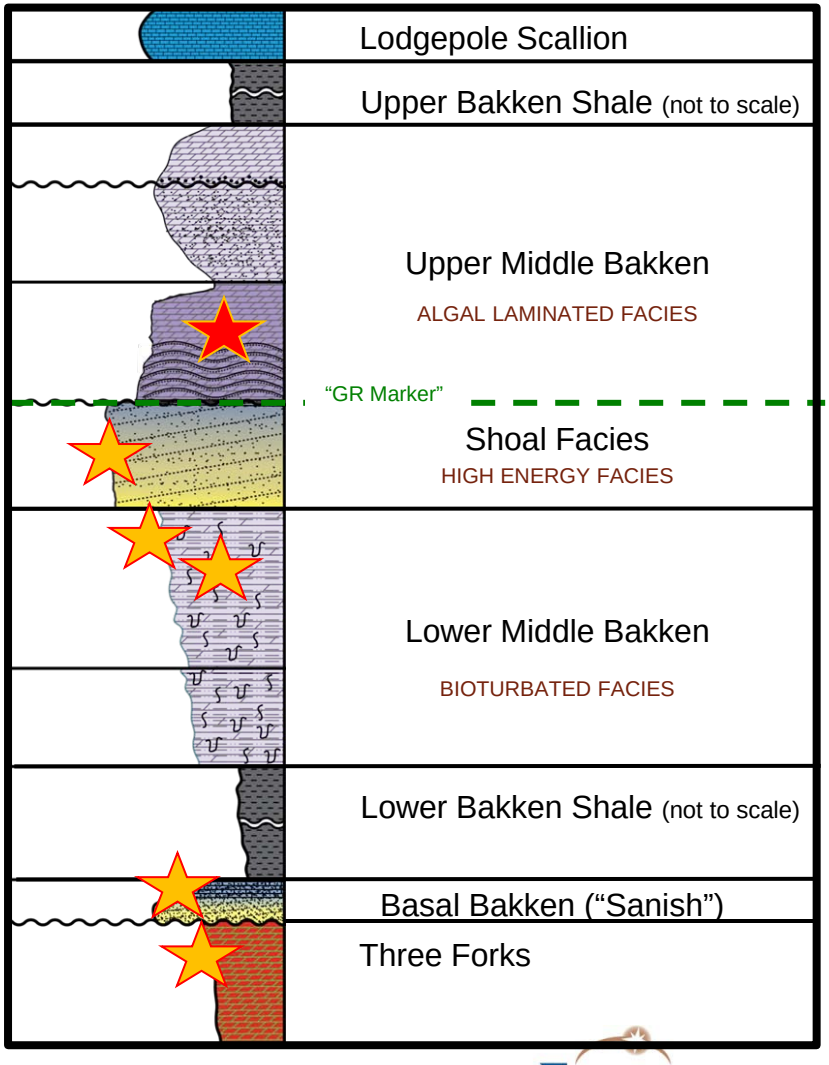
- **EOG Drilled the Parshall 1-36H and completed the well in 6/2006 flowing 463 BOD and 0 BWD Open Hole unstimulated**
- **The total lateral length was approximately 1800’**
- **Well experienced significant pressure and oil and gas to surface while drilling. Pressure was much greater than expected**
- **“Clean Zone” was not encountered in the wellbore**
- **No produced Water**

Bakken Petroleum System

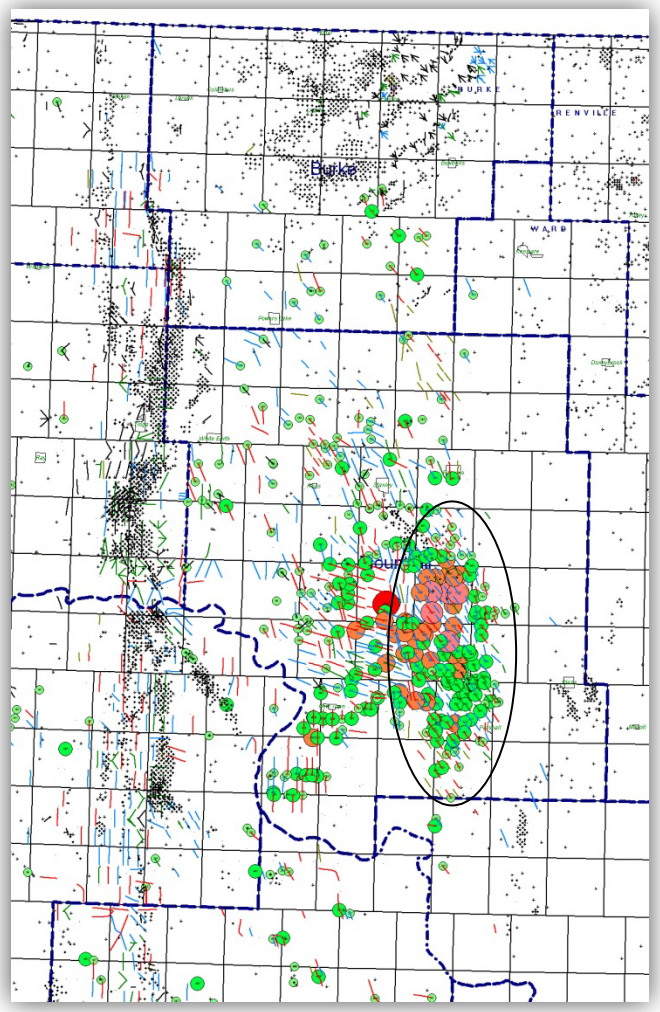
- **Source Rock: Upper and Lower Bakken Shales are World Class**
  - High TOC 11- >20%
  - Thermal History, Kitchen Identified by USGS (Price)
  - **Generated 400+ Billion Barrels (USGS)**
- **Unconventional Regional Reservoirs:**
- **Source Rock/Reservoir Couplet**
  - **"Tight" or "Unconventional" Oil- Continuous Phase**
  - ***NOT* a shale play**
  - Tight: 4-8% Porosity
  - 0.01-0.001 md Perm
  - Lodgepole in US is thick impermeable Seal to Bakken
- **Fracturing of Tight Reservoir Key to Producibility**
  - **Multiple Scales of Natural Fractures**

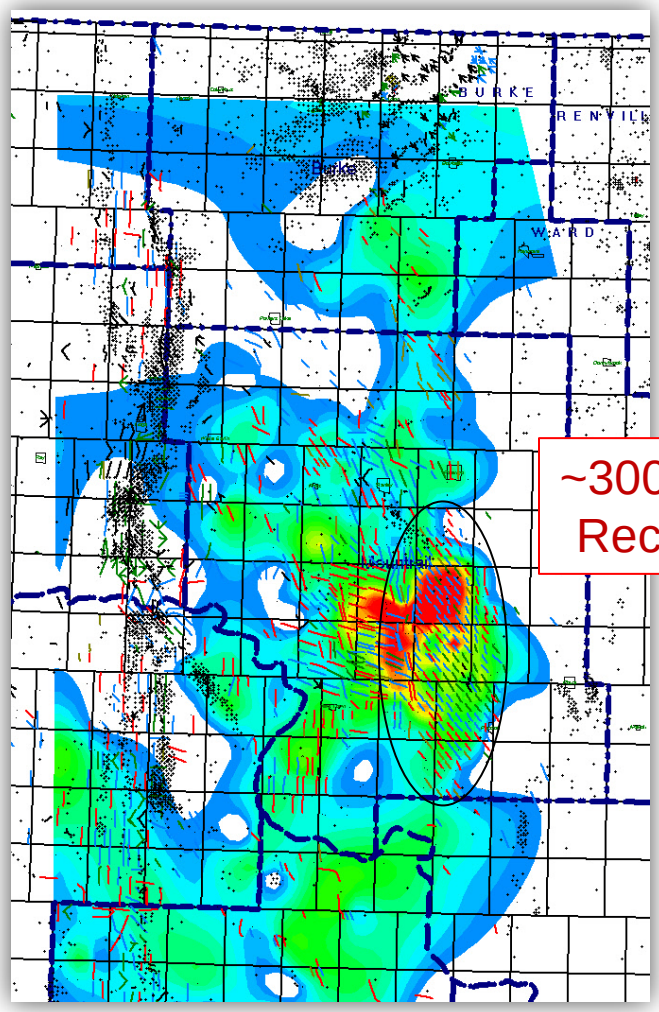
MULTIPLE BAKKEN SYSTEM
RESERVOIR TARGETS

MANY BAKKEN SYSTEM PLAY TYPES
IN THE WILLISTON BASIN



EUR Bakken Wells Only





~300 MMBOE Recoverable

What makes Parshall so Prolific?

