The Giant Continuous Oil Accumulation in the Bakken Petroleum System, Williston Basin

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Horizontal well with multistage hydraulic fracture stimulation

Typical vertical well with hydraulic fracture stimulation

Horizontal versus Vertical Wells
Highly diagramatic
“Relationship between source-rock maturity, hydrocarbon generation, geopressuring and fracturing suggest an opportunity in exploration for unrecognized and unlooked-for “unconventional” accumulations of potentially very large regional extent”
Structure Top Bakken Formation
Bakken and Three Forks Producers shown

- Poplar Dome
- Little Knife Anticline
- Nesson Anticline
- Billings Anticline
- Bicentennial Anticline
- Cedar Creek Anticline
- Painted Wheels Area
- Parshall/Sanish Area
- Fort Berthold Area
- Ambrose Field
- Bailey Area
- St. Demetrius Area
- Ross Field Area
- Painted Woods Area
- Hay Stack Butte Area
- Little Knife Anticline
- Hay Stack Butte Area
- Ambrose Field
- Bailey Area

SYMBOL HIGHLIGHT
- BAKKEN PRODUCERS
- THREE FORKS
### Bakken Petroleum System

#### USGS 2013 Bakken PS Assessment

- **7.4 BBO**
- **6.7 TCFG**

![Diagram of basin evolution](image)

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Modified from LePage, 1992; Anna, 2009.
Unconventional, Continuous Tight Oil Accumulations

- Pervasive accumulations that are hydrocarbon saturated
- Not localized by buoyancy
- Abnormally pressured (high or low)
- Commonly lack downdip water
- Updip contact with regional water saturation
- Low-permeability and low matrix porosity reservoirs
- Reservoirs may be single or vertically stacked
- Commonly enhanced by fracturing
- Associated with mature source rocks that are either actively generating or have recently ceased generation
- Hydrocarbons of thermal origin
- Fields have diffuse boundaries
- Inverted Petroleum Systems
Late Devonian-Early Mississippian black shales (360 Ma)

Bakken Petroleum System Basics

• Upper & lower black shales
  • ‘World Class’ Source Rocks
    • Hard, siliceous, pyritic, fissile, organic rich
    • TOC’s average wt. 11%
    • High OM indicates anoxic conditions (amorphous-sapropelic OM)
    • HC Generation: 10 to 400 B bbl oil

• Middle member (target of horizontal drilling)
  • Dolomitic siltstone to a silty dolomite
  • Low porosity and permeability

• Upper & Middle Three Forks dolostones (target of horizontal drilling)

• Pronghorn dolostones (new target!)
• Abnormal pressure and hydrocarbon generation (> 0.5 psi/ft)
Total US Williston Basin
Bakken and Three Forks
1,289,803,891 BO
1,311,105,241 MCFG
What factors influence productivity?

**GEOLOGY**
- Reservoir quality
- Reservoir thickness
- Oil & water saturations
- HC generation potential
- Maturity
- Overpressure
- Structure and lineaments
- Regional stress regime
- Mechanical stratigraphy
- Natural fractures
- Migration
- Traps

**TECHNOLOGY**
- Well type
- Lateral length
- No. of hyd. fracturing stages
- Proppant volume & type
- Proppant loading
- Fluid volume & type
- Fluid / proppant ratio
- Injection rate
- Treatment pressure
- Choke size
- Plug & perf; sliding sleeves
- Well spacing

*Theloy, 2013*
Elm Coulee
Log suite, BN 9-27, Richland Co., MT (Cramer, 1991)
Note mud log shows in Middle Bakken.
From Findley, 2005
Kelly/Prospector
(Enerplus Resources)
Albin Flb 2-33
Sec. 33-24N-57E

Pfs: 10,451-463
IP: 73 BOPD
Flowed 2,191 barrels oil in the first
30 days beginning March 20, 1996

Treatment:
Water sand frac with 80,260 gallons
water & 151,800 lbs sand

Cum: 92,119 BO; 56,607 MCFG; 10,674 BW
Middle Bakken Reservoir Data

- Formation type: Fractured Silty Dolomite
- Vertical Depth: 8,500’ to 10,500’
- Vertical thickness: 8’ to 14’
- Porosity: 8 to 10%
- Permeability: 0.05 md average
- Oil Saturation: 75% average
- Spacing Units: Primarily 640 to 1280 acres
- Stimulation: Gelled water, sand frac
- Initial Production: 200 to 1900 BOPD; 100 to 900 Mcfd
- Oil Gravity: 42º API @ 60ºF
- Bottom hole temp: 240ºF
- GOR: 500 CFG/Bbl
- Oil in Place (BO/section): 5,000 MBO
- Primary Recovery Factor: 10%
- Primary Oil Recovery: 500 MBO
- Well Cost: ~ $4,500,000

Walker, 2006
Well Spacing Units & Patterns

1280s

“Bow tie” Dual laterals

Long single laterals

640s

“Bird foot” Dual laterals

Single section laterals
Balcron 44-24 Vaira
(Sec. 24-T24N-R54E, Richland County, Montana)

Gamma Ray (API)  Dual Induction (ohm-m)  Bulk Density (gm/cc)  Water Saturation (%)

