The Niobrara Petroleum System, Rocky Mountain Region*

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Abstract

The Niobrara Petroleum System of the U.S. Rocky Mountain Region is a major tight petroleum resource play. The Niobrara is self-sourced and reservoirs are low-permeability chalks, shales, and sandstones. Source beds have total organic-carbon contents that range from 2 to 8 weight percent. Source beds are thermally mature in the deeper parts of many of the Laramide basins in the Rocky Mountain region. Continuous or pervasive accumulations occur in thermally mature areas.

The Niobrara source rocks are dominantly Type II (sapropelic). Oil accumulations occur where source beds are still in the thermogenic oil window (e.g., Denver Basin). Thermogenic gas accumulations occur where the source beds have entered the gas-generating window in deeper parts of basins (e.g., Piceance Basin). Biogenic methane occurs in shallow chalk reservoirs on the east flank of the Western Interior Cretaceous Basin. In addition shallow gas fields are found in northern Montana.

Natural fractures are important in controlling sweet spots in the play and form for several causes. Several models create fractures in the Niobrara and include Laramide tectonics, Neogene extensional tectonics, solution of evaporites, hydrocarbon generation, and regional stress patterns.

The Niobrara is a technology reservoir that requires horizontal drilling and multi-stage hydraulic fracturing. The Niobrara petroleum system is present over most of the Rocky Mountain Region and is prospective in many areas.

Selected References


Selected Websites


The Niobrara Petroleum System, Rocky Mountain Region

Dr. Steve Sonnenberg
Colorado School of Mines
North American shale plays (as of May 2011)

Source: U.S. Energy Information Administration based on data from various published studies. Canada and Mexico plays from ARI.
Updated: May 9, 2011
The Niobrara-Mancos Oil & Gas Play, Rocky Mountain Region
Niobrara/Mancos Fields
Rocky Mountain Region

Fracture Related Fields

Florence Cañon City (Pierre Shale)
- 1881
- 15.3 MMBO

Boulder (Pierre Shale)
- 1901
- 1 MMBO

Rangely (Mancos)
- 1902
- 11.7 MMBO, 12.2 BCF

Salt Creek
- 1907
- “Upper shale” Cretaceous

Tow Creek (Niobrara)
- 1924
- 3 MMBO; 0.3 BCF

Buck Peak (Mancos, Nio)
- 1956
- 4.7 MMBO; 8.2 BCF

Puerto Chiquito (Mancos/Nio)
- 1960
- 18.7 MMBO; 52 BCF

Wattenberg (Nio, Codell)
- 1970
- 86 MMBO, 1.1 Tcf

Silo (Niobrara)
- 1981
- 10.4 MMBO; 8.2 BCF
The Resource Pyramid

Conventional Reservoirs:
Small Volumes, Easy to Develop

Unconventional Reservoirs:
Large Volumes, Hard to Develop

Huge Volumes, Difficult to Develop

Oil
Gas
Tight Oil; Heavy Oil; Bituminous Sands
Tight Gas Sands; CBM; Gas Shales
Oil Shale
Gas Hydrates

Increasing Product Price
Improving Technology

Province Resource Size
The Resource Pyramid

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

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

**Huge Volumes, Difficult to Develop**
- Oil Shale

**Gas Hydrates**

**Increasing Product Price**

**Improving Technology**

**Technology Reservoirs**

**Province Resource Size**
Conventional
- Structural
- Stratigraphic
- Combination

Unconventional
- Coalbed Methane
- Shallow Basin Methane (biogenic)
- Shale Gas
- Shale Oil
- Tight Oil ('continuous')
- Oil Shale
- Tar Sands

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**Modified from Magoon, 1988**
Unconventional, Continuous Tight Oil Accumulations

- Pervasive accumulations that are hydrocarbon-saturated
- Not localized by buoyancy
- Abnormally pressurized (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
Elements of a Successful Tight Oil Play

- Organic Richness
- Maturation
- Pore Pressure
- Porosity-Permeability
- Oil-in-Place
- Thickness
- Mineralogy
- Brittleness
- Productivity
- Porosity-Permeability
- Oil-in-Place
- Thickness
- Mineralogy
- Brittleness
- Productivity
- Porosity-Permeability
- Oil-in-Place
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- Thickness
- Mineralogy
- Brittleness
- Productivity
- Porosity-Permeability
- Oil-in-Place
Factors Related to Tight Oil Production

