
David J. Thul¹,² and Steve Sonnenberg²

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¹²PetroLuminary, LLC, Denver, CO (dthul@petroluminary.com)
²Colorado School of Mines, Golden, CO (ssonnenb@mines.edu)

Abstract

The Niobrara Formation of the Denver Basin is an unconventional oil and gas drilling target composed of alternating chalk and marl units. These units act as the source, seal and trap for hydrocarbons generated in the total organic-carbon-rich marl beds of the Niobrara.

Organic geochemical data, such as oil-to-source rock correlations, oil biomarkers and gas isotopes, indicate that the fluids accumulated within the reservoirs closely match the source rocks in type and maturity; therefore, this is a system of in-situ generation and accumulation as well as low migration. In a system where migration is minimal, proximity to an effective source rock is a prerequisite for a productive well. With such a prerequisite, play delineation should begin with regional source-rock maturity assessment.

Historically, source-rock maturity has been studied through programmed pyrolysis (such as Rock-Eval™), vitrinite reflectance, log interpretation or basin modeling. Recently, a new pyrolysis instrument (the Source Rock Analyzer™) has come to market. With this new addition, questions of data congruence have arisen between the Rock-Eval™ and the Source Rock Analyser™ that preclude combining data sets without further study.

This work establishes the veracity of the data from the Source Rock Analyzer™ and compares its results to those of a Rock-Eval™ instrument, using a suite of 103 source rock samples.

The test of data veracity shows that the S2 and Tmax parameters from the Source Rock Analyzer™ are comparable to those from the Rock-Eval™, showing good correlation and a nearly one-to-one relationship. The other parameters, S1 and S3 show similar trends but there is significant scatter in the data. The calculated parameters (hydrogen index, oxygen index, production index, and total organic carbon) are correlative but deviate significantly from a one-to-one relationship.
Using the newly understood relationship between SRA™ and Rock-Eval™ pyrolysis, regional assessment of the Niobrara shows that the onset of hydrocarbon maturity in the Niobrara is 432 degrees C Tmax and that hydrocarbon expulsion occurs between 438 degrees C and 443 degrees C Tmax. The study also shows that Niobrara production can be predicted by mapping the thermal maturity stages as well as free hydrocarbon anomalies within the basin.

References Cited


David J. Thul\textsuperscript{1,2}
Steve Sonnenberg, PhD\textsuperscript{2}

\textsuperscript{1}PetroLuminary, LLC
\textsuperscript{2}Colorado School of Mines
Outline

• Niobrara Fm. in the Denver Basin

• Previous Maturity Studies
  – Rice, 1984
  – Higley, 1988
  – Landon, 2001

• Understanding the COMB Trend
  – New Analytical Results
  – Burial History Modeling Results

• Niobrara Regional Interpretation

• Conclusions
Niobrara Fm.

[Diagram showing stratigraphic section with labels for different formations and horizons such as Pierre Shale, Smoky Hill Member, Fort Hays Member, Lower Chalk, Middle Chalk, Upper Shale, Beach Island, and Scott & Cobban, 1964.]
Motivation—Niobrara Maturity

Outside of COMB,
Maturity approx. linear with depth

NE Weld County,
Moderate T-Grad.

El Paso, N. Laramie,
S. Goshen Counties,
Low T-Grad

COMB Trend
Near Wattenburg,
High T-Grad

New Cuttings Pyrolysis
Historical Cuttings Pyrolysis (Avg)
Outside of COMB Pyrolysis (Avg)
Basement Structure

Study Area

0 25 50 100 Miles

Basement Structure

Study Area
Previous Maturity Studies
Area of Mature Source Rock

Rice, 1984 Niobrara Maturity Extent
Comb_Axis
Study Area

Rice, 1984
$R_o$ of the Dakota Fm.

Higley, 1988

Vitrinite Avg. Reflectance (%)

- 0.32 - 0.40
- 0.41 - 0.50
- 0.51 - 0.60
- 0.61 - 0.70
- 0.71 - 0.80
- 0.81 - 0.90
- 0.91 - 1.00
- 1.01 - 1.10
- 1.11 - 1.20
- 1.21 - 1.30
- 1.31 - 1.40
- 1.41 - 1.50
- 1.51 - 1.60

Ro Contours

- 0.6
- 0.8
- 1.0
- Comb_Axis
- Study Area
Tmax of the Niobrara Fm.
Data Gap as of 2010
Understanding the COMB Trend & Niobrara Maturity

70 cuttings analyses
22 locations
New analyses were taken along the -2000 ft structure contour (purple diamonds) as well as long the NE-SW COMB Trend (pink diamonds)
COMB Trend & Niobrara Maturity

Along the S-N transect, source rock maturity increases through the COMB Trend.

