Unconventional “Shale Plays” in MT

A Look at the Geology & Development of the Bakken and Heath Formations

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Why Shales?

• Traditional “Source Rocks”
  – Mostly clays - often high organic content
  – Little pore space and no permeability

• Kerogens are baked into oil & gas; migrate out of the shale and into conventional traps

• New technology has turned these traditional source rocks into reservoir targets
Horizontal Drilling & Frac’ing

Technology’s Role
Why the revolution?

Fracture stimulation 5,000’ – 15,000’ below the surface

- Frack
- Hydrocarbon Trap
- Shale organic rich source layer
- Impermeable sealing layer
- Porous and permeable reservoir layer
- Migrating hydrocarbons
Bakken has been the “Proving Ground”

Current estimates of recoverable oil from the Bakken/ThreeForks range from 3-24 Billion bbls

Oil from Shale now ~16% of US Production

Most is from the Bakken (600,000 bopd)
Requirements for Shale Resource Plays

• **Large area** of organic-rich source rock

• **Heat**, pressure, and time to mature

• **Expulsion** of HC from source rocks into adjacent rocks

• **Trapping** of HC in overlying and underlying reservoirs that are porous, but low permeability

• **Technology** to extract HC using natural or artificial fractures
Exshaw / Bakken

One big transgression
Williston Basin Stratigraphy

Bakken
Three Forks
The Bakken “Petroleum System”

**Southwest (MT) to Northeast (ND)**

- **Source beds**
- **Lodgepole - Mississippian**
- **Upper Shale Member**
- **Middle Bakken clastics**
- **Bakken Formation**
- **Mississippian-Devonian**
- **Lower Shale Member**
- **Sanish sand**

**DEPTH:** 9,000-11,000 feet

~120 ft
Burial & Oil Generation

- **U.S.**
  - SW: Mature
  - Mrg. Mature
  - NE: Immature

- **Canada**
  - Immature
  - Ne

- **diagram notes:**
  - "Bakken Kitchen" Continuous Overpressured Oil Cell
  - Lodgepole-Top Seal
  - M migrated Oil Conventional Trap
  - M Bakken
  - Three Forks
  - 275 Miles
The Early Years

Williston Basin, ND & MT

Bakken Shale Production

Gas (Bbl of Oil Equivalent / Day x 1,000)

Oil (Bbl/day x 1,000)

1953 Discovery Well

1996: Middle Bakken Vertical well Tests Elm Coulee Field

1967: Upper Bakken Shale Horizontal Wells Billings Nose

2000: Elm Coulee Middle Bakken Horizontal wells Discovery

2000: Elm Coulee Middle Bakken Horizontal wells Discovery
Elm Coulee Field
The Shift to ND

Williston Basin, ND & MT

Bakken Shale Producing Wells
Bbl Oil per Day (Mean per Quarter)
- 0 - 100
- 101 - 500
- > 500

Gas-Oil Ratio (Mean per Quarter)
- 0 - 1,000 (Oil Bbl >> Gas BOE)
- 1,001 - 6,000 (Oil Bbl > Gas BOE)
- > 6,000 (Gas BOE > Oil Bbl)

Bakken Depositional Limit

1996: Middle Bakken Vertical well Tests Elm Coulee Field

2000: Elm Coulee Middle Bakken Horizontal wells Discovery

1987: Upper Bakken Shale Horizontal Wells Billings Nose

1978: Upper Bakken Shale, Vertical wells Billings Nose

EIA
Geology dictates where the rigs go

Middle Bakken / Three Forks Pay Variation

- Middle Bakken pay not a shale lithology
  Complex, laterally varying lithology & play types
  Stratigraphic / diagenetic trap drivers

- Underlying Three Forks 'non-shale' play potential established 2008
  Also sourced by Bakken shale
  Dual zone development underway

from ConocoPhillips
The “Boom” has Passed
Current Activity

- Rigs are trickling back into MT
  - 10-15 rigs to drill & hold leases

- Still some Elm Coulee infill wells
- Geopressured area
- South edge - upper shale

- Marginal production to the north
- No economic production NW of Brockton-Froid FZ yet
Glacier Co., MT

- Maybe a dozen wells in last 3 years
- < 50 bopd max
- no pressure?
There will continue to be Bakken drilling in Elm Coulee and to the north (?), but probably not elsewhere in the State .....at least for now.
Heath Formation

Depth: 0 to 5000’

