The Pennsylvanian Desmoinesian Mudstone and Carbonates Reservoirs in Southern Denver Basin*

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Abstract

The southern part of the Denver Basin is undergoing resurgence in exploration for Atoka, Cherokee, and Marmaton carbonate reservoirs with the reactivation of the Bolero field and the discovery of the Great Plains and Jolly fields in 2008. The traps are both stratigraphic and structural. The Atoka, Cherokee, and Marmaton formations of Middle Pennsylvanian age in the Denver Basin contain numerous thin carbonaceous mudstones (one to eight feet thick) that are generating and expelling hydrocarbons. In some cases, these mudstones are adjacent to thin highly porous, fractured carbonate reservoirs that cover large areas. The Atoka mudstones average 10% TOC which yield a high pour point 33 to 38 API gravity crude with associated 1,400 to 2,200 BTU gas. The organic matter within the Atokan mudstones is lacustrine in origin. The Cherokee and Marmaton mudstones average 11% TOC that yields a low pour point 35 to 41 API gravity crude with associated 1,450 to 2,100 BTU gas. The organic matter within the Cherokee and Marmaton mudstones is of marine in origin. The thin limestone and dolomites in the Cherokee known as 'A' and 'C' and the 'B' zone within the Marmaton have become the primary targets. This presentation will discuss some of the unique features and reservoir characteristics of the producing Pennsylvanian rocks in the Southern Denver Basin.
THE PENNSYLVANIAN DESMOINESIAN MUDSTONE AND CARBONATES RESERVOIRS IN SOUTHERN DENVER BASIN

Presented by:
Steven A. Tedesco
September 9-12, 2012
Grand Junction, Colorado, USA
Unconventional Plays in the US and Canada

Denver Basin

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The southern Denver Basin is dominated by Mississippian and Pennsylvanian oil production; specifically the Morrow sandstone and Mississippian structural or stratigraphic traps; The present focus is on the Marmaton “A” and “B”; Cherokee “A” and “C”; The oil from these zones and others is derived from the Desmoinesian (Cherokee and Marmaton formations) and is marine in origin; The oils derived from the Atoka rocks are terrestrial in origin; The carbonaceous shale of the Pennsylvanian in the Desmoinesian (Cherokee and Marmaton) and Atoka age rocks are considered the most likely source rocks; Individual carbonaceous shale (mudstone) bed thickness is typically 2 to 5 feet. The carbonaceous mudstones have large areal extent and are also considered a potential reservoir; The nomenclature used here is adapted from the Kansas Geological Survey.
Marmaton Reservoirs
- Two to 15 feet of oomoldic porosity;
- Production generally related to structural highs;
- Shoals can cover townships;
- Calculates oil everywhere due to log characteristics;
- Marmaton “A” and “B”;
- Requires no fracking;
- 5,500 to 7,500 feet.

Cherokee Reservoirs
- Two to 15 feet of porous limestones or dolomites;
- Stratigraphic or structurally controlled related;
- Shoals can cover townships in areal extent;
- Cherokee “A”, “B” and “C”;
- Source rocks usually adjacent;
- Requires no fracking;
- 6,200 to 8,300 feet.

Atoka Reservoirs
- To date no porous carbonates;
- This sandstones related to alluvial fans to the west or carbonaceous shale;
- 6,500 to 8,500 feet.

Under pressured basin: 0.2 to 0.34 psi per foot, local over pressured areas.
Marmaton

Cherokee

Atoka

Morrow

Mississippian
North – South Cross-section
Stratigraphic Section

<table>
<thead>
<tr>
<th>Layer</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Marmaton</td>
<td>Reservoir rocks, after Raymond C. Moore et al. (1951), Paul L. Hilman (1959), and Daniel F. Merram and Edwin D. Gehrel (1968).</td>
</tr>
<tr>
<td>Cherokee A</td>
<td>Includes Cherokee reservoirs, described by Marmaton et al. (1951).</td>
</tr>
<tr>
<td>Cherokee B</td>
<td>Marmaton reservoirs, described by Moore et al. (1951).</td>
</tr>
<tr>
<td>Cherokee C</td>
<td>Cherokee reservoirs, described by Marmaton et al. (1951).</td>
</tr>
<tr>
<td>Little Osage</td>
<td>Reservoir rocks, described by Marmaton et al. (1951).</td>
</tr>
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<td>Atoka</td>
<td>Reservoir rocks, described by Marmaton et al. (1951).</td>
</tr>
<tr>
<td>Tebo</td>
<td>Reservoir rocks, described by Marmaton et al. (1951).</td>
</tr>
<tr>
<td>Tebo B</td>
<td>Reservoir rocks, described by Marmaton et al. (1951).</td>
</tr>
</tbody>
</table>