LODGEPOLE

Perforated Interval

BAKKEN

Upper Shale
Middle Dolostone
Lower Siltstone

THREE FORKS

IP: 83 BOPD and 61 MCFD
Core description of the Balcron #44-24 Vaira

Upper Bakken shale

Middle Bakken dolostone

Lower Bakken siltstone

LITHOLOGY
- Mudstone
- Siltstone
- Dolostone

SEDIMENTARY STRUCTURES
- Parallel lamination
- Ripple lamination
- Bioturbated

TRACE FOSSILS
- Phycosiphon
- Planolites
- Zoophycos

FOSSILS
- Brachiopod
Isopach Bakken
CI: 20 ft

Montana
North Dakota

Nesson Anticline
Antelope Anticline
Poplar Dome
Sanish Field

Parshall Field

Non-productive

Source Beds:

Sanish Field: Mature
Over-pressured

Parshall Field: Marginally mature
Highly over-pressured

Non-productive: Immature
 Normally pressured
Isopach Middle Bakken
Facies D
CI: 10 ft

50 Miles

Montana
North Dakota

CANADA
Isopach Middle Bakken
Facies E-F
CI: 10 ft
Bakken
1st 90 days
Oil/(Oil+Wtr)
From Theloy, 2013

Oil / Oil + Water ratio times 90 day Cum

- **Rough Rider**
  - Most aggressive completions

- **Elm Coulee**
  - Bar facies
  - Diagenesis
  - Stratigraphic trap

- **Upper Bakken**
  - Natural fractures
  - High maturity

- **N Nesson**
  - Locally entrapped accumulations

- **Sanish - Parshall**
  - High pressure
  - Updip migration
  - Stratigraphic & Diagenetic trap

- **Bear Den**
  - High Pressure
  - High maturity
  - Central position

983 wells
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modified from Sandberg et al., 1988; Hartel et al., 2012
Modified from Sandberg et al., 1988
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Legend: Quartz, Dolomite, Calcite, K-feldspar, Plagioclase, Mica/ilite, Chlorite, Halite, Pyrite, Hematite, Anhydrite, "Unidentified"
Isopach Lower
Three Forks
CI: 25 ft

50 Miles
Isopach Upper Three Forks CI: 10 ft

50 Miles
Modified from Berwick, 2009; Gantyno, 2010; Johnson, 2013
Three Forks
1st 90 days
Oil/(Oil+Wtr)
Results – Kerogen type (majority Type I/II)

Modified van Krevelen diagram (OI vs HI)

HI = S2/TOC * 100
OI = S3/TOC * 100

Jin, 2013
Braaflat 9940
Sec. 11-T153N-R91W
Lower Bakken Shale

TOC 15.6
Tmax 435
HI 669
PI 0.06

Braaflat 9864 ft
Sec. 11-T153N-R91W
Upper Bakken Shale

TOC 14.5
Tmax 435
HI 656
PI 0.05
Lower Bakken Shale

Hydrogen Index (mg HC/g OC)

Tmax °C

Immature Bakken

Bakken Oil Window

Bakken Wet Gas Condensate

Tmax/HI

~430\500 onset

~437\300 peak

~445/90 late mature
Isopach Upper Bakken Shale Cl: 5 ft

Montana North Dakota CANADA

Poplar Dome

Nesson Anticline

Antelope Anticline

Anomalous UBS thick Lodgepole Mound area
Stark County, ND
92 BHP and DFIT data points + 6 hydrostatic points at eastern margin + 6 Sanish-Parshall points

No DST data

From Theloy, 2013
Indicative plot for inverted continuous system, leaking pressure at top

From Theloy, 2013
Beginning of intense oil generation based on Tmax and HI constraints of both Upper and Lower Bakken shales

Theloy, 2013
Faults & Fractures

• Tectonic
  • Faults
  • Force Folds
  • Recurrent movement on basement faults
  • Evaporite dissolution
  • Differential compaction

• Regional Stress Field \((Sh_{\text{max}})\)

• Diagenetic
  • Hydrocarbon generation
  • Overpressure
  • Compaction/Dewatering (PFS)
Regional Fractures

Direction of Fractures
N63°E
Elm Coulee
Microseismic

Direction of Maximum Stress
Sh Max NE/SW
(Zoback’s, 1990)

Maxus Shapiro 13-3
Sec. 3-T142N-R102W

Nesson State 42X-36H
Sec. 36-T156N-R95W

Fidelity 43-28H DCR
Sec. 28-T154N-R92W

Direction of Natural Fractures
Sh Max N55°E
From Whiting
Microseismic

Little Knife Field Narr and Burrus
Structure Top Bakken Formation
Bakken and Three Forks Producers shown

Total US Williston Basin
Bakken and Three Forks
1,289,803,891 BO
1,311,105,241 MCFG
Conclusions

- A “giant” continuous accumulation is present in the Bakken and Three Forks of the Williston Basin.

- Sophisticated completion technology and geological factors have a large impact on productivity.

- Sweetspots influenced by hydrocarbon generation, pore-overpressure, inferred oil saturations and productivity, net pay, facies, natural fractures, etc.

- Optimal completion design depends on area and field maturity:
  - 40-stage completions may not be economic in low productivity areas.
  - Simpler (cheaper) completions may be preferable for infill wells at late development stage.

- Multistage hydraulic fracturing and horizontal drilling are game changers for tight oil systems.
Total US Williston Basin
Bakken Only
1,022,855,380 BO
1,011,814,857 MCFG
Three Forks Wells
263,448,155 BO
294,728,845 MCFG