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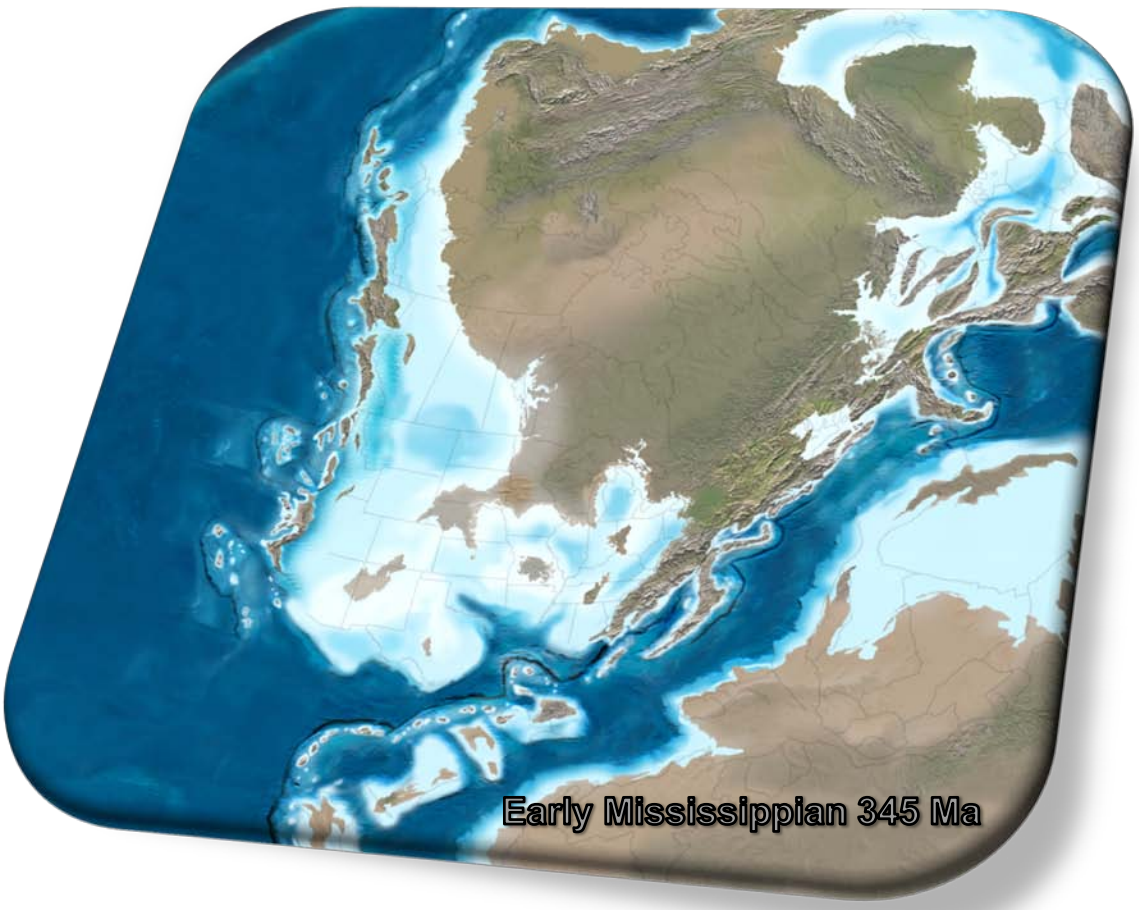
Blakey Depositional Setting for Bakken



Ron Blakey, NAU Geology

- Widespread Carbonate Deposition in NA
- Williston Basin on Equator
- Bakken: Mixed Carbonate Clastics
- Clastic influence from Landmass NE, E, and SE

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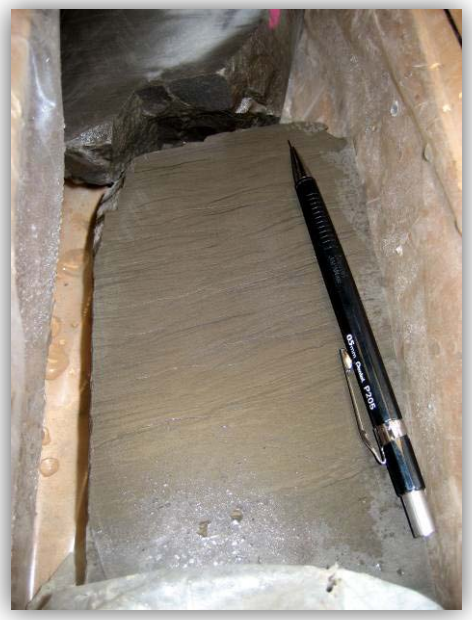
Comparison of similar log character in Core

(and the trouble with Rasters)

