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!
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
Location

North American shale plays
(as of May 2011)

Williston Basin

Bakken

Source: U.S. Energy Information Administration based on data from various published studies. Canada and Mexico plays from ARI.
Updated: May 5, 2011
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
Middle Bakken: Large Area, Variable Deposition Patterns (Multiple Play types, Multiple Reservoir Targets)

- Williston Basin Bakken: 3.2-24 billion barrels recoverable

- Elm Coulee 2000: ~270 MMBOE recoverable

- Parshall Field 2006: ~300 MMBOE recoverable
How did EOG get here first and why did they like this prospect?

EOG was actively exploring in this area
EOG was actively playing Elm Coulee
EOG had a unique experience in all disciplines in unconventional reservoirs at that time

Exploration driven by:

- Resistivity anomalies
- Elm Coulee analogues

2005: Identified several resistivity anomalies east of Nesson Anticline

- Leased and drilled the Nelson Farms 1-24 to try to test “clean zone” seen in Gulf Nelson Farms. 1
- Digital data derived an Archie SW model
- Land block at Parshall area looked interesting based on petrophysical model
- Purchased acreage from Mike Johnson, et al

2006: PARSHALL DISCOVERY WELL WAS DRILLED
Evolution of Parshall Field Area: Lear Well

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
"Clean Zone" not encountered in the wellbore
- 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
- No produced Water
Drilling as of 12/31/2011

EOG RESOURCES INC
PARSHALL 2-36H
283 FNL 545 FWL
TWP: 153 N - Range: 90 W - Sec. 36

<table>
<thead>
<tr>
<th>Correlation</th>
<th>Depth</th>
<th>Reservoir</th>
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<tbody>
<tr>
<td>GR</td>
<td>100</td>
<td>9144</td>
</tr>
<tr>
<td>OAM</td>
<td>2</td>
<td>9146</td>
</tr>
<tr>
<td>OPEN</td>
<td>20</td>
<td>9148</td>
</tr>
<tr>
<td>CALICAL</td>
<td>16</td>
<td>9150</td>
</tr>
<tr>
<td>OENAL</td>
<td>150</td>
<td>9510</td>
</tr>
</tbody>
</table>

Target Depth (TD) = 9510
High pressure and flowing oil encouraged EOG to drill second well, Parshall 2-36 Pilot hole and lateral core and logs from Parshall 2-36 provided significant understanding of the nature of the accumulation.

**Engineering Solution:** Parshall 2-36H was the first multistage completion in the Williston Basin Bakken

- Swell Packers were utilized to keep cement off the formation at the Geologists’ request

5th Well in program sustained > 1800 BOPD IP

A fully integrated approach with all disciplines; geology, engineering and land; led to the success of Parshall Field and the Bakken Play in North Dakota.
1. Open Hole completion with no frac – 445 BOD IP
   1. 5 wells drilled
   2. Lateral length from 2900 to 5200 feet

2. Parshall 2-36H – first multistage frac
   1. Original completion open hole 
      1. 5 stage
      2. Prod before frac 301 BOD
      3. Prod after frac – 456 BOD

3. Ehler 1-35H – decided to frac a new well
   1. IP after 7 stage frac – 918 BOD

4. All subsequent wells in Parshall were staged fraced
   1. 30 day avg IP – 1400 to 3300 BOD
What makes Parshall so Prolific?

EUR Bakken Wells Only

~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
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

Lodgepole Scallion

Upper Bakken Shale (not to scale)

Upper Middle Bakken

ALGAL LAMINATED FACIES

“GR Marker”

Shoal Facies

HIGH ENERGY FACIES

Lower Middle Bakken

BIOTURBATED FACIES

Lower Bakken Shale (not to scale)

Basal Bakken (“Sanish”)

Three Forks

FIDELITY
Exploration & Production Company
An MDU Resources Group company
Whiting Stratigraphic Model for Sanish Field

SANISH BAY
42-12H
IP: 2,638 Boe/day

WHITING
Braaflat 11-11H
IP: 2,997 Boe/day

EOG
Van Hook 1-13H
IP: 1,661 Boe/day

10,000'

MIDDLE BAKKEN

INDUCED FRACTURES

 UPPER BAKKEN SHALE

LMB

LOWER BAKKEN SHALE

THREE FORKS

UNCONFORMITY

FRACTURE TRENDS

Modified from Whiting Petroleum
Comparison of similar log character in Core
(and the trouble with Rasters)

<table>
<thead>
<tr>
<th>West</th>
<th>NESSON ANTICLINE</th>
<th>East</th>
<th>Southeast</th>
</tr>
</thead>
<tbody>
<tr>
<td>Silty Clay-rich Limestone</td>
<td></td>
<td>Partially Dolomitized Limestone</td>
<td>Dolomite</td>
</tr>
</tbody>
</table>

