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.
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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!
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
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+

North Dakota Oil Production
January 2004 to May 2010

Source: N.D. Department of Mineral Resources

http://www.theoildrum.com/node/3868
Middle Bakken: Large Area, Variable Deposition Patterns
(Multiple Play types, Multiple Reservoir Targets)

~300 MMBOE Recoverable

~270 MMBOE Recoverable
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 m³/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 m³) 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 m³) in 2006 to 7.4 million barrels (1,180,000 m³) in 2007.
2005: The hunt for Elm Coulee Analogs

- Resistivity anomaly
- Very Subtle Shows

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 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
• 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
What makes Parshall so Prolific?

~300 MMBOE Recoverable
Blakey Depositional Setting for Bakken

- Widespread Carbonate Deposition in NA
- Williston Basin on Equator
- Bakken: Mixed Carbonate Clastics
- Clastic influence from Landmass NE, E, and SE
Comparison of similar log character in Core (and the trouble with Rasters)

- **Silty Clay-rich Limestone**
- **Partially Dolomitized Limestone**
- **Dolomite**
- **Clay-rich Silt**
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)

Belize image from Geology.com

Dr. Clif Jordan, 2002
Middle Bakken: Large Area, Variable Deposition Patterns (Multiple Play types, Multiple Reservoir Targets)
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
Isopach

Upper Middle Bakken (Algal Facies)

Facies consistent across this part of the basin and represent Carbonate Factory.

Lagoonal restriction caused by movement of Nessan Anticline.

Interbedded algal and Lagoonal Dolomite (after Lagoonal carbonate mud)

A restricted, hypersaline environment.

Primary sedimentary structures preserved.
Middle Bakken: Large Area, Variable Deposition Patterns (Multiple Play types, Multiple Reservoir Targets)
Middle Bakken: Internal source of TOC

Algal Bioherm in EOG Hoff 1-H
Photo from NDIC Website
Diagenetic Model for Parshall

Dolomitization shortly after deposition of Upper Middle Bakken

Ubiquitous Dolomitization Increases Reservoir H

Little or no Dolomite

SHOAL SHADOW

Upper Middle Bakken

Lower Middle Bakken

SHOAL SHADOW

Limey ooid shoal
Role of Fractures in the Bakken Play

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.
Middle Bakken Reservoir Properties at Parshall Field

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

Fracturing at All Scales Contributes to Reservoir Performance

Cirque Trippell #32-16H
Cirque Gunnison St #44-36H

Vertical Fracture in EOG Long 1-H
Photo from NDIC Website
Bakken Formation- Hydrogen Index
Source Rock Maturity Indicator

Legend
- bakken_reval
- bakken_hi_cntr

Value
- High: 750
- Low: 0

(L. Price data from USGS, mapped by J. Flannery)

Less mature
More mature

Migration out of Kitchen

Parshall
Lower Bakken Shale Isopach

Lower Bakken Shale Isopach (ft)
Red = > 45'

Bakken EURS Bubbles
Qualitative
Source Rock Maturity

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

SANISH FIELD

PARSHALL FIELD

TMAX 426 ISOTHERM

Regional Pressure Regime
0.55 psi/ft

Thermally Bound Pressure Cell
0.72 psi/ft

Modified from Whiting Petroleum
Pressure and Sw (UMB) Correlate

Pressure Gradient

Water Saturation & Lineaments
Upper Middle Bakken

EUR
Upper Middle Bakken

Parshall Oil Field

43
0.31
0.34
0.37
0.41

0.20
0.34
0.38
0.43
0.47

~100 MBO
~1MMBO
CONCLUSIONS

- Complex System
- Stratigraphy, Facies, & Depositional Setting Matter
- Diagnosis 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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