West — NESSON ANTICLINE — East — Southeast

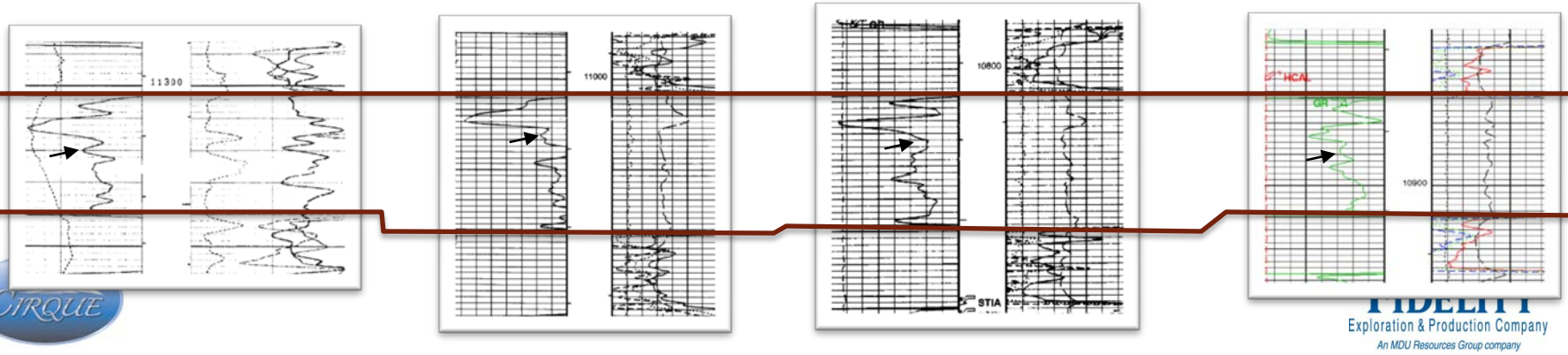


Silty Clay-rich Limestone

Partially Dolomitized Limestone

Dolomite

Clay-rich Silt



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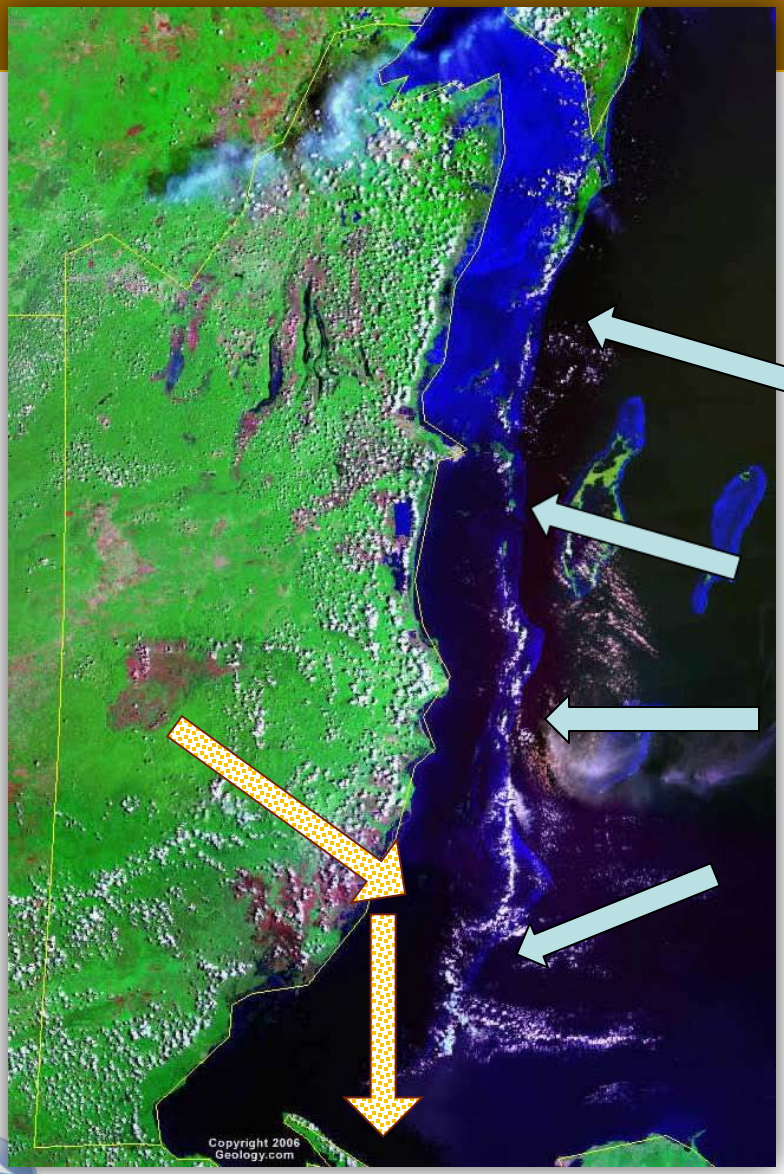
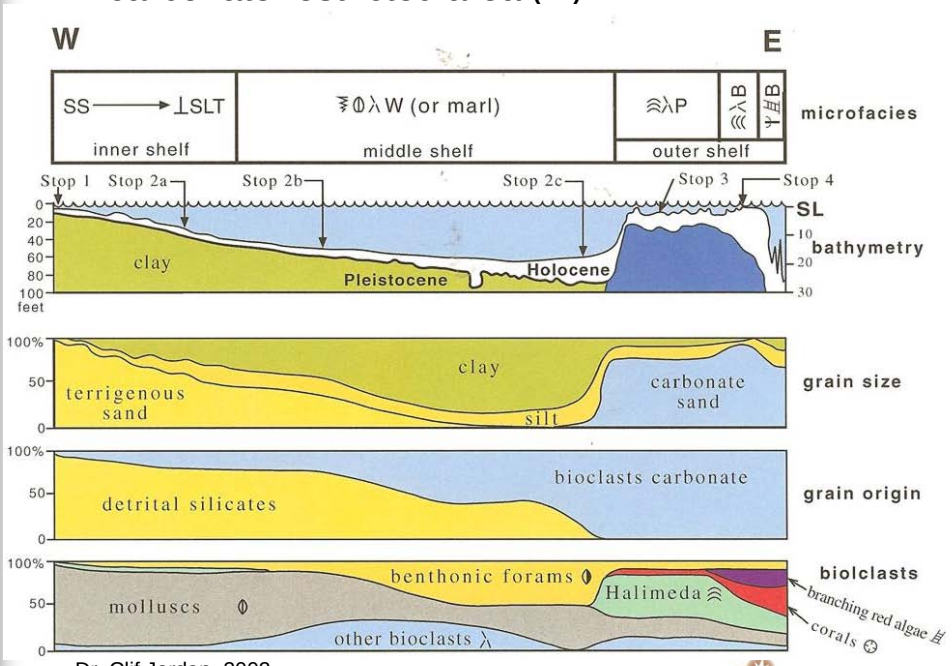
Present-Day Belize Model
Mixed Carbonate Clastic Setting



- Shallow Shelf & Shoreline
- Transitional facies Pattern
- Sediments from Maya Mountains (SW)
- Point sources of Sand Influx (rivers)
- Distribution of sand by long shore drift to south
- **Barrier** (reef) acts as protection to carbonate restricted area (N)



Dr. Clif Jordan, 2002

1 mi

Belize image from Geology.com

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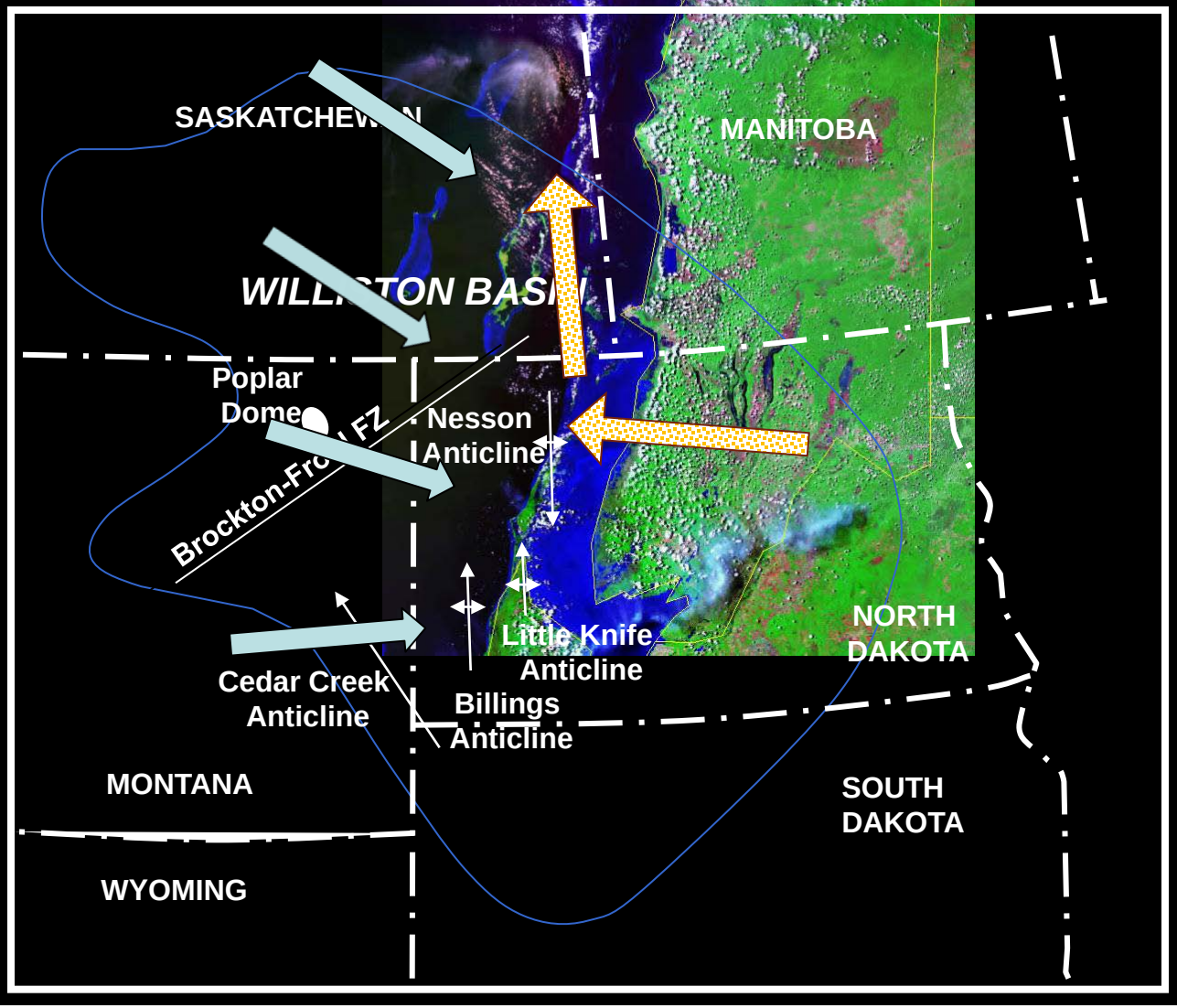
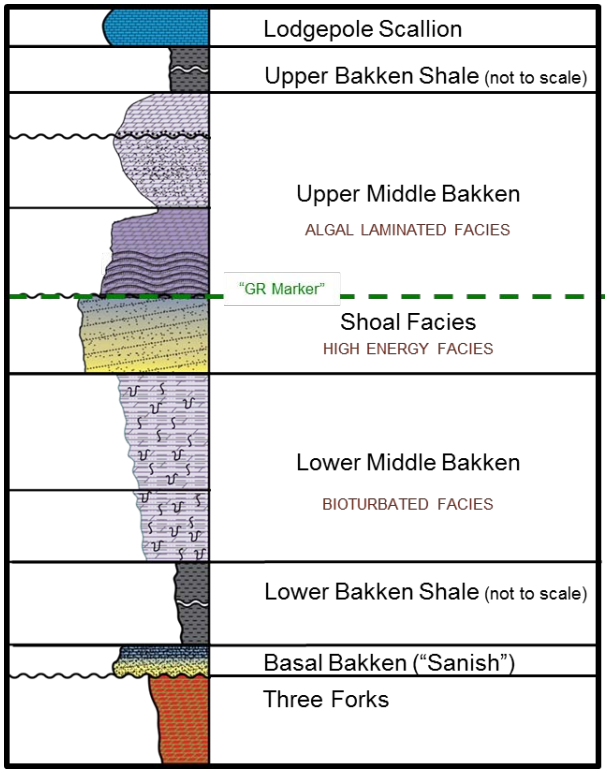
Middle Bakken: Large Area, Variable Deposition Patterns (Multiple Play types, Multiple Reservoir Targets)