- Source beds
- Mature source rocks form continuous oil column (*pervasive saturation*)
- Reservoir - favorable facies and diagenetic history (*matrix permeability*)
- Favorable history of fracture development: folds, faults, solution of evaporites, high fluid pressures, regional stress field (*fracture permeability*)
- Mechanical stratigraphy
Western Interior Cretaceous Basin
Late Cretaceous
85Ma
Modified from Longman et al., 1998
Isopach Niobrara

Location of Transcontinental Arch

CI: 100 ft

Modified from Longman et al., 1998; Weimer, 1978
Modified from Longman et al., 1998, after Barlow, 1986
Stratigraphy

- Does not fit well into traditional classifications
- Gradation between units and similar facies makes lithostratigraphic correlations difficult
Modified from Lockridge and Pollastro, 1988
Oil Source Rocks
Sapropelic Deposition

- stratified water column
- minimum depth of 150 ft (below photic zone and wave action)
- heavy rain of organic material (predominantly marine phytoplankton)

Modified from Meissner et al., 1984; Webster, 1984
Modified from Sonnenberg and Weimer, 1993
Niobrara Fractures
Origin of Fractures

- Folding and Faulting
  - Tectonic, diapiric, slumping
  - Wrench faults
- Geologic History of Fractures
  - Recurrent movement on basement shear zones
- Solution of evaporites
- High Fluid Pressure
  - Maturation of source rocks
- Compaction and dewatering
- Regional stress field
- Regional epeirogenic uplift
Force Folds, Faults, and Fractures
Hinge perpendicular

Fractures related to folds

Hinge parallel
Structures and Associated Fractures

From Austin Chalk Outcrops

Friedman et al., 1992
Compaction-Dewatering
North Sea Overpressured Shale
(Brown, 2004)
Polygonal Fault Systems

• Layer-bounded fault systems
• Small extension faults
  – 10-50 m throw
  – Faults dip 30 to 70°
• Random oriented fault patterns
Polygonal Fault Systems

- Volumetric contraction resulting from compaction-driven fluid expulsion
- Compaction dewatering occurs at depth
- Vertical effective stress exceeds horizontal effective stress and inclined fractures result
- Stress state in plane in which polygons are developed is either isotropic or close to isotropic
Faults and Salt Edge

Svoboda, 1995
Structure Top Niobrara

Sonnenberg and Weimer, 1993
Extension Fractures and Wrench Faults

Shmax

Sonnenberg and Weimer, 1993
Generalized stress map, western US. Arrows represent direction of either least (outward directed) or greatest (inward direction) principal horizontal stress (modified from Zoback and Zoback, 1980)
Regional Fractures
Systematic and Non-systematic

Modified from Lorenz et al., 1991, Nelson 2010
Overpressuring in Rockies Basins

INCREASING THERMAL METAMORPHISM

INCREASES THERMAL STRESS

VOLUME OF ORIGINAL UNMETAMORPHOSED "IMMATURE ORGANIC MATERIAL (KEROGEN)"

VOLUME OF GENERATED FLUID HYDROCARBONS

VOLUME OF METAMORPHOSED ORGANIC MATERIAL

ASSUMES GENERATED HYDROCARBONS ARE RETAINED IN SYSTEM & CONVERT TO STABLE SPECIES

Modified from Spencer, 1987 and Meissner, 1980
Technology for Source Bed Plays

- Source rock evaluation
- Normal surface and subsurface mapping (i.e., the fundamentals)
- Resistivity mapping (e.g., logs)
- Lineament discrimination (local, regional)
- 3-D, 3-C Seismic Imaging
- Borehole fracture mapping (FMS, etc.)
- Surface geochemistry (microseeps)
- Horizontal drilling
- Microseismic
- Multistage hydraulic-fracture stimulation
Niobrara Petroleum System - Denver Basin
Shallow Biogenic Gas
Deep Thermogenic Oil and Gas
Niobrara vitrinite reflectance versus "K" zone resistivity, Denver Basin

Smagala et al., 1984
Niobrara Source Rock Maturity-Denver Basin

Smagala et al., 1984
Resistivity Mapping and Accumulation

Sonnenberg and Weimer, 1993
Lineament Analysis
S. Perry, ca 1985
New locations (all zones)

Niobrara oil

Niobrara gas

Structure Niobrara
Denver Basin
CI: 1000 ft
**Structure Niobrara**  
**Silo Field**  
CI: 50 ft

