The Niobrara Petroleum System, Rocky Mountain Region

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Niobrara and Mancos Production, Rocky Mountain Region
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
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

http://jan.ucc.nau.edu/~rcb7/namK85.jpg
WIC Seaway
Niobrara Time

Modified from Longman et al., 1998
Cretaceous Cross Section, Western Interior Basin

Modified from Kauffman, 1977
Isopach Niobrara

Location of Transcontinental Arch

CI: 100 ft

Modified from Longman et al., 1998; Weimer, 1978
Modified from Longman et al., 1998
Modified from Longman et al., 1998, after Barlow, 1986
Modified from Lockridge and Pollastro, 1988
Requirements of Source Rock Deposition

- High organic productivity
  - Sunlight
  - Nutrients
  - Absence of poisons (H₂S)
- Low destruction rate of organic material
  - Absence of O₂ and biologic consumers
- Lack of dilution by other constituents
  - i.e., shale, sandstone, etc.
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 Pollastro, 1992
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 (i.e., regional fractures)
• Regional epeirogenic uplift
Structures and Associated Fractures

From Austin Chalk Outcrops

Friedman et al., 1992
Compaction-Dewatering North Sea Overpressured Shale (Brown, 2004)
3-D Seismic

Pierre
Kn
Grnhrn
Graneros
D SS
Faults and Salt Edge

Svoboda, 1995
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)
Overpressuring in Rockies Basins

INCREASING THERMAL METAMORPHISM

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

VOLUME OF GENERATED FLUID HYDROCARBONS

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

Modified from Spencer, 1987 and Meissner, 1980
Powder River Basin
Background Geology

- Pelagic carbonate in water depths of 200-500 feet (Similar to Austin Chalk)
- Only Smoky Hill Mbr. present in PRB. Chalks, marls and calcareous shales.
- Upper contact: Pierre, Conformable. Lower contact: Sage Breaks member of Carlile Shale, Unconformable
- Matrix perm < .01 md
- Porosity ~ 8-10%

(Anna, 2009)
Stratigraphy

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
- **Total Niobrara Isopach**
- Niobrara exhibits an overall westward thickening trend in the study area.
- Unusually thick area in the northeastern portion of the study area:
  - C bench is drastically thicker due to scouring into the underlying Sage Breaks.
  - Total Niobrara thickness approaches 500 ft.
- **Niobrara C Isopach**
- Infilling of scours into underlying Sage Breaks Member of the Carlile Shale.
  - Abnormally thick
- Interpretations for erosional mechanism includes
  - Fluvial
  - Submarine
- Area of max fill
  - Total NBRR package thickens up to 500 ft.
- Some areas, Sage Breaks is completely eroded.
  - C bench directly overlies the Turner
Niobrara B Isopach.

Niobrara B bench currently the most exploited horizontal drilling target.
- Southern portion of the basin
- Converse and Campbell Counties.

Favorable reservoir conditions
- Cleaner chalk facies
- Aerially extensive, thick

Shows an overall westward thickening trend
**Mineralogy**

*Inexco 1-12 JT Federal. T32N R69W Sec. 12*

- **Sampled part of the marl between the A and B chalk.**
  - Higher clay percentages in the first sample.
  - Decrease in clay percentages in samples taken only from the B chalk.

Log showing the interval of XRD analysis.
Thermal Maturity

- Western PRB, Niobrara hydrocarbon generation started about 30 Ma.
  - Depth 8,000 ft., %R_o 0.60
- Average 3 wt.% TOC
- Oil prone type II marine kerogen

Niobrara enters hydrocarbon window %R_o ≥ .60

Burial history diagram of the western PRB (Modified from Anna, 2009).
Thermal Maturity

- Thermal Maturity.
- Published works state that 8,000 ft is the cutoff for oil generation in the Niobrara in the Powder River Basin (Anna, 2009).
  - Based on observed %Ro.
  - Burial depths of 8,000 ft or greater correspond to %Ro values of 0.6 or greater.