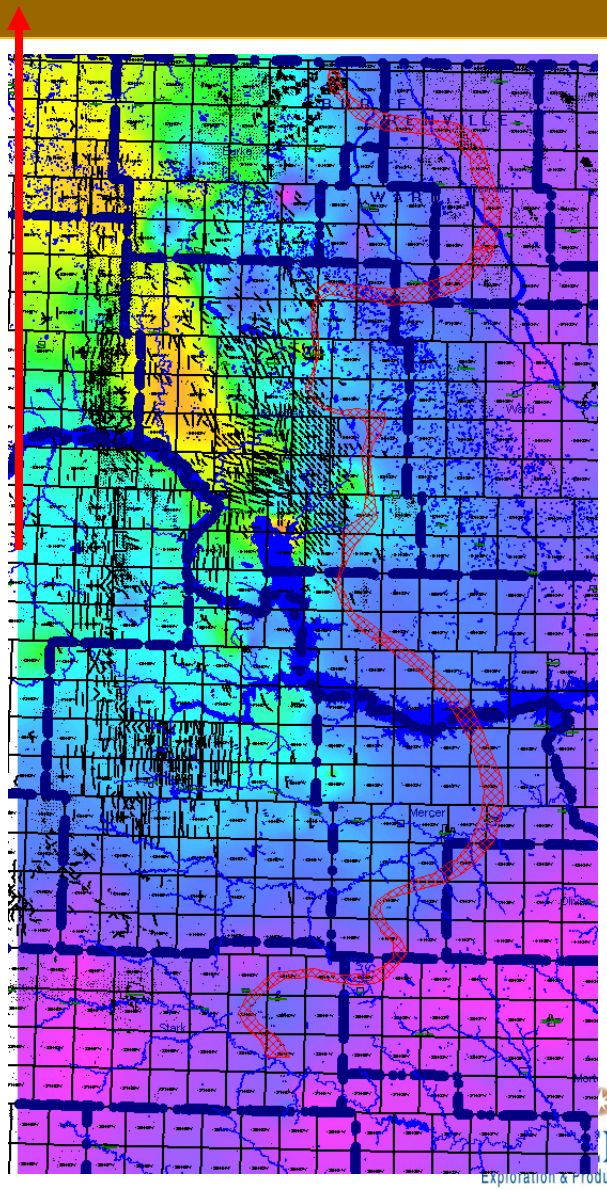
Location Map with Structural Elements (after Heck et al., 2004, Belize image from Geology.com)

ISOPACH
TOTAL MIDDLE BAKKEN

- Represents what most consider to be the distribution of “the Bakken play”
- Consists of all Middle Bakken lithologies
- Depositional thick along and east of Nesson Anticline



Total Middle Bakken Isopach Interval



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Isopach

Upper Middle Bakken (Algal Facies)

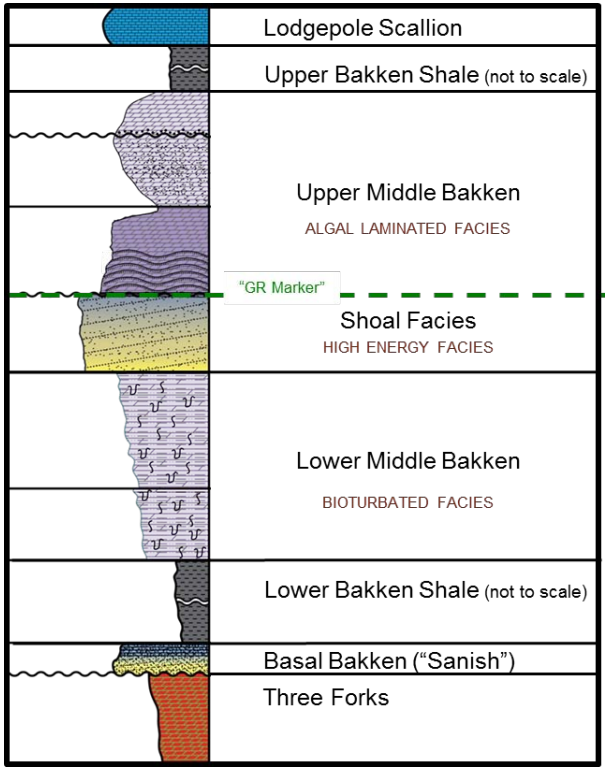
Facies consistant across this part of the basin and represent Carbonate Factory

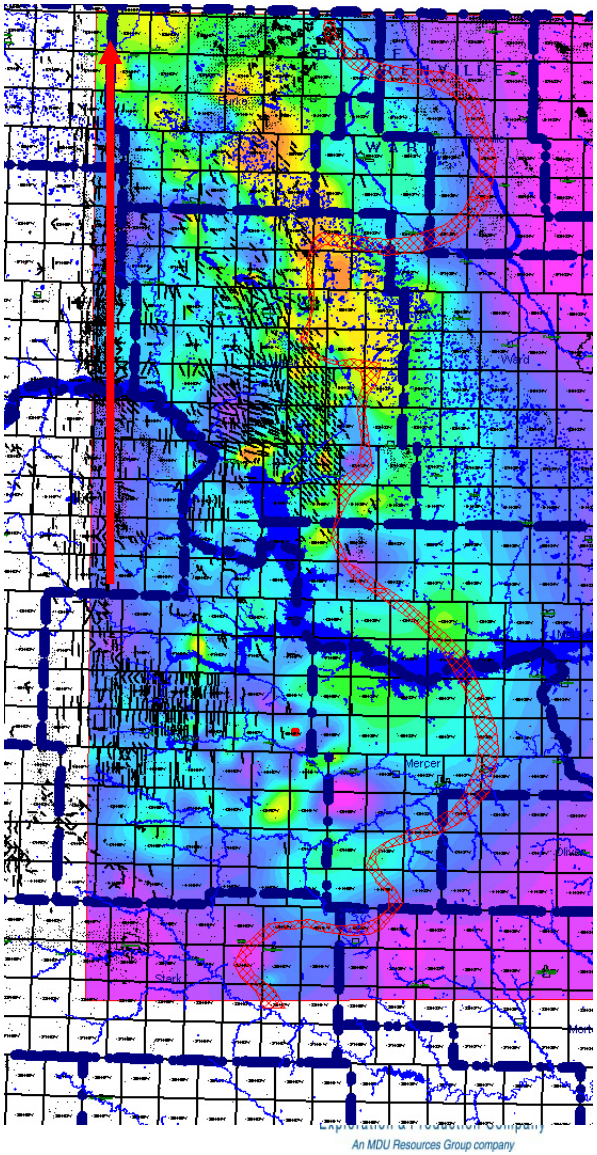
Lagoonal restriction caused by movement of Nesson Anticline

Interbedded algal and Lagoonal Dolomite (after Lagoonal carbonate mud)