West: Silty Clay-rich Limestone

NESSON ANTICLINE: Partially Dolomitized Limestone

East: Dolomite

Southeast: Clay-rich Silt

Images show core samples and graphs representing the different rock types and their properties.
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. Cliff 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
**ISOPACH**

**Lower Middle Bakken And Shoal Facies**

- Consists of heterogeneous lithologies
- Depositional thick along and east of Nesson Anticline

<table>
<thead>
<tr>
<th>Layer</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lodgepole Scallion</td>
<td></td>
</tr>
<tr>
<td>Upper Bakken Shale (not to scale)</td>
<td></td>
</tr>
<tr>
<td>Upper Middle Bakken</td>
<td>ALGAL LAMINATED FACIES</td>
</tr>
<tr>
<td>Shoal Facies</td>
<td>HIGH ENERGY FACIES</td>
</tr>
<tr>
<td>Lower Middle Bakken</td>
<td>BIOTURBATED FACIES</td>
</tr>
<tr>
<td>Lower Bakken Shale (not to scale)</td>
<td></td>
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<tr>
<td>Basal Bakken (“Sanish”)</td>
<td></td>
</tr>
<tr>
<td>Three Forks</td>
<td></td>
</tr>
</tbody>
</table>

Lower Middle Bakken And Shoal Facies Isopach Interval
Facies consistent 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 restricted, 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
Diagenetic Model for Parshall

Dolomitization shortly after deposition of Upper Middle Bakken

Ubiquitous Dolomitization Increases Reservoir H

Upper Middle Bakken

Lower Middle Bakken

SHOAL

SHADOW
Middle Bakken Reservoir Properties at Parshall Field

Parshall 2-36 Pilot Hole
Discovery Well
~35+ Feet of Reservoir H
All Porous Dolomite (>4%)
Scales of Fracturing
Microfractured, Microporous

Facies
Stratigraphy
Diagenesis
Fracturing
Control Development of Parshall “Super” Reservoir
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

Fracturing at All Scales Contributes to Reservoir Performance

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

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

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

MICROFRACTURES IN THE ROCK FABRIC
Bakken Formation- Hydrogen Index
Source Rock Maturity Indicator

Legend
- bakken_reval
- bakken_hi_cntr

Value
- High : 750
- Low : 0

Less mature
L. Price data from USGS, mapped by J. Flannery
More mature

Migration out of Kitchen
The ‘HI Wall’

Parshall

HI > 600 Immature

HI < 100 Mature

n = 579
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
• Gradient highest at Parshall Field
• 0.72 psi/ft
• Pressure decreases towards Sanish Field
• Over-pressured trend continues to the north
• TMAX 426 Contour shows updip limit of thermal Maturity
Upper Middle Bakken

- Maximum Saturation at Parshall Field
  - >75% So
  - Oil Wet

- Lineaments affect distribution of oil saturation

- TMAX 426 contour shows updip thermal maturity limit
Pressure and Sw (UMB) Correlate
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**
Bakken Production History

- Increased Frac stages
- Play expanding
- Increasing EUR’s and IP’s
- Three Forks completions
- Current Rig Count ~ 210
North Dakota Production - 1970 to present

North Dakota Daily Oil Produced and Price

- BOPD
- $/BO

Graph showing the daily oil production and price trends from 1970 to 2015.
Improvement in IP Performance

Monthly Oil Production

- 2007
- 2008
- 2009
- 2010

- 140 BOPD
- 373 BOPD

- 2007
- 2008
- 2009
- 2010
Recent North Dakota Bakken wells show superior EUR’s versus adjacent marginal EUR wells drilled only 3-4 years prior.
Sanish Field Infill Program – Bakken & Three Forks

September 2008
- 2 Bakken Wells / DSU
- No mention of Three Forks potential
- 180 total wells

May 2010
- 2.5 Bakken Wells / DSU
- 2 Three Forks Wells / DSU
- 382 total wells

September 2009
- 2 Bakken Wells / DSU
- No mention of Three Forks potential

December 2010
- 4 Bakken Wells / DSU
- 3 Three Forks Wells / DSU
- 535 total wells
- Further downspacing is inevitable

Cirque
FIDELITY Exploration & Production Company
An MDU Resources Group company
EOG & Bakken Team, Past, Present, and Future
Mike Johnson
Bob Coskey
USGS Price Dataset
Cirque Resources
Fidelity E&P
Cliff Jordan (Belize)
Ron Blakey, NAU Geology