The Bakken Petroleum System of the Williston Basin

Presented By:
Steve Sonnenberg

Colorado School of Mines
Bakken Consortium
The Bakken Petroleum System of the Williston Basin: a Tight Oil Resource Play

- Viewfield Area
- Blooming Prairie Area
- Nesson Anticline
- Billings Nose
- Rough Rider
- Elm Coulee
- Sanish/Parshall Area
- Cedar Creek Anticline

Limit of Bakken Fm.

Structure Base Miss

Stephen A. Sonnenberg
Colorado School of Mines
The Resource Pyramid

Conventional Reservoirs: Small Volumes, Easy to Develop

Unconventional Reservoirs: Large Volumes, Hard to Develop

Huge Volumes, Difficult to Develop

Increasing Product Price

Improving Technology

Province Resource Size
The Resource Pyramid

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Technology Reservoirs

Oil Shale
Gas Hydrates
Tight Sands;
CBM;
Gas Shales

Oil
Gas

Tight
Heavy Oil;
Bituminous Sands
Tight Oil Plays
A New Game
Late Devonian-Early Mississippian black shales (360 Ma)

NDIC (2010) estimated ultimate production
Bakken Petroleum System:

Bakken: 2.1 Billion barrels
Three Forks: 1.9 Billion barrels
Bakken Petroleum System

Reservoirs: Middle Bakken & Three Forks
Source Beds: Upper & Lower Bakken Shales

“What was made in the Bakken, stayed in the Bakken PS”
“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”
Bakken Petroleum System Basics

Upper & lower black shales

„World Class“ Source Rocks
Hard, siliceous, pyritic, fissile, organic rich
TOC’s as high as 40 wt% (average 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 Three Forks dolostones (target of horizontal drilling)
Abnormal pressure and hydrocarbon generation (> 0.5 psi/ft)

Modified from LeFever, 2005
Antelope Field
“Unusual Characteristics”

- Very high reservoir pressure
- High productivity of several wells
- Production associated with steepest dip in central part of basin
- Nebulous, ill-defined reservoir
- Almost complete absence of water
- Porosities 5-6%
- Permeabilities < 0.1 md

Murray, 1968
Williston Basin Bakken and Three Forks Production

WILLISTON BASIN - 3365 Grouped Wells (Daily Rates)

Total GOR: 957 cf/bbl
Facies after Canter et al., 2008; LeFever, 2007; Berwick, 2009
Factors Related to Bakken/Three Forks Oil Production

• Source beds - UB, LB; Reservoirs-MB, TF
• Reservoir-favorable facies and diagenetic history (matrix permeability)
• Mature source rocks form continuous oil column (pervasive saturation)
• Favorable history of fracture development: folds, faults, solution of evaporites, high fluid pressures, regional stress field (fracture permeability)
• Drilling and completion technology
Bakken Mudrocks
Facies after Canter and Sonnenfeld, 2008; LeFever, 2007; Berwick, 2009
Comments on the Bakken shales:

“Any restricted reservoir in direct contact with either of the two shale units should be productive anywhere in the deeper part of the basin, regardless of structural position”

“One of the most important conclusions is the recognition that the upper and lower Bakken shale beds are supercharged oil shales and that they probably are the immediate source of most of the oil”
Depositional Setting: Lower and Upper Bakken Black Mudstone

Modified from Smith and Bustin, 1996; Meissner et al., 1984
Isopach Upper Bakken Shale
High Paleogeothermal Gradient Area

Lower Bakken Res

Limit Middle Bakken

Limit Lower Bakken Shale

Limit Upper Bakken Shale

Structure Bakken Formation

Resistivities Bakken Shales
Change in pore-fluid volume (porosity) and pore-fluid species which may accompany hydrocarbon-generation (maturity) in source rocks.