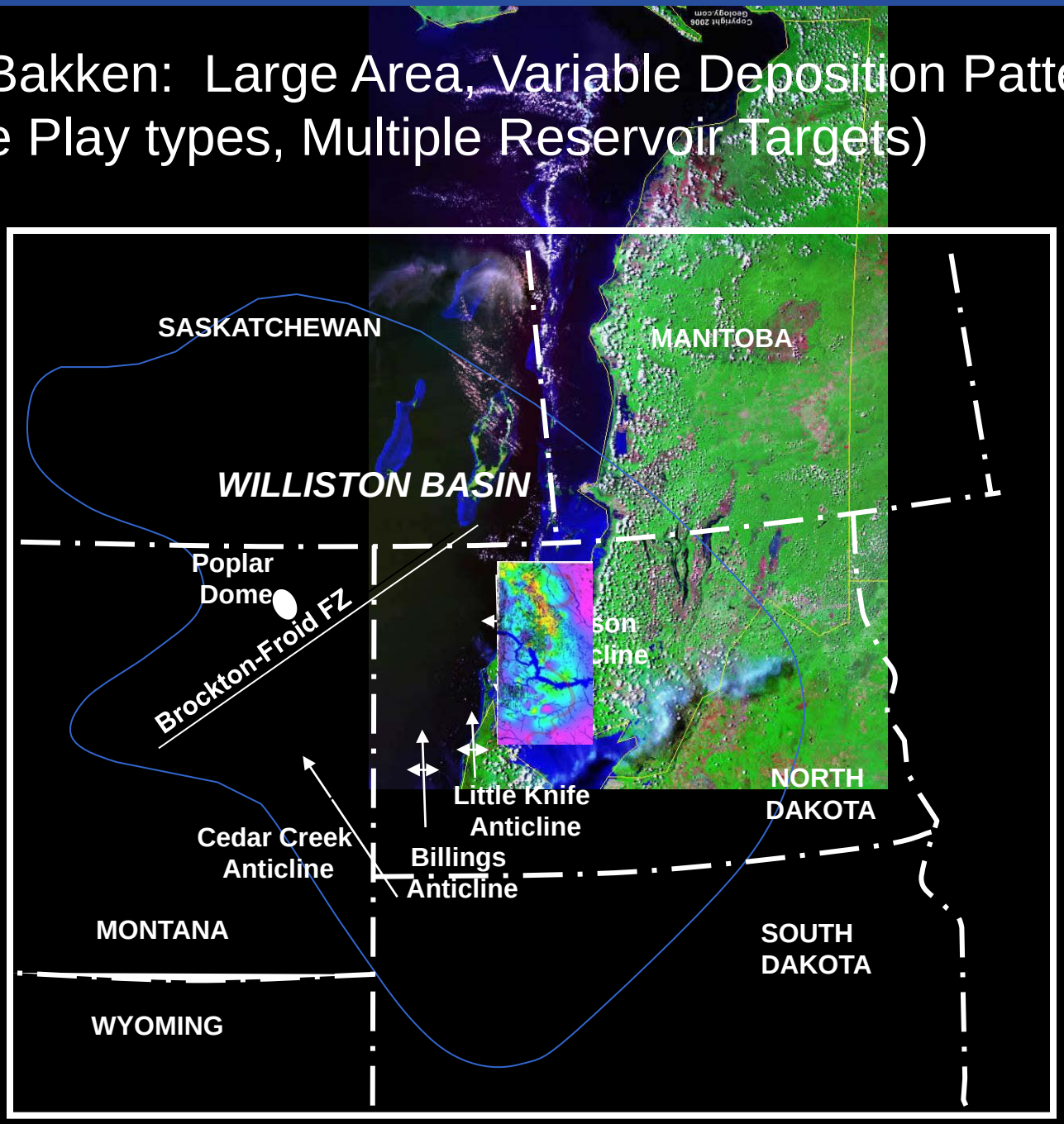
A resticted, hypersaline environment

Primary sedimentary structures preserved





Middle Bakken: Large Area, Variable Deposition Patterns (Multiple Play types, Multiple Reservoir Targets)



Location Map with Structural Elements (after Heck et al., 2004, Belize image from Geology.com)

Middle Bakken: Internal source of TOC

Algal Bioherm in EOG Hoff 1-H
Photo from NDIC Website

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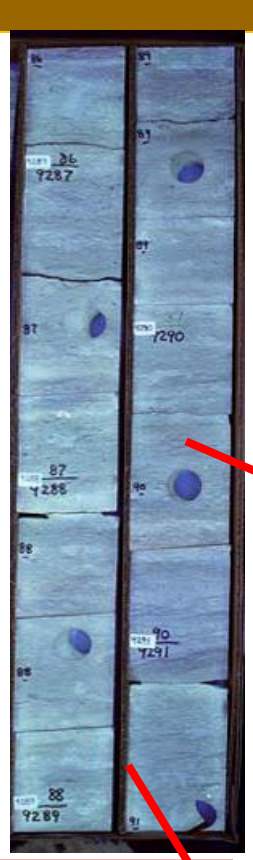
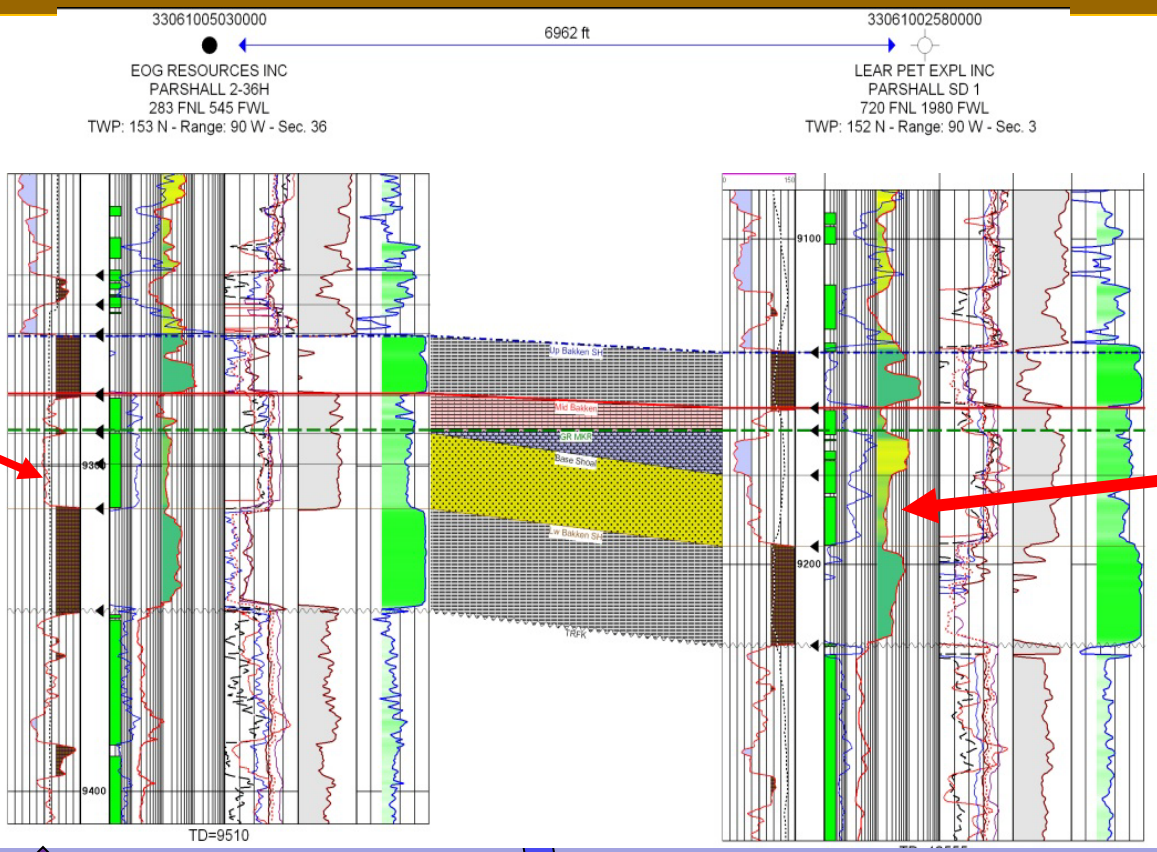
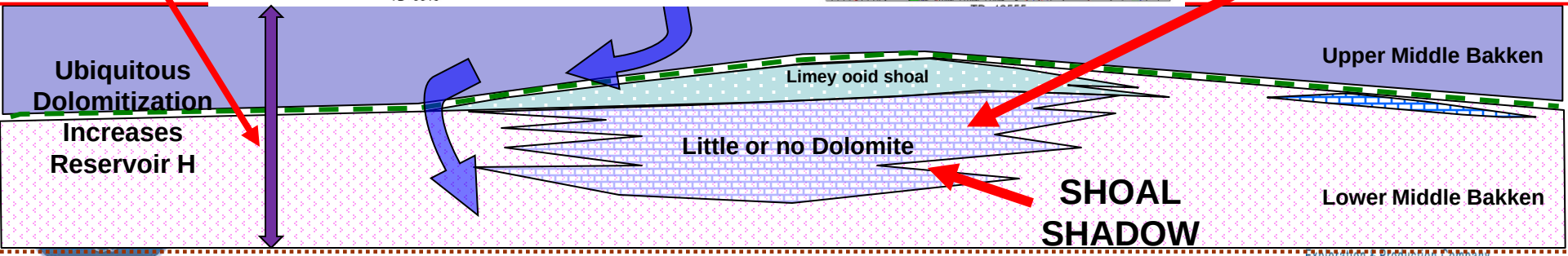
Diagentic Model for Parshall

Dolomitization shortly after deposition of Upper Middle Bakken

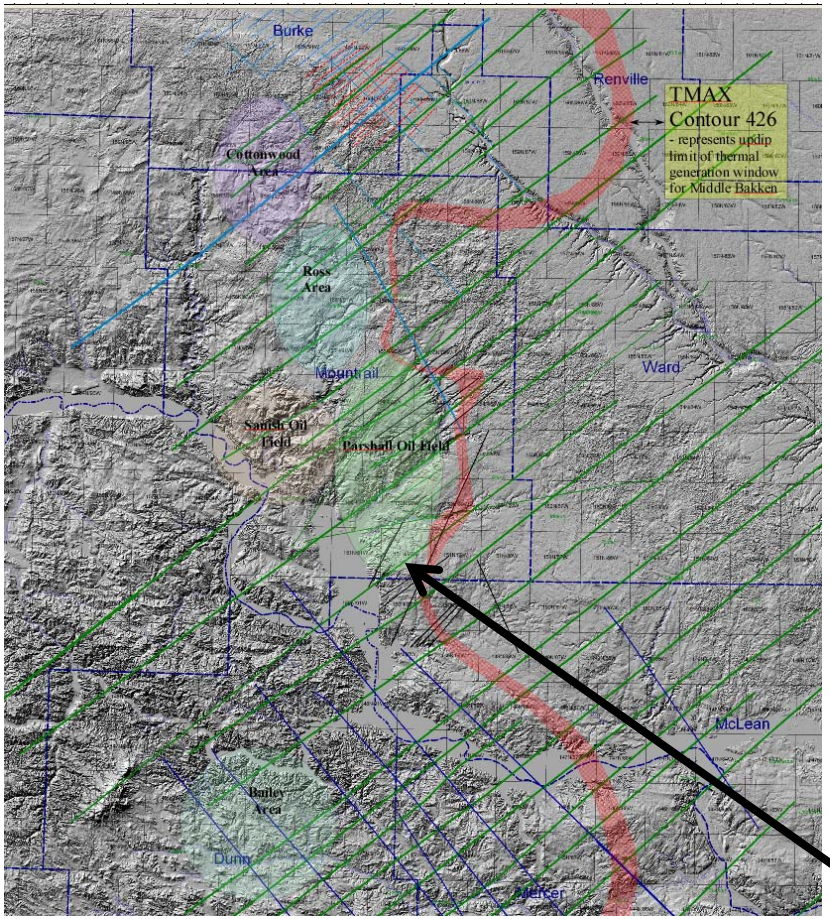




SHOAL SHADOW



Role of Fractures in the Bakken Play



Digital Elevation Map

Scales of Fracturing

- Regional
- Macro/Reservoir Scale
- Microfractures (Rock Fabric Scale)

Fracture content in Bakken important in reservoir development

More Fractures = More Production

Fractures affect basement heat flow

Variations in Thermal Maturity controlled by Fractures

Pressure cells are occasionally bound by sealing fractures.