Additional Information:
- Mississippian: Includes Chiricahua Shale, Eastern two-thirds of Kansas only. Misener sand in Sedgwick basin only.
- Hunton Limestone: Salina, Sedgwick, and Forest City basins.
- Meadeo Shale: Not everywhere present.
- Vicksburg Limestone: Simpson sand. Also St. Peter, "Willow".
- Silicous Lime: Reagen or Larned Sargods. Precambrian granite, quartzite, and other crystallines.
- Overlying rocks consist of ascending order, chiefly of upper Pennsylvanian, member beds, and eocene, Cretaceous shales, sandstones, limestones, and cherty shales, and the late Tertiary Oligocene formation of continental origin.
Reservoir Characteristics

- The Marmaton reservoirs are highly porous oomoldic zones, produce generally from structural highs or isolated reservoirs. Five to fifteen feet thick;
- The Cherokee reservoirs tend to be thin limestone highly porous and fractured limestone zone the Cherokee “A” and dolomites in the Cherokee “C”. One to ten feet thick, 6% to over 24% porosity;
- Atoka is limited to the shale and isolated sandstones;
- Morrow is typically low BTU gas;
- Mississippian structural closures.
### Stratigraphic Section

**Upper Atoka**
- Overlying rocks consist, in ascending order, chiefly of upper Permian red beds and evaporites, Cretaceous shales, sandstones, limestones, and chalky shales, and the late Tertiary Ogallala formation of continental origin.
- **Top of reservoir section (as of 1968).**
- **Chase Group.** The principal gas reservoir in the Hugoton embayment.
- **Council Grove Group.** Gas reservoir in Hugoton embayment. Permian rocks crop out in central Kansas.
- **Adair Group.** Shallow reservoir on Nemaha anticline.
- **Wabaunsee** is the uppermost group in the Pennsylvanian. Pennsylvanian rocks from the Cherokee to the Wabaunsee crop out in eastern Kansas.
- **Shawnee Group.** Includes Crede and other producing limestones in Kansas.
- **Douglas - Podue Groups.**

**Lower Atoka**
- **Marmaton** Group. Both limestone and sandstone reservoirs may be present.
- **Cherokee Group.** Contains Bartlesville and other sands. Absent across Central Kansas uplift.
- **Atoka Group.** Hugoton embayment only.
- **Morrowan Group.** Hugoton embayment only. Pennsylvanian basal sand or conglomerate on western uplifts.

**Mississippian**
- **“Mississippian Lime.”** Also “chat.” Absent across top of Central Kansas uplift. The oldest rock to crop out in Kansas (in southeastern corner of Kansas, where it directly underlies the Cherokee Shale).
- Also reservoirs in the Chester and Meramecian (Upper Mississippian) and Osage and Kinderhook (Lower Mississippian) series.
- **Chirarogoosha Shale.** Eastern two-thirds of Kansas only. Mancos sand in Sedgwick basin only.
- **“Hunton” Limestone.** Salina, Sedgwick, and Forest City basins.
- **Mancos Shale.** Not everywhere present.
- **Viola or Kimmswick Limestone.**
- **Simpson sand.** Also St. Peter, “Witco.”
- **“Silicous Lime.”**
- **Reagan or Lamotte Sandstone.**
- **Precambrian granite, quartzite, and other crystallines.**
Atoka Core
Microphotographs from the Atoka

