The Bakken Petroleum System

Stephen A. Sonnenberg

Colorado School of Mines
Colorado School of Mines
Bakken Consortium
The Resource Pyramid

**Conventional Reservoirs:**
Small Volumes, Easy to Develop

**Unconventional Reservoirs:**
Large Volumes, Hard to Develop

- Oil Shale
- Gas Hydrates

- Tight Oil; Heavy Oil; Bituminous Sands
- Gas Sands; CBM; Gas Shales

**Increasing Product Price**
**Improving Technology**

**Province Resource Size**
Unconventional, Continuous Tight Oil Accumulations

- Pervasive petroleum saturation
- Mature source rocks
- Abnormally pressured
- Generally lacks down-dip water
- Up-dip water saturation
- Low porosity and permeability reservoirs
- Fields have diffuse boundaries
- Enhanced by fracturing and partings
The Bakken Petroleum System of the Williston Basin: a Tight Oil Resource Play

Stephen A. Sonnenberg
Colorado School of Mines
<table>
<thead>
<tr>
<th>Sequence</th>
<th>Systems</th>
<th>Lithology</th>
<th>Rock Units</th>
<th>Thickness FT (m)</th>
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Modified from Webster, 1984

NDIC (2010) estimated ultimate production
Bakken Petroleum System:

Bakken: 2.1 Billion barrels
Three Forks: 1.9 Billion barrels
Late Devonian-Early Mississippian black shales (360 Ma)

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”
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
Permeability/ Porosity

Bakken

Wattenberg

Peoria

Morrow Sorrento

D SS Sooner

megapores

macropores

mesopores

micropores

submicropores

K/PHI 1

K/PHI 10

K/PHI 100

K/PHI 1000

Permeability

Porosity

0.01

0.1

1

10

100

1000

10000

0 10 20 30

Bakken

Peoria

Morrow Sorrento

D SS Sooner

Permeability

Porosity
Upper Bakken Shale Play
Post 1987
Horizontal Play

1970-80s
Upper Bakken Shale Play
Post 1987
Horizontal Play

Parshall\Sanish Field - 2006

Antelope Field
Sanish & Bakken 1953

Bakken Fm.

Structure

Bakken

Three Forks

Elm Coulee 2001-P
Horizontal Middle Bakken

Brigham "Painted Woods"

Nesson Anticline

Ross

Bailey

Willmen

St. Demetrius

"Painted Woods"
Williston Basin Bakken and Three Forks Production

Total GOR: 957 cf/bbl
Factors Related to Bakken/Three Forks Oil Production

• Source beds - UB, LB, FB; 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
Facies after Canter et al., 2008; LeFever, 2007; Berwick, 2009
Facies after Canter and Sonnenfeld, 2008; LeFever, 2007; Berwick, 2009
Van Krevelen HI/OI

HI (mg HC/gm OC)
OI (mg CO2/gm OC)

Type I
Type II
Type III

0-4000
4001-6000
6001-8000
8001-10000
10001-12000
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

Upper Bakken Res

Limit Upper Bakken Shale

Structure Bakken Formation

Resistivities Bakken Shales
- 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

Formation fluid pressure psi/ft

Modified from Meissner, 1978
Isopach Middle Bakken
Facies after Canter and Sonnenfeld, 2008; LeFever, 2007
Depositional Environment

after Walker and Plint (1992) from Smith and Bustin, 1996
Facies after Canter and Sonnenfeld, 2008; LeFever, 2007

XRD Data

L. Texel #21-35  API: 3306100187  State: North Dakota  County: Mountrail
Overview of Upper Three Forks

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

- Sanish Sandstone
  - Fine-grained and burrowed
  - Locally developed
  - Sharp contact with upper Three Forks
Late Devonian
360 m.a.
Supratidal
Modified from Berwick, 2009; Gantyno, 2010

Sanish (~5 ft)

Upper Three Forks (~40 ft)

Subtidal

Supratidal/Intertidal Mudflat

Intertidal

Supratidal

Dolomitic Claystone

Dark Black Shale

Burrowed Silty, Sandy Dolomite

Silty Dolomite and Shale, Rippled, Mud Cracks

Massive to Rippled Silty Dolomite

Chaotic to Brecciated Silty Dolomite

Modified from Berwick, 2009; Gantyno, 2010
Isopach
Lower Bakken
Cl: 10 ft

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

- Folding and faulting
- High fluid pressures
- Solution of evaporites
- Geologic history: recurrent movement on basement shear zones
- Regional stress field with open fracture direction
Regional Fractures

[Map showing regional fractures with annotations for directions and specific locations such as Carus Fee 21, Nesson State 42X-36H, Fidelity 43-28H DCR, Maxus Shapiro 13-3, and Little Knife Field Narr and Burrus.]
Bakken Petroleum System

• A low perm, ‘tight oil’ system
• What makes it work?
  – Technology
    • Horizontal drilling
    • Fracture stimulation
  – World class source rocks
  – Large “kitchen” area
  – Abnormal pressure
  – Middle Bakken facies, Three Forks facies
  – Matrix and fracture permeability
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