Abstract

The Mancos Shale Formation within the Piceance Basin is one of the richest hydrocarbon-bearing formations in the world but remains a relatively unexplored play. Numerous wells have tested the liquid-rich, transitional and dry gas window, with variable results. The main drilling targets are typically the Niobrara Formation, comprised mainly of marls, siltstones and shales, and the overlying Mancos B Formation, comprised mainly of silty shales with relatively low carbonate content.

Beginning in 2008, several horizontal wells have targeted these formations, mostly in gas-prone deposits on the southern side of the Piceance Basin. Results to date have been mixed, but the highest initial production comes from the more overpressured, carbonate-prone benches, such as the Tow Creek and Rangely Bench. The wells drilled before 2014 were typically shorter with lower frac intensity, resulting lower production rates. Beginning in 2014, longer laterals with higher frac intensity resulted in higher production rates. The increased yields are due to a combination of improved frac design and drilling strategies. Importantly, the Niobrara Formation is well suited to test the impact of more modern frac designs, including higher proppant and 63 Wyoming Geological Association – September 15-18, 2019 water volumes, shorter stage lengths, and plug-and-perf completion techniques.

The Niobrara Formation has been drilled in the liquids window along the western and northern margins of the Piceance Basin from 2014 to 2018, with longer lateral lengths and higher proppant volumes, but the results have proven somewhat disappointing. Due to the lower number of wells, it is difficult to determine the exact cause of lower production rates. However, available data indicate that it is likely due to a combination of lower formation pressures, higher hydrocarbon viscosities, reservoir properties, and ill-suited completion techniques.

The Piceance Basin has substantial gas processing and transport infrastructure in place and can be competitive against existing US gas markets. If Piceance Basin operators can merge newer completion styles with access to international LNG markets, there is unlimited potential for future natural gas production.
Selected References


Website Cited

The Past, Present and Future of Niobrara/Mancos B Horizontal Development in the Piceance Basin

Jason Eleson, Manager of Technical Sales @ Enverus (Drillinginfo) & Owner of GeoIntegra Consulting, LLC

RMS-AAPG Sectional Meeting, September 18, 2019
Acknowledgements

Many thanks to these folks for their assistance!

- **Caerus Piceance LLC** – Mike Leibovitz, Nate Cumella, Nick Barber, Maurice Dukes, Mike Mengers, John Benton, Cole Spurgeon, Mike Strabala, Kristine Mize-Spansky, Allison Woolston
- **Augustus Energy Partners II** – Graham McClave
- Gus Gustason
- Steve Cumella
- Retamco Operating – Chip Oakes
- Terra Energy Partners – Steve Sunnenberg
- **Ursa Resources** – Duke Cooley
- **Gunnison Energy** – Barrett Lavergne, Karl Umland, Salar Nabavian
- Chris Martin
- **Encana** – For acquiring so much good data!
Own your own Han Solo Frozen In Carbonite replica, Available on Ebay for $6000!

“Description: This life size prop/replica of Star Wars Han Solo in Carbonite is cast in fiberglass and hand-finished in metallic paint to create the carbon-freeze prop used in the landmark films The Empire Strikes Back and Return of the Jedi. This item, produced in 1997, is unique as it is signed by the artist, Mario Chiodo, in the bottom right front corner and dated on Halloween, 10/31/96. This authentic piece with authentic signature is the size of a normal door and features four vents on each side. It is still in the original box. Makes a great addition to your collection!”
10 Year US Natural Gas Prices
Nowhere to go but down since 2008!

https://www.macrotrends.net/2478/natural-gas-prices-historical-chart
Key Piceance Niobrara Players
Lots of P.E.-backed Asset Transitions From 2012-2017

https://www.macrotrends.net/2478/natural-gas-prices-historical-chart
Western Interior Seaway During Niobrara Deposition
Carbonates Prominent To The East, Clastic Prominent to the West

Don’t forget: 40-50 miles of crustal shortening during Laramide!
Mancos: Big Changes from NW/SE
Thinning to SE, Increase in TOC/Calcite, Slight Change in Organic Matter Type

Northwest Piceance:
- Higher clastic content
- Lower calcite & TOC content
- Mixed Type III/II Source Rock (gas-prone at lower thermal maturity, slightly lower quality)

Southeastern Piceance:
- Lower clastic content
- Higher calcite & TOC content
- Mixed Type II/III Source Rock (less gas-prone at lower thermal maturity, slightly higher quality)