Along the NE-SW transect, shallow samples in the NE have similar maturities to those deeper in the basin.
There is a clear increase in maturity within the COMB boundaries.
Burial History Modeling

\[ R_0 \text{ Modeled: } 0.7 \]
\[ E R_0: 0.6 \]
Removal Needed: 800 ft.

\[ R_0 \text{ Modeled: } 0.74 \]
\[ E R_0: 0.93 \]
Tert. Removal: 3270 ft.
Removal Needed: 5200 ft.

\[ R_0 \text{ Modeled: } 0.76 \]
\[ E R_0: 1.3 \]
Tert. Removal: 3210 ft.
Removal Needed: 7300 ft.

\[ R_0 \text{ Modeled: } 0.63 \]
\[ E R_0: 0.76 \]
Tert. Removal: 2200 ft.
Removal Needed: 4200 ft.

\[ R_0 \text{ Modeled: } 0.63 \]
\[ E R_0: 0.59 \]
Tert. Removal: 2360 ft.
Removal Needed: 1500 ft.
Niobrara Regional Interpretation

1360 pyrolysis analyses
1370 TOC analyses
220 well locations
Niobrara Regional Interpretation

The maturation pathway for the Niobrara source rocks is defined by the decreasing HI with increasing Tmax.

Hydrocarbon generation appears to begin between Tmax values of 430°C and 435°C.
The free petroleum and normalized oil content show a sharp increase at a Tmax of 432°C & plateau at Tmax of 438°C. Interpreted as onset of petroleum generation & petroleum expulsion.
To eliminate analytical noise in HI (and Transformation Ratio) it is useful to model TR based on Tmax using a sigmoidal function.
From the modeled values, the onset of petroleum generation is 432°C Tmax (TR 0.1) and expulsion occurs at 438°C Tmax (TR 0.25) which agrees with the volumetric-based analysis of Momper, 1980.
From Crossplots to Maps

Onset of HC generation: 432 °C
First HC expulsion event: 438 °C
Niobrara Regional Interpretation

Using the data and model of HC generation and expulsion, regions of each maturity are delineated.

Expulsion maturity occurs in the greater Wattenberg area as well as Adams, Arapahoe, Elbert and Douglas counties.

Onset maturity occurs in NE & NW Weld county as well as parts of Wyoming and Nebraska.
Free hydrocarbon anomalies are present in NE Weld County, SE Wyoming and in the western reaches of the basin.

The Greater Wattenberg Area, notably, shows no free hydrocarbon anomaly.
## Niobrara Regional Interpretation

### Prospect Ranking Definitions

<table>
<thead>
<tr>
<th>Priority Level (Favorability)</th>
<th>Maturity</th>
<th>S1</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Expulsion (Tmax &gt; 438)</td>
<td>Elevated</td>
</tr>
<tr>
<td>2</td>
<td>Expulsion (Tmax &gt; 438)</td>
<td>Not elevated</td>
</tr>
<tr>
<td>3</td>
<td>Onset (432 &lt; Tmax &gt; 438)</td>
<td>Elevated</td>
</tr>
<tr>
<td>4</td>
<td>Onset (432 &lt; Tmax &gt; 438)</td>
<td>Not elevated</td>
</tr>
<tr>
<td>5</td>
<td>Immature (tmax &lt; 432)</td>
<td>Elevated</td>
</tr>
</tbody>
</table>
The highest priority targets are located along the COMB trend with lower priority targets flanking that zone and dispersed throughout the basin.
The highest level prospects are, in all cases associated with higher geothermal gradients.
Niobrara Regional Interpretation

Most of the established production is inside the two highest exploration target categories.

The notable exception is Silo Field which may be due to its favorable structural history.
Summary

Increased heat, not burial history, best explains increased source-rock maturity along the COMB Trend.

Areas of varying prospectivity can be identified using regional interpretation of pyrolysis datasets.

Using a stacked polygon method (a la Tainter, 1982) creates exploration fairways that encircle existing production.

Several other areas in the basin appear prospective using this method but more data is needed.