7,280’
Calcareous Shale

7,280’
Zoom In of Adjacent Slide

7,287’
Carbonaceous Shale

7,299
Calcareous Shale

7,310
Carbonaceous Shale

7,323
Carbonaceous Shale
Most of the Cherokee Group (6,914’-6,942’) is predominantly carbonate (limestone). The carbonate section has evidence of both drilling-induced and natural fracturing, as does the shale (Excello). The shale is laminated much like the other shale intervals below, but this interval is more fractured than the others.
The VShale has the typical high uranium and finely laminated sediments (snapshot A). Immediately above the VShale, however, there is more of the very finely laminated layers, local increase in gas, and increased porosity (snapshot B). The fine laminae and elevated gas levels continue up to 6,286’.
The highest gas values (lt. blue shaded curve) over the logged interval are found in the Keyes, Morrow, and Atoka units. There is some association with fractures (red bars overlying gas curve), but may not be the only cause of gas entry into the wellbore.

A spectral gamma ray log was provided and analyzed in conjunction with the open hole logs and image log. Many intervals in the well are apparent shales and have high uranium content (black arrows in the diagram below), suggesting they are a high in organic content. The next several pages will highlight these intervals and explain characteristics observed therein.
Depositional Environment Setting

- Restricted basin adjacent to deep-water basinal separated by Las Animas Arch from the northwestern part of the Anadarko Basin;
- Anoxic, restricted basin shale deposition was interrupted by frequent pulses of marginally organic shale and carbonates sedimentation and volumetrically minor thin sandstones, via advancing alluvial fans from the Fountain Formation;
- Carbonate sediment sources were probably from adjacent shallow shelf/platforms along to the north and east margins of the Denver Basin;
- Interfingering with the clastic Fountain Formation to the south and west.

Sequence Stratigraphy

- Atoka, Cherokee and Marmaton formations was deposited during a major global transgressive during the Middle Pennsylvanian;
- Atokan sediments represents lacustrine or terrestrial sediments;
- Cherokee and Marmaton represents a large order marine condensed section;
- Many high frequent cycles;
- Sequences are volumetrically dominated by HST deposits.
Cherokee and Marmaton Shale

- Low pour point
- 37 to 41 API Gravity
- Marine
- No sulfur
- Gas BTU 1300 to 1800
- 3 to 6 carbonaceous shales
- 2 to 10 feet thick individually
- 2% to 24% TOC, Ave 12%

Atoka Shale

- High Pour point
- 34 to 38 API Gravity
- Terrestrial
- Paraffin
- No sulfur
- Gas BTU 1400 to 2100
- 10 to 18 carbonaceous shales
- 1 to 2 feet individually thick
- 2% to 27% TOC, Ave 11%

Maturity

- 0.55 to 0.98 Ro
- Increase with depth
- Some oil may have migrated

Carbonaceous Shales

- 20% to 50% Clays
- Non swelling
- 30% to 50% Carbonate
- 30% to 50% Quartz
- Fractures common
- Bleeding cores and samples
Source Rock Data

Immature
Mature
Postmature

TYPE I
ioil-prone usually lacustrine

TYPE II
ioil-prone usually marine

TYPE II
oil-gas-prone

TYPE III

gas-prone

TYPE IV
ininert

Oil Window

Condensate-Wet Gas Zone

Dry Gas Window

HYDROGEN INDEX (HI, mg HC/g TOC)

HYDROGEN INDEX (HI, mg HC/g TOC)

HYDROGEN INDEX (HI, mg HC/g TOC)

TYPE I
oil-prone usually lacustrine

TYPE II
ioil-prone usually marine

TYPE II
oil-gas-prone

TYPE III
gas-prone

TYPE IV
inert

Immature

Mature

Postmature

Tmax (°C)

Tmax (°C)

Tmax (°C)

0 10 20 30 40 50 60 70 80 90 100

0 100 200 300 400 500 600 700 800 900 1000

0 100 200 300 400 500 600 700 800 900 1000

0 10 20 30 40 50 60 70 80 90 100

0 100 200 300 400 500 600 700 800 900 1000

0 100 200 300 400 500 600 700 800 900 1000

OXYGEN INDEX (OIL, mg CO₂/g TOC)

OXYGEN INDEX (OIL, mg CO₂/g TOC)

OXYGEN INDEX (OIL, mg CO₂/g TOC)