**SILO FIELD**  
*Niobrara Fm.*

**Discovery:**

1981  
Amoco Champlin 300 1  
SE SE Sec 5, T15N, R64W  
Ft Hays completion  
78 BOPD

1990  
First horizontal:  
Warren # 1  
Sec. 11, T15N, R65W  
600 BOPD

**Vertical Depths:**  
7100 to 8800 ft

**Cum Prod:**  
10.4 MMBO  
8.9 BCFG  
6.3 MMBW
UPR Berry 41-13
NE NE NE NE Sec. 13-T16N-R66W

Casing Point

Side Track # 2

Side Track # 3
Other Shows of Interest

- Greenhorn
  - Rec. 5280 GCO
  - Bridge Creek LS
  - Hartland Shale
  - Lincoln LS

- Mowry
  - J SS

- Niobrara
  - Rec. 7700 O&G

- Codell
EOG Resources
DJ Basin Horizontal Niobrara

- Current 2-Rig Drilling Program
  - Plan 45 Wells in 2011

Operational Activity

- Drilling Activity to Date on 80,000 Net Acre Hereford Ranch Field
  - Continuing to Exploit with Good Well Results

- Recent Drilling on Two Additional Prospects, 89,000 Net Acres Total

- Encouraging Economic Results from 169,000 of 220,000 Total Net Acres to Date

- Good Long-Term Stable Production Rates; Wells Have Low Initial Rates and Flat Declines
  - Jake 2-01H
    - 1st Month IP Rate – Late 2009 – 645 Bopd
    - Stable Rate of 250-300 Bopd Since 1Q11
  - Elmer 8-31H
    - 1st Month IP Rate – March 2010 – 283 Bopd
    - Current 225 Bopd

- Other Recent Well Tests – Controlled Rates

  \[
  \begin{array}{c|cc}
  \text{Well} & \text{Bopd} & \text{Mcfd} \\
  \hline
  \text{Fiscus Mesa 9-10H} & 335 & 174 \\
  \text{Gravel Draw 9-09H} & 277 & 146 \\
  \end{array}
  \]

EOG Resources
EOG_0811-24

EOG: http://www.eogresources.com/investors/investor_pres.html
Stratigraphy – Powder River Basin

Inexco 1-12 Federal, T32N, R69W, Sec. 12

- Three chalk facies separated by marls.
  - Similar to the stratigraphy of the Denver Basin.
- No Fort Hays member.
  - Incorporated into the underlying Sage Breaks Mbr. of the Carlile Shale.
- “B” and “C” benches seem most prospective.
  - Regional Continuity
  - Historical Production/Shows
  - Thickness
Niobrara Drilling/Leasing

Niobrara drilling and leasing activity in the southern Powder River Basin. Stars denote Niobrara activity (Courtesy of Tofer Lewis).
<table>
<thead>
<tr>
<th></th>
<th>Bakken</th>
<th>Niobrara</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Age</strong></td>
<td>Late Dev/Miss</td>
<td>Upper Cret.</td>
</tr>
<tr>
<td><strong>Lithology</strong></td>
<td>silt, dolostone</td>
<td>chalk, marl</td>
</tr>
<tr>
<td><strong>Depth</strong></td>
<td>9-10,000 ft</td>
<td>8,000 ft</td>
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<tr>
<td><strong>Thickness</strong></td>
<td>70 ft</td>
<td>40 ft</td>
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<tr>
<td><strong>Porosity</strong></td>
<td>5-10%</td>
<td>8-10%</td>
</tr>
<tr>
<td><strong>Perm</strong></td>
<td>&lt;0.1 md</td>
<td>&lt; 0.1 md</td>
</tr>
<tr>
<td><strong>Fractures</strong></td>
<td>M &amp; F</td>
<td>M &amp; F</td>
</tr>
<tr>
<td><strong>Spacing</strong></td>
<td>1280</td>
<td>640</td>
</tr>
<tr>
<td><strong>Oil Gravity</strong></td>
<td>42°</td>
<td>32-62°</td>
</tr>
<tr>
<td><strong>Pressure</strong></td>
<td>Mod-High</td>
<td>Normal to H</td>
</tr>
<tr>
<td><strong>Costs</strong></td>
<td>$7-8 MM</td>
<td>$5-6 MM</td>
</tr>
</tbody>
</table>
Summary

• Unconventional tight oil resource plays are ‘changing the game’
• Niobrara Petroleum System present in most Rockies basins
• 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
Niobrara Consortium

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‘Unlock the Chalk’

Niobrara and Mancos Production,
Rocky Mountain Region