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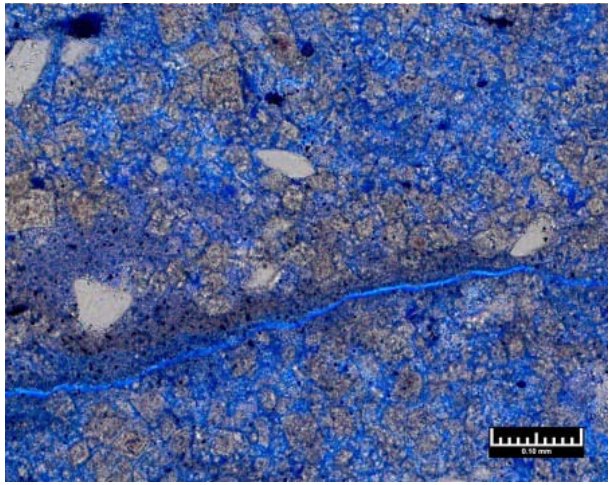
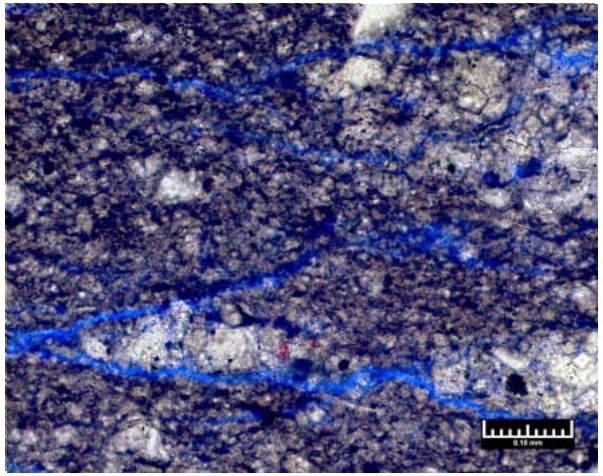
Middle Bakken Reservoir Properties at Parshall Field

Horizontal Fractures in EOG Hoff 1-H
Photo from NDIC Website

MICROFRACTURES IN THE ROCK FABRIC



Cirque Trippell #32-16H

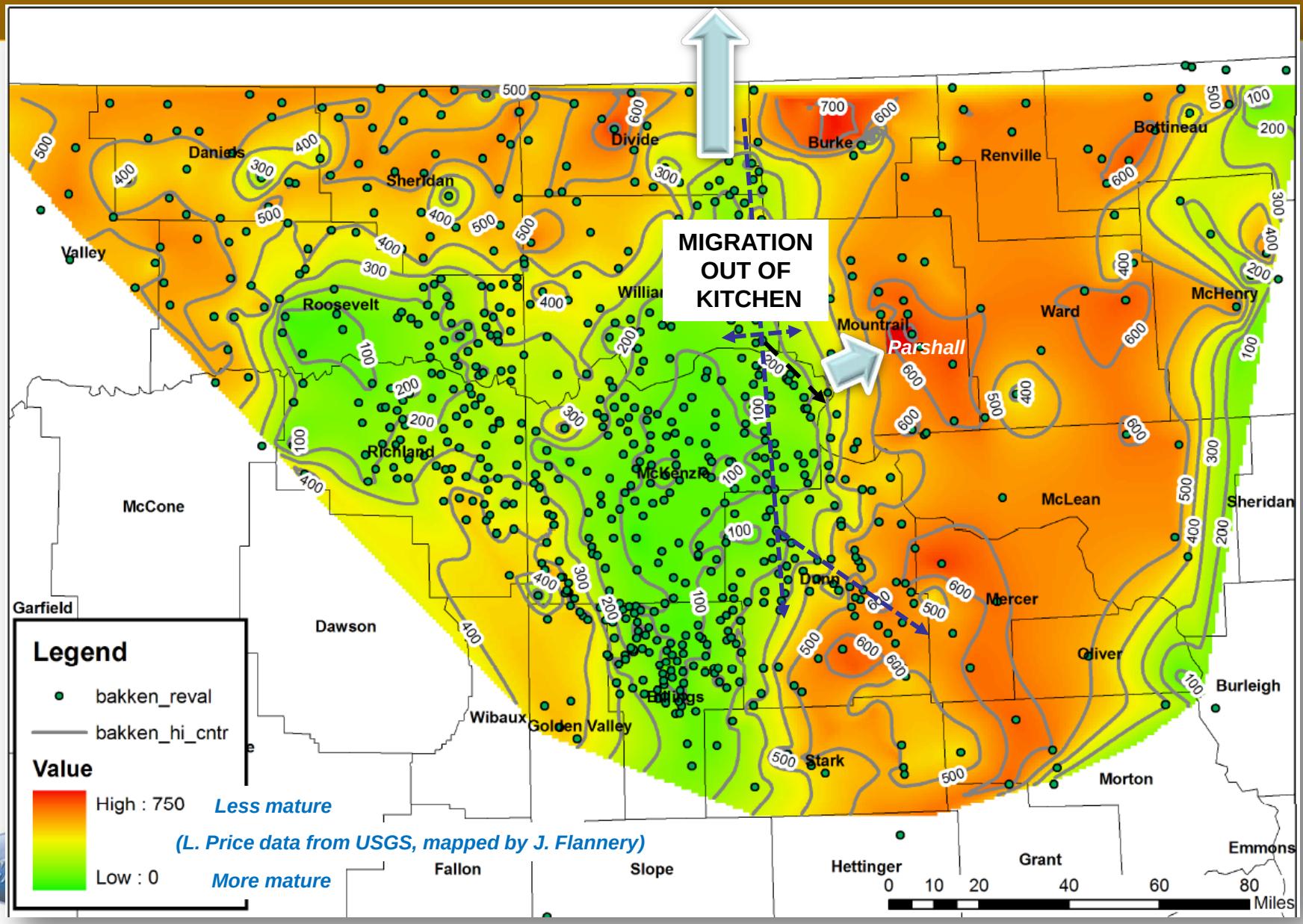


Cirque Gunnison St #44-36H

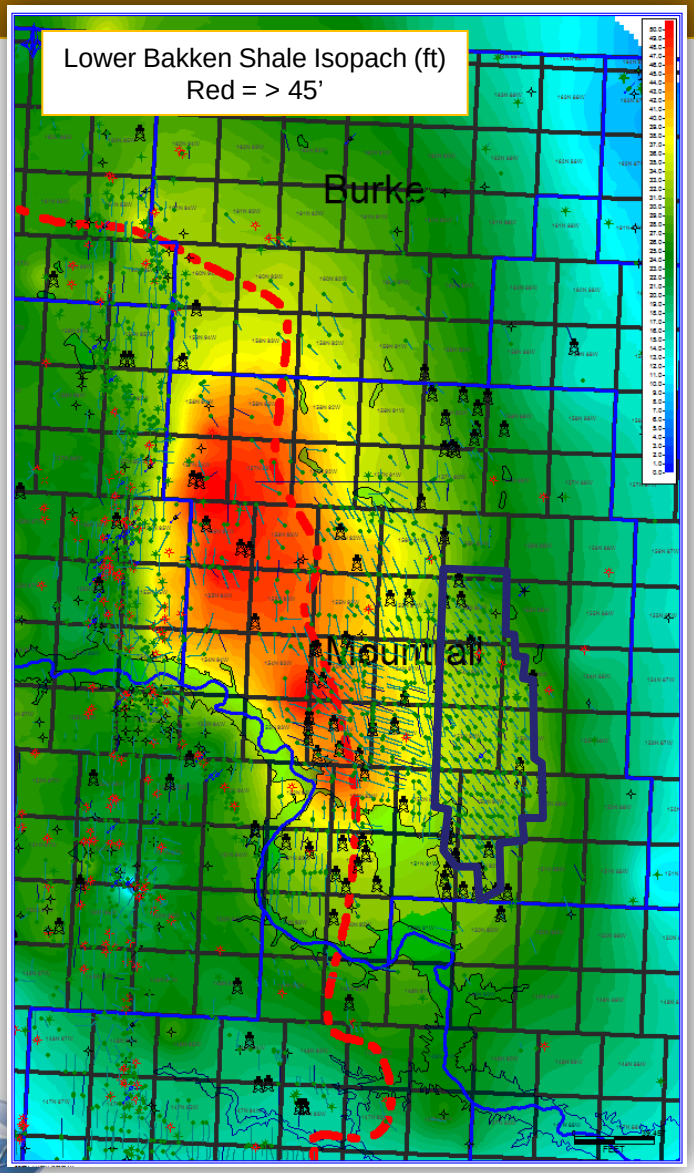
Vertical Fracture in EOG Long 1-H
Photo from NDIC Website