Images & Content Courtesy of Caerus Piceance LLC
High Volcanic Heat Flow in Southern Piceance
Results in high thermal maturities at shallower depths

- Modern day BHL temperature maps indicate notably hotter temps in southern Piceance
- Volcanic intrusives along SE Piceance margin results in high thermal maturities at shallower depths
- Low chance of encountering significant liquid accumulations in SE Piceance basin
- Higher chance of encountering liquid accumulations in north/northeastern Piceance basin

Bottom Hole Temperature Map @Niobrara

Yurewitz, et al. 2003
Issue: Resistivity Not Always Tied To Sw in Shale Gas Plays

Cumella et al., 2014
Petrophysical Model Indicates Multi-bench Potential

<table>
<thead>
<tr>
<th>Gamma Ray</th>
<th>Resistivity</th>
<th>Porosity</th>
<th>Sw</th>
<th>Multimin</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

- **Vclay-log**: 6500
- **Vclay-core**: 7000
- **PHIE-log**: 7500
- **PHIE-core**: 8000
- **Sw-log**: 6500
- **CALC-core**: 7000
- **Qtz-log**: 7500
- **CALC-log**: 8000
- **Qtz-core**: 8500

**EUR per vertical 200’ of section (BCF)**

Images & Content Courtesy of Caerus Piceance LLC
Favorable Geomechanical Properties in Calcite & Silica Prone Benches

**Conclusions**

- Most brittle intervals are Mancos B & Wolf Mountain, likely due to higher quartz content.
- Least brittle intervals are “Uppermost Nio” and lower portion of Rangely Bench, likely due to higher clay content.
- Lower Tow Creek target has similar intermediate brittleness in both wells, but Buck Peak target is less brittle in the Fed 24-16 well (closest proximity to Orchard).

Images & Content Courtesy of Caerus Piceance LLC
## Orchard Niobrara & Mancos B Bench Summary

Poor to Fair RQ, Overpressured, Thick Stacked Pay, No Aquifers

### Potential for a “Permian Basin of Gas”

<table>
<thead>
<tr>
<th>Bench</th>
<th>Lithology</th>
<th>Thickness</th>
<th>Average Porosity</th>
<th>EUR (2 mile well, 200' Frac height)</th>
<th>Pressure (psi/ft)</th>
<th>Brittleness</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mancos B</td>
<td>Sandstones, siltstones &amp; interbedded grey shales</td>
<td>1000'</td>
<td>6-8%*</td>
<td>5-35 BCF*</td>
<td>0.55</td>
<td>High</td>
</tr>
<tr>
<td>Uppermost Nio</td>
<td>Grey shales, siltstones &amp; lenticular pelleted carbonates</td>
<td>125'</td>
<td>3-6%</td>
<td>2-10 BCF</td>
<td>0.55</td>
<td>Low</td>
</tr>
<tr>
<td>Buck Peak</td>
<td>Black shales, pelleted carbonates and siltstones</td>
<td>200'</td>
<td>6-8%</td>
<td>15-25 BCF</td>
<td>0.60</td>
<td>Moderate</td>
</tr>
<tr>
<td>Tow Creek</td>
<td>Grey shales, pelleted carbonates and siltstones</td>
<td>325'</td>
<td>5-7%</td>
<td>8-18 BCF</td>
<td>0.65</td>
<td>Moderate</td>
</tr>
<tr>
<td>Wolf Mountain</td>
<td>Siltstones, grey shales</td>
<td>290'</td>
<td>4-6%*</td>
<td>2-10 BCF*</td>
<td>0.65-0.68</td>
<td>High</td>
</tr>
<tr>
<td>Rangely Bench</td>
<td>Grey shales, pelleted carbonates and siltstones</td>
<td>300'</td>
<td>3-5%*</td>
<td>2-12 BCF*</td>
<td>0.65-0.68</td>
<td>Moderate</td>
</tr>
</tbody>
</table>

*More detailed petrophysical model needed to refine estimate

Images & Content Courtesy of Caerus Piceance LLC
Niobrara/Mancos B Geologic Domains

Bottom line: The Niobrara dry gas play has lowest exploration risk, and best chance for high production rates & positive economics*

* Not everyone agrees with me on this; stay tuned...