Posted Niobrara oil API gravity.
(Modified from Anna, 2009)
Thermal Maturity

Data collected from 30 locations throughout the southern portion of the basin.
- USGS Core Research Center Denver, Colorado
- Both cuttings and core data used.
- Tmax values range from 426-444°C.
- Interpretations limited by availability of data

Contour map of maximum Tmax values for the 30 wells in the southern portion of the basin.
Thermal Maturity

- Thermal Maturity.
- Data collected from 30 locations throughout the southern portion of the basin.
  - USGS Core Research Center Denver, Colorado
- Max TOC% values range from 0.91-2.99 wt%
- Analysis method: Rock-Eval 2
- Data indicates the Niobrara is organic rich

Contour map of maximum TOC% for the 30 sampled wells in the southern portion of the basin.
Fracturing

- Natural fractures are crucial for economic production in shale-oil reservoirs.
- In the PRB, overpressuring is seen on a basin wide scale in the Cretaceous shale section.
- Initial investigations indicate that natural fractures are present in the Niobrara at this locality.
- Area of overpressuring (red outline) coincides with area where Niobrara depths greater than 8,000 ft, and in the oil window.

Southern Powder River Basin showing the area overpressuring seen in Cretaceous strata (red), and the Niobrara thick freeway (green) (modified Parks and Gale, 1996).
Fracturing

Table showing pre-drill predictions and the actual post-drill data for mudweights and fracture azimuth direction for five wells in the southern Powder River Basin. #: Number of fractures > than 1mm. M: Max aperture measured. I: Average individual fracture spacing. S: Average fracture swarm spacing (modified Parks and Gale, 1996).

<table>
<thead>
<tr>
<th>Target Horizon</th>
<th>Pre-Drill</th>
<th>Post-Drill</th>
<th>Result</th>
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<tbody>
<tr>
<td></td>
<td>Fracture Azimuth</td>
<td>Mudweight</td>
<td>Fracture Azimuth</td>
</tr>
<tr>
<td>Amoco Morton Ranch 1-25H 33N-72W-25</td>
<td>N60W</td>
<td>10.0</td>
<td>N73E</td>
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<tr>
<td>ARCO Red Mountain #1 33N-71W-35</td>
<td>N70E</td>
<td>11.5</td>
<td>N65E</td>
</tr>
<tr>
<td>Vastar Idarado 1-27H 33N-71W-27</td>
<td>N70E</td>
<td>11.5</td>
<td>N60E</td>
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<tr>
<td>Vastar Lizard Head 1-8H 33N-71W-8</td>
<td>N70E</td>
<td>10.5</td>
<td>N70E</td>
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<tr>
<td>Vastar Rooster Rock 1-36H 33N-71W-36</td>
<td>N70E</td>
<td>11.4</td>
<td>N75E</td>
</tr>
</tbody>
</table>
Fracturing

- Natural Fractures.
- Previous workers have established that the fracture orientation in the southern portion of the basin is approximately N70E.
  - Shear-wave seismic analysis
  - Down hole analysis
- Wells with higher fracture density correspond to areas of increased pressure.
- Knowledge of fracture orientation is crucial for horizontal wellbore orientation.

Predicted fracture orientation (N65E) based on shear wave from seismic analysis (Parks and Gale, 1996).
Niobrara Drilling/Leasing

Figure 1: Niobrara drilling and leasing activity in the southern Powder River Basin. Stars denote Niobrara activity (Courtesy of Tofer Lewis).
Niobrara Drilling/Leasing

- Majority of activity still located in the deep, southern portion of the basin adjacent to the basin center.
- Some activity out of the basin center, along the flanks.
- Prominent operators: Chesapeake, EOG, Devon
- Majority of the activity is located in the Southern PRB in Converse and Campbell Counties.
  - Niobrara is in the oil window.
- Currently, not as active as Denver Basin.
  - Activity is on the rise.

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

Type log (modified from Weimer and Flexer, 1985)
Conclusion

• The Niobrara is emerging as a significant resource play in the Rocky Mountain Region.

• Based on the presented information, promising reservoir conditions exist in the Niobrara in the southern Powder River Basin.
  – Stratigraphy
  – Favorable Mineralogy
  – Thermal Maturity/Organic Richness
  – Natural Fracturing

• More analysis is currently underway to evaluate the extent of these reservoir parameters throughout the southern portion of the basin.
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Niobrara Consortium

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