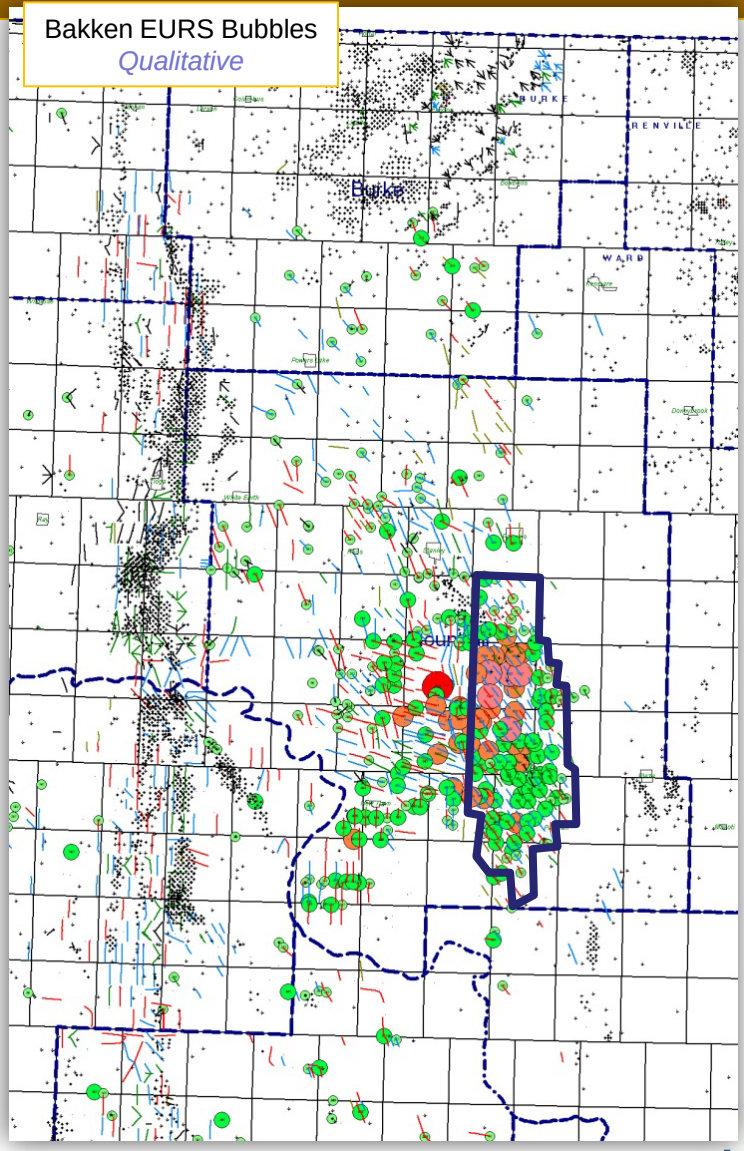
Fracturing at All Scales Contributes to Reservoir Performance

Bakken Formation- Hydrogen Index Source Rock Maturity Indicator



Lower Bakken Shale Isopach





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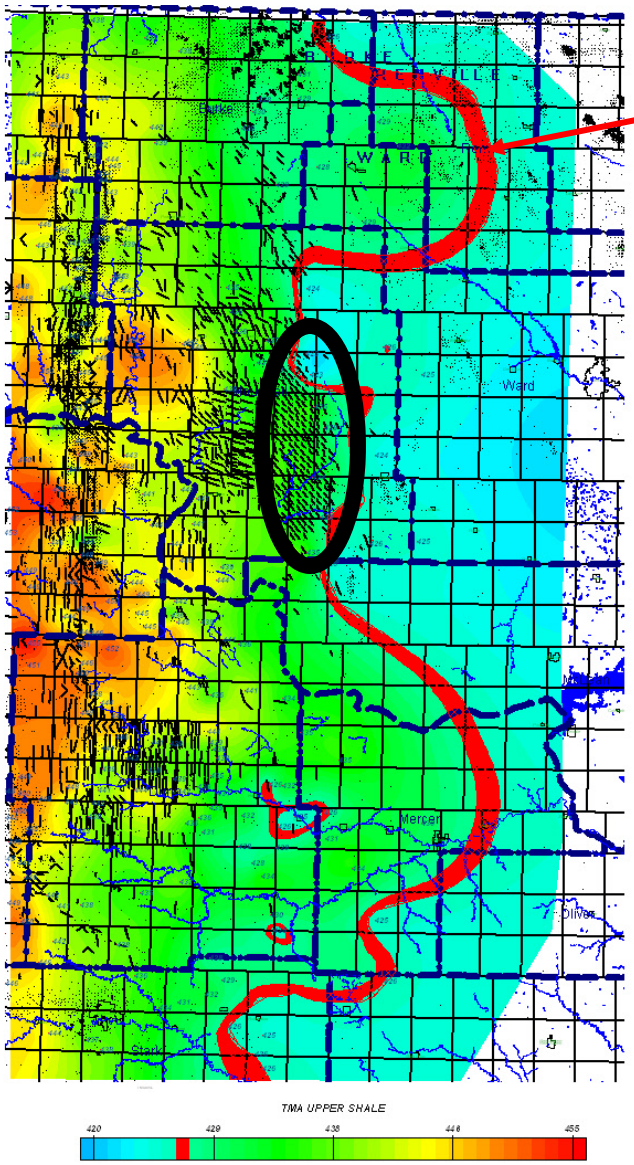
Source Rock Maturity



TMAX 426 Upper Shale

- Lineament distribution and magnitude appear to control basement heat flux
  - Accounts for lateral “shoulders” in updip maturity

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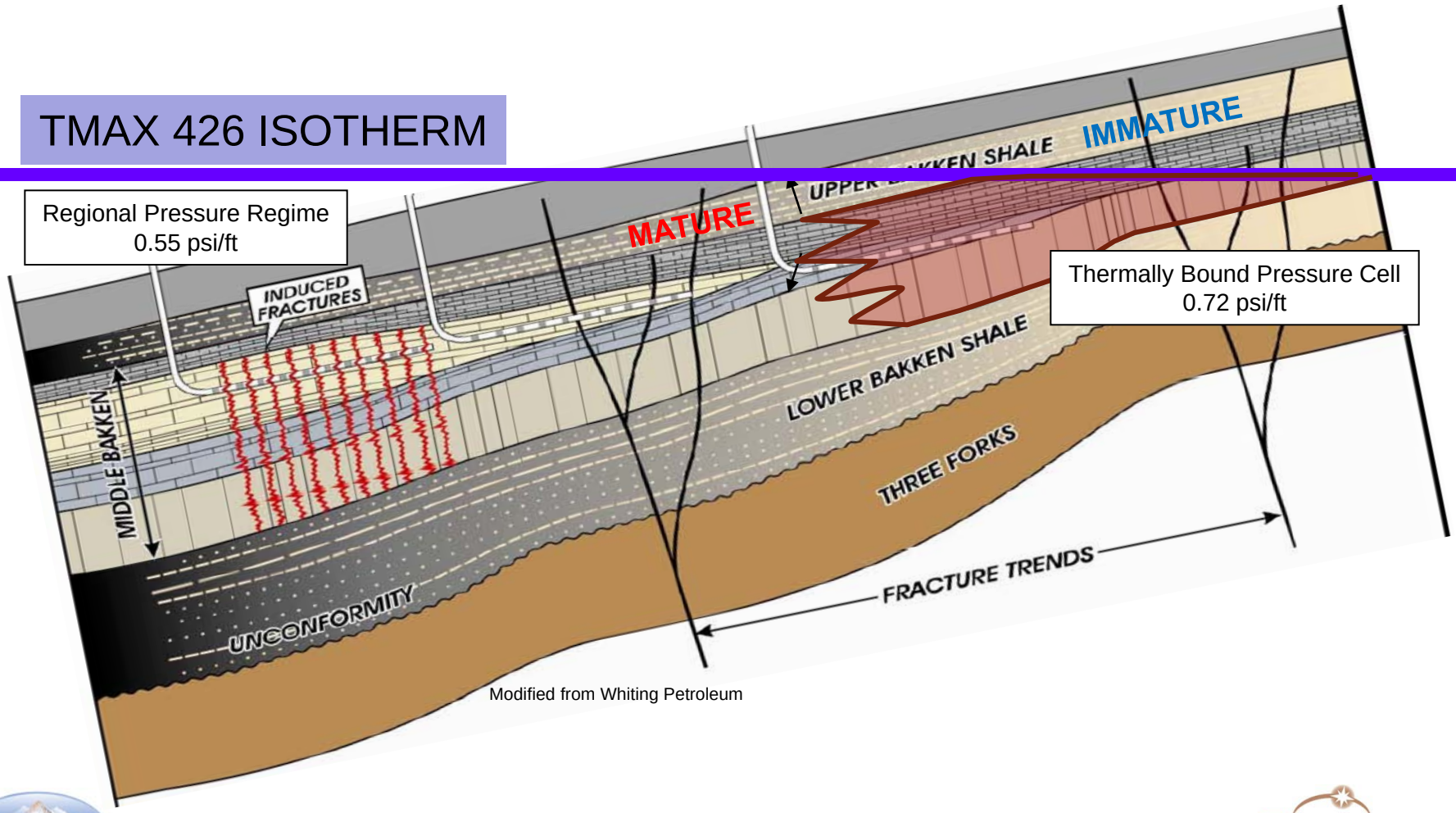
Pressure Model for Parshall Field