Images & Content Courtesy of Caerus Piceance LLC

<table>
<thead>
<tr>
<th>Domain</th>
<th>BTU Content</th>
<th>CO2 Content</th>
<th>Pressure Profile (psi/ft)</th>
<th>Summary</th>
</tr>
</thead>
<tbody>
<tr>
<td>Oil</td>
<td>1300 +</td>
<td>&lt;1.0%</td>
<td>0.43 -0.5</td>
<td>Favorable commodity price, but low production rates</td>
</tr>
<tr>
<td>Rich Wet Gas</td>
<td>1200 - 1300</td>
<td>1.0-1.5%</td>
<td>0.50 -0.5</td>
<td>Favorable commodity price, but low production rates</td>
</tr>
<tr>
<td>Lean Wet Gas</td>
<td>1100 - 1200</td>
<td>1.5-2.5%</td>
<td>0.55 -0.6</td>
<td>Neutral commodity price, but low to moderate production rates</td>
</tr>
<tr>
<td>Dry Gas</td>
<td>980-1100</td>
<td>2.5-3.5%</td>
<td>0.65 -0.8</td>
<td>Lower commodity price &amp; higher CO2 content, but higher production rates</td>
</tr>
<tr>
<td>Dry Gas High Overpressure</td>
<td>&lt;980</td>
<td>3.5% +</td>
<td>0.8+</td>
<td>Lower commodity price, higher CO2 content, challenging drilling, but highest production rates</td>
</tr>
</tbody>
</table>
Tow Creek = Main Horizontal Target
Mancos B, Rangely Bench = Second Target. Buck Peak = ~Untested Opportunity?
Lower Tow Creek = Main Horizontal Target
Mancos B, Rangely Bench = Second Target. Buck Peak = ~Untested Opportunity?

Content Courtesy of Caerus Piceance LLC
Nio Drilling & Completions Through Time
Longer laterals, higher frac intensity, tighter stage spacing

Images & Content Courtesy of Caerus Piceance LLC
Nio Case Study: Encana’s Orchard Experiment

Longitudinal wells: interesting idea, poor result

Concept: Tightly spaced wells parallel to Shmax in folded/fractured area to maximize vertical growth and minimize interference with other laterals

Images & Content Courtesy of Caerus Piceance LLC
Nio Case Study: Encana’s Orchard Experiment
Longitudinal Wells: Interesting idea, poor result

Reality: Tranverse Wells Perform Better Than Longitudinal Wells

Max Mudweight: 16ppg
85 days to drill!

Max Mudweight: 15ppg
145 days to drill!

Max Mudweight: 12-14ppg
30-60 days to drill!

Cumella et al., 2014
Nio Case Study: Black Hills Homer Deep Liquids Rim
Longer laterals & bigger fracs, with poor to moderate results

<table>
<thead>
<tr>
<th>Well Name</th>
<th>Max MW (PPG)</th>
<th>Completed Lateral</th>
<th>Stages</th>
<th>Feet per Stage</th>
<th>Fluid (BBLs)</th>
<th>Total Proppant (LBS)</th>
<th>BBLs/FT</th>
<th>LBS/FT</th>
<th>Avg Daily Gas Production - 90 days (MMCFCD)</th>
<th>Avg Daily Oil Production - 90 days (BOPD)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Homer Deep 9-41AH</td>
<td>12</td>
<td>8242</td>
<td>42</td>
<td>196</td>
<td>532360</td>
<td>9418933</td>
<td>65</td>
<td>1143</td>
<td>5.5</td>
<td>0</td>
</tr>
<tr>
<td>Homer Deep 9-41BH</td>
<td>12</td>
<td>9842</td>
<td>50</td>
<td>197</td>
<td>726783</td>
<td>15776109</td>
<td>74</td>
<td>1603</td>
<td>5.9</td>
<td>0</td>
</tr>
<tr>
<td>Homer Deep 9-41CH</td>
<td>12</td>
<td>9118</td>
<td>46</td>
<td>198</td>
<td>542987</td>
<td>10452798</td>
<td>60</td>
<td>1146</td>
<td>6.2</td>
<td>0</td>
</tr>
</tbody>
</table>

Image Courtesy of COGCC

Image Courtesy of Caerus Piceance LLC
Nio Case Study: WPX High Pressure Puckett Gas Well