Some in Judith Basin
Central Montana Stratigraphy

Not simple layer-cake
Heath Formation – Complex Mix of Lithologies

Key components:

- **Middle Carbonate Member** (up to 40’ thick)
  - Thin limestones and dolomites
  - Porosity developed in places (up to 13%, 5% avg)
  - Possible ‘carrier’ beds; tested oil
    Brittle, fractures – especially on structure

- **Cox Ranch Member** (‘Hot’ Shale)
  - 10 to 60 feet thick (4 – 20% porosity, 11% avg)
  - High organic content
  - Thermally mature to volatile oil window
  - Tested 30 – 35.5 API gravity oil

**SHALE +/- Coal, gypsum, DM, LS**
Complex Geology: folded & faulted

Oil Migrated into Permeable Rocks & Conventional Traps

- Over 40 oil fields in Central MT
- Most are Amsden-Tyler
- Cumulative oil production 110-140 MMBO (sourced from Heath)
Exploration Status?

• We just don’t know that much yet; few wells drilled

• Since 2009
  – ~10 vertical wells drilled
    • Coring: oil shows, fractures, water/oil saturation, porosity, etc
  – ~15 horizontal wells drilled
    • Operators testing drilling and completion techniques
    • Only 2-3 on production

• 1 rig currently running
So, is it another Bakken?

We probably won’t know for a while yet……..“wait & see”

- The potential is certainly there: Both have
  - Organic rich black shales of similar age
  - Low porosity, low perm shales, high TOC
  - Both in oil window – thermally mature
Heath is a little more Complex

• Oil has migrated out of the system
  – Juxtaposition with conventional reservoirs
  – Faults may provide pathways

• Central MT is structurally complex: faulted / folded, erosional unconformities

• Testing different zones – which is the “Reservoir”? 

• Reservoir Pressure – can production be sustained?

......but remember, it took ~50 years for the Bakken to become what it is today
Impact on Groundwater?

• Potential for leakage of Frac fluid into groundwater aquifers
  • At depth due to frac’ing
  • Surface spills
  • Operators do not want to frac into water-bearing fms

• Water consumption
  • 2-mile lateral uses ~2 million gal of water for frac job.
Groundwater Protection
through proper well construction

- Cement
- Conductor casing
- Aquifer
- Cement
- Surface casing
- Drilling fluid
- Intermediate casing

Impervious rock layers:
- 1,000 ft.
- 2,000 ft.
- 3,000 ft.
- 4,000 ft.
- 5,000 ft.
- 6,000 ft.
MBOG Rules Adopted 2011

- Pressure test casing & equipment
- Report constituents in Frac fluid
- Trade secrets protected unless health care emergency demands disclosure
### Hydraulic Fracturing Fluid Product Component Information Disclosure

**Fracture Date:** 12/29/2011

**State:** MT

**County:** Richland

**API Well Number:** 35-683-32853

**Operator Name:** Continental Resources

**Well Name and Number:** Ripley 1-24H

**Longitude:** -104.68829

**Latitude:** 47.98436

**Long/lat Projection:** NAD27

**Production Type:** Oil

**True Vertical Depth (TVD):**

**Total Water Volume (gallons):** 2,092,002

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### Hydraulic Fracturing Fluid Composition:

<table>
<thead>
<tr>
<th>Trade Name</th>
<th>Supplier</th>
<th>Purpose</th>
<th>Ingredients</th>
<th>(CAS #)</th>
<th>Concentration in Additive (% by mass)**</th>
<th>Concentration in HF Fluid (% by mass)**</th>
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</thead>
<tbody>
<tr>
<td>WF125,</td>
<td>Schlumberger</td>
<td>Base Fluid, Bactericide, Breaker, Crosslinker, Non-Emulsifying Agent, Propellant, Sand, Stabilizer</td>
<td>Water (including Mix Water Supplied by Client)</td>
<td>-</td>
<td>-</td>
<td>83.96559%</td>
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<tr>
<td>YF125FLEX</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
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<tr>
<td></td>
<td></td>
<td></td>
<td>Crystalline silica</td>
<td>14808-60-7</td>
<td>59.84812%</td>
<td>9.53275%</td>
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<td></td>
<td></td>
<td></td>
<td>Ceramic materials and waxes, chemicals</td>
<td>80402-06-4</td>
<td>33.76111%</td>
<td>5.41894%</td>
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<tr>
<td></td>
<td></td>
<td></td>
<td>Distillate (petroleum), hydrocracked light</td>
<td>64742-47-8</td>
<td>2.14020%</td>
<td>0.34316%</td>
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<td></td>
<td></td>
<td></td>
<td>Aliphatic polyol</td>
<td>Proprietary</td>
<td>0.56154%</td>
<td>0.05011%</td>
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<td></td>
<td></td>
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<td>Methanol</td>
<td>67-66-1</td>
<td>0.33083%</td>
<td>0.05305%</td>
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<td>Tetramethylammonium chloride</td>
<td>75-67-6</td>
<td>0.32060%</td>
<td>0.05141%</td>
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<td></td>
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<td>Potassium hydroxide</td>
<td>1310-55-3</td>
<td>0.28924%</td>
<td>0.04056%</td>
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<td></td>
<td>Decyl-dimethylamine oxide</td>
<td>2605-79-0</td>
<td>0.08014%</td>
<td>0.01285%</td>
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<td></td>
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<td>Oxirallylated alkyl alcohol (1)</td>
<td>Proprietary</td>
<td>0.04727%</td>
<td>0.00756%</td>
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<tr>
<td></td>
<td></td>
<td></td>
<td>Oxirallylated alcohol (2)</td>
<td>Proprietary</td>
<td>0.04727%</td>
<td>0.00756%</td>
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<td>Diammonium peroxysulphate</td>
<td>772-54-0</td>
<td>0.03143%</td>
<td>0.00504%</td>
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<td>Heavy aromatic naphtha</td>
<td>64742-04-6</td>
<td>0.02364%</td>
<td>0.00370%</td>
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<tr>
<td></td>
<td></td>
<td></td>
<td>Quaternary ammonium compound</td>
<td>Proprietary</td>
<td>0.02364%</td>
<td>0.00370%</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Oxirallylated alcohol (1)</td>
<td>Proprietary</td>
<td>0.02364%</td>
<td>0.00370%</td>
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<tr>
<td></td>
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<td>Tetraakali(hydroxymethyl)phosphonium sulfate</td>
<td>85568-30-8</td>
<td>0.01515%</td>
<td>0.00243%</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Amorphous silica</td>
<td>Proprietary</td>
<td>0.01515%</td>
<td>0.00243%</td>
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</tbody>
</table>
Estimated Water Use in MT in 2000

Frac needs: about 1 million gal/day
It’s all about reservoir contact & drainage

- Patterns to drain efficiently
- Longer laterals
- Natural Fractures (SW-NE)
- Hydraulic Fractures
- Reservoir Pressure

Northwestern Elm Coulee
Rig Count

Rig Count as of 7/20/12
Montana 20
North Dakota 198
Wyoming 47
Oil and Natural Gas Production Tax Revenue Collections

Total State Share: $958,629,814
Total Local Share: $949,382,548
TOTAL $1,908,012,362
Summary – 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 Productivity**
  - Multiple Scales of Natural Fractures

**MULTIPLE BAKKEN SYSTEM RESERVOIR TARGETS**

**MANY BAKKEN SYSTEM PLAY TYPES IN THE WILLISTON BASIN**
### MIDDLE BAKKEN RESERVOIR DATA

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
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</thead>
<tbody>
<tr>
<td>Formation Type</td>
<td>Fractured Silty Dolomite</td>
</tr>
<tr>
<td>Vertical Depth</td>
<td>8,500’ – 10,500’</td>
</tr>
<tr>
<td>Vertical Thickness</td>
<td>8’-14’</td>
</tr>
<tr>
<td>Porosity</td>
<td>8%-10% average</td>
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<tr>
<td>Permeability</td>
<td>0.05 md average</td>
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<tr>
<td>Oil Saturation</td>
<td>75% average</td>
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<tr>
<td>Spacing Unit Size</td>
<td>160 to 1960 acres (Primarily 640-1280 acres)</td>
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<tr>
<td>Stimulation</td>
<td>Gelled Water/Sand Frac</td>
</tr>
<tr>
<td>Initial Production Rates</td>
<td>200-1,900 BOPD, 100-900 MCFGPD &amp; 5-30 BWPD</td>
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<tr>
<td>Oil Gravity</td>
<td>42° API @ 60° F</td>
</tr>
<tr>
<td>Bottom Hole Temperature</td>
<td>240° F</td>
</tr>
<tr>
<td>GOR (over life of well)</td>
<td>1200 MCFG/BBL (~1500 BTU gas)</td>
</tr>
<tr>
<td>Oil-In-Place (BO/640 Acres)</td>
<td>5,000 MBO</td>
</tr>
<tr>
<td>Primary Recovery Factor</td>
<td>10% average (to 18%)</td>
</tr>
<tr>
<td>Primary Oil Rec/well (decl curve)</td>
<td>500 MBO+ (State Hearing Data)</td>
</tr>
<tr>
<td>(Headington Reserves Study</td>
<td>indicates ~ 588 MBO</td>
</tr>
<tr>
<td></td>
<td>+ 705 MCFG)</td>
</tr>
</tbody>
</table>