SANISH FIELD **PARSHALL FIELD**



Modified from Whiting Petroleum

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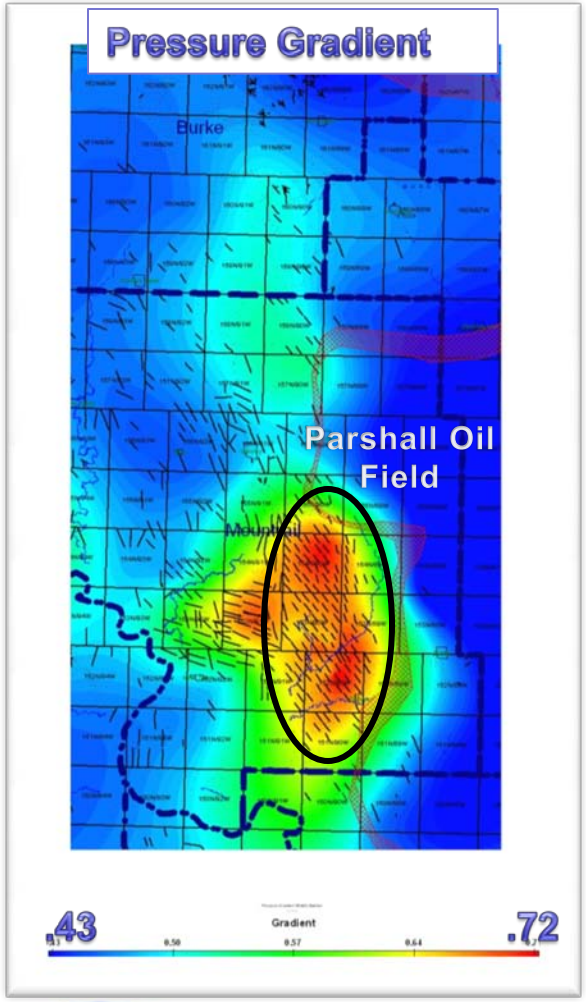
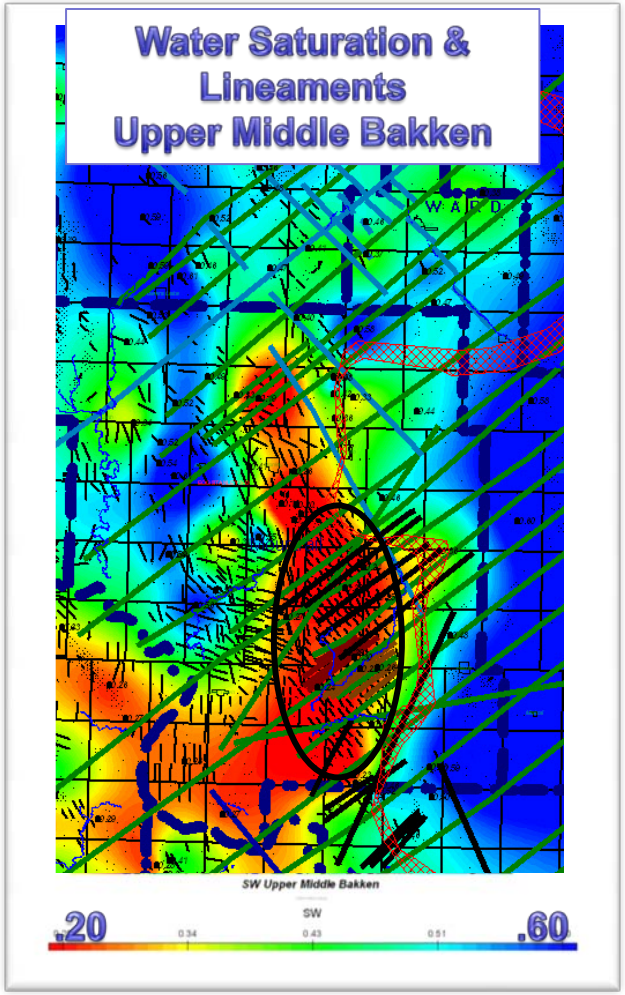
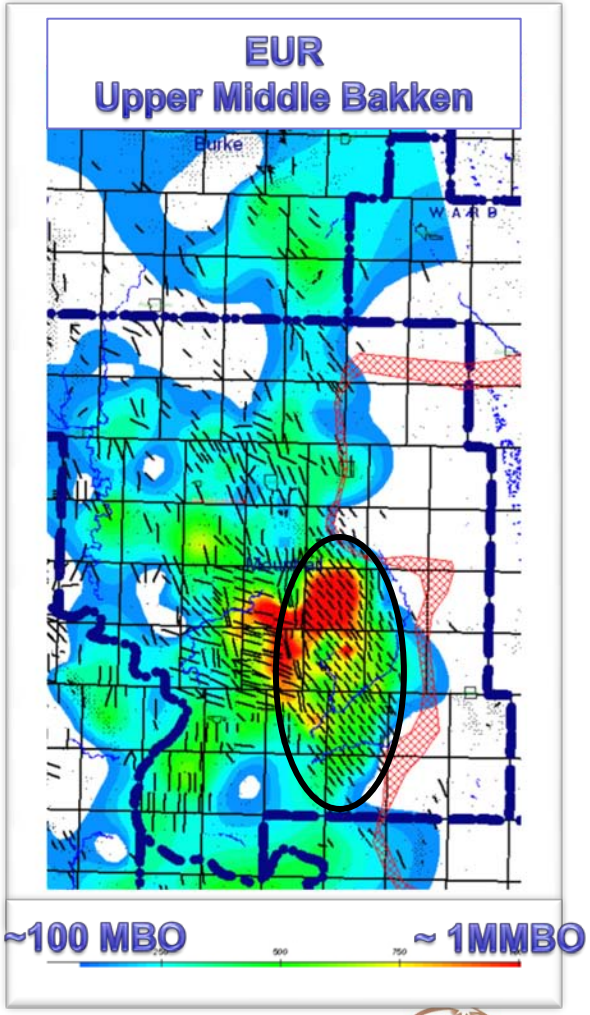
Pressure and Sw (UMB) Correlate







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CONCLUSIONS

- Complex System
- Stratigraphy, Facies, & Depositional Setting Matter
- Diagnesis plays a role in reservoir development and emplacement of hydrocarbons
- Fracturing contributes to Reservoir development at Pore to Regional scale
- Unique Trapping at Parshall
  - *Lineaments*
  - *Maturity*
  - *Pressure*
  - *Facies*
- The Perfect Storm results in “power-charging” of Parshall Reservoir
- Petrophysical solution requires understanding of all variables
- Core is essential to calibrating Exploration Models
- Completion Techniques Critical!
- **Multiple Bakken System Play Types in the Williston Basin**

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Acknowledgements

- *EOG & Bakken Team, Past, Present, and Future*
- *Mike Johnson*
- *Bob Coskey*
- *USGS Price Dataset*
- *Cirque Resources*
- *Fidelity E&P*
- *Clif Jordan (Belize)*
- *Ron Blakey, NAU Geology*

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Exploration & Production Company
An MDU Resources Group company