Encouraging results from one of the biggest fracs to date

<table>
<thead>
<tr>
<th>Well Name</th>
<th>Max MW (PPG)</th>
<th>Completed Lateral (FT)</th>
<th>Stages</th>
<th>Fluid (BBLs)</th>
<th>Total Proppant (LBS)</th>
<th>FT/Stage</th>
<th>BBLs/FT</th>
<th>LBS/FT</th>
<th>Avg Daily Gas Production - 90 days (MMCFD)</th>
<th>Avg Daily Oil Production - 90 days (BOPD)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Puckett SG 714-44-23-HN1</td>
<td>15.2</td>
<td>8906</td>
<td>23</td>
<td>23572</td>
<td>17003411</td>
<td>202</td>
<td>59</td>
<td>1909</td>
<td>12.8</td>
<td>1.2</td>
</tr>
</tbody>
</table>

Images & Content Courtesy of Caerus Piceance LLC
Nio Case Study: Endeavour/Augustus Liquids Play
Higher pressure liquids window, moderate production rates; understimulated(?)
Nio Case Study: Endeavour/Augustus Liquids Play

Higher pressure liquids window, moderate production rates; understimulated(?)

Shut-in pressures: 0.67 psi/ft,
Mud Weight: 10.7-12.7 ppg
Both wells flared gas during drilling
Nio Case Study: Endeavour/Augustus Liquids Play
Higher pressure liquids window, moderate production rates; understimulated(?)

Images & Content Courtesy of Augustus Energy Partners II, LLC

<table>
<thead>
<tr>
<th>Well Name</th>
<th>Max MW (ppg)</th>
<th>Completed Lateral</th>
<th>Stages</th>
<th>Feet Per Stage</th>
<th>Fluid (BBLs)</th>
<th>Fluid Type</th>
<th>Total Proppant</th>
<th>FT/Stage</th>
<th>BBLs/FT</th>
<th>LBS/FT</th>
<th>Avg Daily Gas Production - 90 days (MMCFGD)</th>
<th>Avg Daily Oil Production - 90 days (BOPD)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wiley 23-3-97 H1</td>
<td>11.8</td>
<td>4,940</td>
<td>20</td>
<td>247</td>
<td>269,551</td>
<td>Slickwater</td>
<td>2,809,770</td>
<td>247</td>
<td>55</td>
<td>569</td>
<td>0.82</td>
<td>366</td>
</tr>
<tr>
<td>J22-15-397-2RH</td>
<td>12.8</td>
<td>8,300</td>
<td>40</td>
<td>207.5</td>
<td>237,000</td>
<td>Hybrid</td>
<td>7,140,000</td>
<td>207.5</td>
<td>29</td>
<td>860</td>
<td>0.84</td>
<td>516</td>
</tr>
</tbody>
</table>

Well shut in for pressure survey

Images & Content Courtesy of Augustus Energy Partners II, LLC
Nio Case Study: Endeavour/Augustus Liquids Play
Higher pressure liquids window, moderate production rates; understimulated(?)

- J22 well: Hybrid frac with mix of Xlink Gel, Linear Gel and Slickwater
- Injected tracers indicate clear trend of higher production in slickwater stages
- Augustus uses slickwater fracs in PRB as analog for predicted uplifting in future slickwater completions
- Augustus believes 2 mile HZ with 2000#/Ft will yield 1500 bopd in Rangely Bench in their future well(s)
Future Piceance Nio Activity

Augustus Energy
- Actively seeking partner
- Wants to drill 3 HZs in next year
- 2 HZs in Rangely Bench, 1 HZ in Frontier
- 3 wells permitted, 1 pending

Retamco Operating
- Actively seeking partner
- Plans to drill vertical pilot hole in 2020
- Wants to drill HZ target (Rangely Bench?) in 2021
- No wells permitted at this time

Caerus Operating
- Actively seeking partner
- Wants to shoot 3D seismic at Orchard, then drill 4 pilot development of horizontal wells (Tow Creek or Buck Peak)

Laramie Energy
- No Nio plans at this time

Anschutz Exploration
- No known Nio plans at this time
- 6 approved HZs, 2 pending HZs

XTO Energy
- No known Nio plans at this time

Ursa Energy
- No Nio plans at this time

Terra Energy Partners
- No Nio plans at this time

Grizzly Energy
- Formerly Vanguard, just emerged from Chapter 11 bankruptcy
- No known Nio plans at this time

Gunnison Energy
- Wants to drill 5 horizontals by EOY 2020
- Main target is Rangely Bench, +/- Wolf Mountain
Haynesville = Useful Niobrara Gas Reservoir Analog