### CURRENT WELL COST

| Completed Well Cost:            | $2,500,000 to over $5,500,000                                     |
| Return on Investment:          | 3-5 times                                                          |
| Cost Recovery:                 | 2-3 years                                                          |
Middle Bakken: Large Area, Complex Depositional Env., Multiple Reservoir Targets

~270 MMBOE Recoverable

~300 MMBOE Recoverable
Typical CLR Completion

**Completion Technique**
- Plug and perf method
- 24-30 stage fracs
- Isolate with swell packers and plugs
- Perforate 6 one foot intervals per stage
- 6 shots per foot
- Complete 8 stages per day

**Volumes and rates per stage**
- 80-100,000# 20-40 sand/ceramic proppant
- Lead with 25-40,000# 40-70 sand
- 2,000 bbls of fluid (X-link gel)
- Treating pressures 5,000-8,500 psi @ 40 bbls/minute

$6.5MM CWC

- 6” wellbore
- Swell packers
- 4 1/2” Liner
- 7” Casing
- 9,500’ lateral
- 10,000’ deep
- Continental Resources
Horizontal Drilling

- Horizontal drilling not new...1980’s
- But the ability to land it in a thin zone and stay there
  - Rotary steerable bit
  - LWD/MWD logging
- Increase length to contact more reservoir
- Intercept as many natural fractures as possible
Fractures

- Permeability
- Early days – find structures & depo edges
- Natural Fractures created by tectonics (stress fields)
- Micro Fractures created by increased pressure from fluid expansion as kerogens go to oil generation (increased volume)
- Artificial: hydro-fracturing
Hydrofracturing ("fracking")

- Hydrofracturing is also not new (late 1940’s)
- Pressurize to exceed fracture gradient, crack the rocks & prop the cracks open
- Create pathways for fluid flow (permeability)
- Frac fluid is ~99% water and sand (or ceramics); 1% things to worry about.

- Fracking has not caused any earthquakes
- Water contamination can be mitigated; water conservation may be a bigger issue
TYPE LOG – ELM COULEE AREA
Balcron Oil - #44-24 Vaira
SESE Sec. 24, T.24N., R.54E.

GR/Caliper
Density/Neutron Porosity

Lodgepole Fm.
Upper Shale

BAKKEN 45 FT Middle Member (Dolomite, var silty, arg)

Target

Three Forks Fm.

0 (API Units) 100 30 20 10 0%

Modified after J. LeFever
Original Oil in Place (OOIP)

• At 10.5 gal/ton (good stuff); 2.8 gal/ton (rest)

• Estimates of Heath OOIP:
  • ~3 MMbbls per mi$^2$ (Cox only)
    – But we could add another 10 MMbbls if we assume another 75’ of lower TOC rocks
  • Cirque suggests ~20 MMbbls per mi$^2$

• Compare to Bakken commonly taken to be about 5 MMbbls per mi$^2$

............*but is it still there?*
Expulsion & Migration

- Oil generated at depth
- Expansion – Pressure – Fractures?
  - Forced into nearby tight rocks
  - OR migrates out
Two recently completed wells have reported production.
This is the big deal
Oil from Shale now ~16% of US Production

Figure 1. Annual U.S. oil production

Sources: U.S. Energy Information Administration; HPDI, LLC 2011 is through November
Heath Shale: Central Montana Trough
Big Snowy Group

Depth: 0 to 5000’
Some in Judith Basin
Geology can be Complex: complicated by erosional surfaces, lateral facies changes & later folding

Heath 200-300’
Oil Migrated into Permeable Rocks & Conventional Traps

Sumatra Field
But remember – it took ~50 years for the Bakken to become what it is today.