Meissner, 1978

Legend:
- Matrix
- Kerogen
- Non-organic
- Pore fluid:
  - Water
  - Oil

Water Wet

Oil Wet
• Bakken/Sanish/UTF abnormal pressured
• Regarded by Meissner (1978) to be due to hydrocarbon generation which results from excess volumes of oil in shales

Normal or Hydrostatic fluid pressure based on average Paleozoic Formation water salinity of 325,000 ppm and a related fluid pressure gradient of 0.53 psi/ft
Bakken Facies
Lear Pet Expl Parshall SD 1
Sec. 3-T152N-R90W

“False Bakken”
Scallion

U-M
E-F

M-M
D
C
B
A

L-M

Bakken

Upper Shale

Middle Mbr.

Lower Shale

Three Forks
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<tbody>
<tr>
<td></td>
<td>L2 – Interbedded dark-gray shale and buff, silty sandstone, moderate to intense bioturbation (Cruziana ichnofacies), fossiliferous.</td>
<td>L3 – Sandstone, upper &amp; lower wavy to flaser silty sandstone, Skolithos ichnofacies. Middle coarse-grained, massive to xbedded.</td>
<td>C – Rhythmic, varve-like, mm to cm laminated, well sorted, v.f.g. sandstone and siltstone with calcite cement, hummocks and wave ripples.</td>
<td>E – Thin-bedded dolomud/wackestone, more dolomitic.</td>
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<td>L4 – Interbedded dark-gray shale and buff, silty sandstone, coarsens upward, moderately bioturbated (Cruziana ichnofacies).</td>
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<td>A – Calcitic, whole fossil, dolo- to lime wackestones: fossil-rich beds.</td>
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<td>A2 - Thin-bedded dolomud/wackestone, more dolomitic.</td>
<td>E - Thin-bedded dolomud/wackestone, more dolomitic.</td>
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<td>A3 - Thin organic-rich mudstone, gamma ray marker.</td>
<td>F1 - Pyritic dolostones.</td>
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<tr>
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<td></td>
<td>B - Canclitic, whole fossil, dolo- to lime wackestones: fossil-rich beds.</td>
<td>A2 - Thin-bedded dolomud/wackestone, more dolomitic.</td>
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<tr>
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<td>A1 - Calcitic, whole fossil, dolomitic.</td>
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<td>B1 - Highest energy, coarsest grained alternating cross-bedded bioclast, v.f.g. sandstone.</td>
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<td>E - Thin-bedded dolomud/wackestone, more dolomitic.</td>
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<td>F1 - Pyritic dolostones.</td>
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<td>A0 - Patterned pyritic dolostones.</td>
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<td>L5 – Siltstone, gray-green, massive, mottled, dolomitic, Nerites ichnofacies.</td>
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<td>L2 – Interbedded dark-gray shale and buff, silty sandstone, moderate to intense bioturbation (Cruziana ichnofacies), fossiliferous.</td>
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<td>L1 – Siltstone, gray-green massive, bioturbated (Nerites ichnofacies), fossiliferous.</td>
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<td>D - Bioturbated, argillaceous, calc. poorly sorted, vfg, sandstone/siltstone with helminthopsis/sclarituba.</td>
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<td>A - Intraclastic-skeletal lime wackestone, 1-4 ft thick.</td>
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**MIDDLE BAKKEN LITHOFACIES**


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<tr>
<th>mfs</th>
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Skeletal wackestone

Bioturbated siltstone, Vfg ss

Laminite, Vfg ss-siltstone

Thin bedded, dolomud, wackestone

X-bedded bioclast, SS

Skeletal wackestone

Bioturbated siltstone, Vfg ss

Facies B
(10,119 – 10,142 feet)
(3084.3 – 3091.3 meters)

Facies D1 & D2
(10,084 – 10,102 feet)
(3073.6 – 3079.1 meters)

Facies C1 & C2
(10,102 – 10,119 feet)
(3079.1 – 3084.3 meters)

Facies E1, E2 & F
(10,077 – 10,084 feet)
(3071.5 – 3073.6 meters)