S. Piceance XRD Indicates Similar Clay/Quartz/Calcite Content + Dry Gas + Overpressure

<table>
<thead>
<tr>
<th>Property</th>
<th>Haynesville</th>
</tr>
</thead>
<tbody>
<tr>
<td>Location</td>
<td>E. Texas/W. Louisiana</td>
</tr>
<tr>
<td>Age</td>
<td>Upper Jurassic</td>
</tr>
<tr>
<td>Depth (feet)</td>
<td>10000-14000</td>
</tr>
<tr>
<td>Net Thickness (feet)</td>
<td>200</td>
</tr>
<tr>
<td>Gross Thickness (feet)</td>
<td>200</td>
</tr>
<tr>
<td>Pressure (PSI)</td>
<td>8500</td>
</tr>
<tr>
<td>Pressure gradient (PSI/ft)</td>
<td>0.8-0.95</td>
</tr>
<tr>
<td>TOC (%)</td>
<td>3</td>
</tr>
<tr>
<td>Vitrinite Reflectance (%Ro)</td>
<td>2.2</td>
</tr>
<tr>
<td>Total Porosity (%)</td>
<td>8.5-10</td>
</tr>
<tr>
<td>BHT (Degrees F)</td>
<td>340</td>
</tr>
</tbody>
</table>

M Dutton 1-34B & Savage 8-21B XRD

100% Quartz

100% Carbonate

100% Clay

Scatter Plot

Haynesville XRD

Color by Shale
- Niobrara

Shape by Well Name
- M Dutton 1-34B
- Savage 8-21B

Size by
- Bit from Lith2

≥ 48.84
- ≤ 44.00
Haynesville = Useful Niobrara Gas Reservoir Analog
S. Piceance XRD Indicates Similar Clay/Quartz/Calcite Content + Dry Gas + Overpressure

- Intervals with highest degree of brittleness are Wolf Mountain, Tow Creek, Rangely Bench & Mancos B
- Intervals with lowest degree of brittleness are Buck Peak & Uppermost Nio
- Overall, the Niobrara section in this well appears to be more brittle than Haynesville, comparable to the DJ Niobrara, but less brittle than the Williams Fork formation
- Williams Fork is far more brittle than the key Niobrara benches, indicating that proppant less fracs would not work in Niobrara horizontals
Haynesville Paleogeography: Varying Carbonate/Clastic Content

Cicero et al., 2010
Haynesville Paleogeography: Varying Carbonate/Clastic Content

Cicero et al., 2010
Next Steps: Use DI Data for “Res-Frac” Analog

- Piceance Niobrara play has been “frozen in time”, and modern well completions in dry gas intervals are non-existent since 2015.
- Haynesville shale has similar lithologies, temperatures, pressures and drilling depth, and represents a useful frac analog.
- Using Haynesville data, we could be able to quantify:
  - Predicted improvements from newer reservoir stimulation with longer laterals, higher frac intensity, frac fluid types, narrower stage spacing, etc.
  - Differences in reservoir performance in marly vs. silty Haynesville lithologies.
- Bossier shale may also be a useful analog for the silty Mancos B reservoirs of the Piceance basin.
- Powder River Basin Niobrara depositional environment appears analogous to Piceance Nio play; fewer wells, but may yield insight into best frac techniques for overpressured liquids window on northern margin of Piceance basin.
Conclusions

Tremendous potential exists within the Piceance Basin Niobrara play, but updated completion design & improved commodities prices are crucial to “un-freezing” this basin

• Most horizontal development targeted the lower Tow Creek and Rangely Bench in the dry to wet gas window
• Majority of existing horizontal well bores produce from ~1 mile laterals with <700#/ft of proppant; newer completion design should provide significant uplift to initial and long term production rates
• Commercial rates have been demonstrated in some of the overpressured gas HZ wells, but the liquids-rich HZ wells have not yet been proven (remedied by overpressure + slickwater + more proppant?)
• If suitable completion strategy can be identified, there are 3-5 target benches within the Niobrara/Mancos B succession, and perhaps even more below
So, When Will The Piceance Nio Play Be Unfrozen?

Not sure, but improved drilling & completions improvements and commodities price support, this can be avoided...
Piceance Basin Basin During Niobrara Times:
Deepwater setting at crossroads of clastic/carbonate sedimentary systems

Sevier Highlands

40-50 miles of crustal shortening from Laramide orogeny

No scale implied