Facies A
(10,142 – 10,146 feet)
(3091.3 – 3092.5 meters)

Facies G
(10,077 – 10,077 feet)
(3071.5 – 3071.5 meters)
Late Devonian-Early Mississippian black shales (360 Ma)
Depositional Environment-Shallow Shelf

Layer-Cake Shelf Model:

- **S**
- **N**
- **~ 50 m**

- high $O_2$
- high productivity
- anoxic

- slow subsidence or slow rise in sea level
- sedimentation rates > rate of sea level rise

- high $O_2$

- rapid subsidence or fast rise in sea level
- sedimentation rates < rate of sea level rise

After Theloy, 2010
QEMSCAN ANALYSIS Middle Bakken

Deadwood Canyon Ranch #43-28H

- Quartz
- K-feldspar
- Plagioclase
- Illite/Smectite
- Calcite
- Dolomite
- Pyrite
- Chlorite
- Kaolinite
- Others

Mass (%) 0% 20% 40% 60% 80% 100%

Depth (ft):
- 10079.1:
- 10081.62:
- 10082.71:
- 10083.07:
- 10095.87:
- 10109.72:
- 10113.57:
- 10120.07:
- 10134.02:
- 10134.98:
- 10135.99:
- 10146.12:

Simenson, 2010
Overview of Upper Three Forks

• Upper Three Forks Facies
  – Silty dolomite; highly deformed and brecciated: tidal mud flat to sabkha
  – Silty dolomite, dolomitic siltstone, and shale (green) deposited in tidal mud flat
  – Burrowed dolomitic unit deposited in subtidal environment

• Sanish Sandstone
  – Fine-grained and burrowed
  – Locally developed
  – Sharp contact with upper Three Forks
  – Sharp contact with Lower Bakken Shale
Jorgenson 1-15H
Sec. 15-T148N-R96W

Jorgenson 1-15

XRD

Lodgepole
U Bakken
M Bakken
L Bakken
Sanish
Upper Three Forks

0% 20% 40% 60% 80% 100%

10970
10976
10989
11041
11049
11060
11068
11077
11082

Quartz
Feldspar
Calcite
Dolomite
Pyrite
Chlorite
Illite
Modified from Berwick, 2009
- Contact between Facies C and B. Bounding Discontinuity (Paleobathymetric shift)
- Contact between Facies D and C. Flooding Surface
  Fresh Water Recharge
  Hypersaline Sea Water Recharge

Saline Tidal flat-Sabkha (precipitation of evaporites)

Fresh Surface Water Recharge (dissolution of evaporites)

Bi-directional cross-laminations
Uni-direction cross-laminations
Tidal Creek

10’s of miles (?)

Berwick, 2009

* Not to scale
Isopach
Upper
Three Forks
Isopach
Lower Bakken
CI: 10 ft

Resistivity lines from Hester and Schmoker, 1985
Fractures
Origin of Bakken Fractures

- Folding and faulting
- High fluid pressures
- Solution of evaporites
- Recurrent movement on basement shear zones
- Regional stress field with open fracture direction
Bakken & Three Forks Fractures Working Hypothesis

• Vertical fractures, bedding plane partings (i.e., horizontal fractures) all play a role

Carus Fee
Upper Bakken Shale
11293
NDIC
Regional Fractures
Summary

• Unconventional tight oil resource plays are “changing the game”
• It all starts with good to excellent source beds
• Source beds mature over large areal extent
• Natural fracturing enhances tight reservoirs
• Horizontal drilling and fracture stimulation technology important in tight oil plays
Colorado School of Mines Bakken Consortium

Samson Marathon XTO EOG Resources FIDELITY Exploration & Production Company

Totalenerplus

SAVANT

Anschutz Exploration Corporation The Discovery Group Inc

NEWFIELD

Husky Energy

HENDRICKS and Associates, Inc.

DRI Denbury Resources Inc.

Statoil

Rosetta Resources

MJ SYSTEMS

TGS