HYDROGEN INDEX (HI, mg HC/g TOC)

HYDROGEN INDEX (HI, mg HC/g TOC)

HYDROGEN INDEX (HI, mg HC/g TOC)

OXYGEN INDEX (OIL, mg CO₂/g TOC)

OXYGEN INDEX (OIL, mg CO₂/g TOC)

OXYGEN INDEX (OIL, mg CO₂/g TOC)
Source Rock Data

Figure 1. Geochemical log of TOC, remaining potential (S2), kerogen type (HI), normalized oil content, and calculated and measured vitrinite reflectance.
Figure 1. Geochemical log of TOC, remaining potential (S2), kerogen type (H1), normalized oil content, and calculated and measured vitrinite reflectance.
Source Rock Data

Jolly Ranch 16-1 well, Running Foxes Petroleum, Lincoln Co., Colorado

Figure 2. Kerogen Quality
Gas Composition Analysis

Sample Name: Jolly Ranch 16-1 Well Gas Analysis
Date Analyzed: 10/28/2008

All calculations based on 14.696 psia pressure and 60F (15.6C) temperature conditions

<table>
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<tr>
<th>Gas Component</th>
<th>Normalized</th>
<th>Specific</th>
<th>Gross Compressibility</th>
<th>Calorific Temperature</th>
<th>Fractional</th>
<th>Fractional Pressure</th>
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<td></td>
<td>(Mole %)</td>
<td>X1</td>
<td>X1G1</td>
<td>X1H1</td>
<td>X1B1</td>
<td>(R)</td>
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<td></td>
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<td>Methane (CH4)</td>
<td>46.03</td>
<td>0.4603</td>
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<td>isobutane (C4H10)</td>
<td>1.80</td>
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<td>0.0361</td>
<td>58.5755</td>
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<td>n-Butane (C4H10)</td>
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<td>217.1878</td>
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<td>0.1685</td>
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<td>n-Pentane (C5H12)</td>
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<td>Non-Hydrocarbons</td>
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<td>0.9536</td>
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<tr>
<td>Non-Hydrocarbons</td>
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<td>Oxygen (O2)</td>
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<td>0.0227</td>
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<td>1622.2763</td>
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</table>

Compressibility Factor z: 0.9929
Ideal Specific Gravity of Mixture: 1.0227
Real Specific Gravity of Mixture: 1.0296
Ideal Gross Heating Value, Dry Basis (btu/scf): 1622.2763
Real Gross Heating Value, Dry Basis (btu/scf): 1633.8645
Ideal Gross Heating Value, Sat. Basis (btu/scf): 1594.0487
Real Gross Heating Value, Sat. Basis (btu/scf): 1605.4352
Pseudocritical Temp. (R): 484.7057
Pseudocritical Pressure (psia): 647.9658

References:
ASTM 1945-96: Analysis of Natural Gas by Gas Chromatography
ASTM D3588-98: Calculating Heat Value, Compressibility Factor, and Relative Density of Gaseous Fuels
BOLERO FIELD

- Drilled in 1985 by BHP Petroleum and Mull Drilling;
- Cum: 40,903 BO and 17.143 MMCFG, no reported water;
- Completed in Cherokee “C” (less than 2 feet thick)
- Acidized only;
- IP: 407 BOPD/170 MCFGPD and 90 BOPD respectively no water;
- Running Foxes re-opened the field in 2009;
- Field production at 123,930 BO as of December 2012;
- Presently making 60 BOPD from three wells out of the Cherokee “A” and “C”.
Jolly Ranch and Bolero fields
Present-day Horizontal Stress
Denver-Julesberg Basin
Great Plains Field

Production Zones:
- Morrow A
- Upper Bench Morrow
- Morrow B
- Fort Scott Lower Bench
- Cherokee A
- Cherokee B
- Arka
- Monticello
- Mississippian

IP is listed to right of well symbol (calc. 24 hrs)

CONFIDENTIAL
2/20/13

Mississippian Faults (Seismic Survey)
Basement Faults (Aeromag Survey)
3-D Seismic Survey Area

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2/19/13
Production for the Great Plains Field
17 wells, discovered in 2009
Multiple pays
8 uneconomic wells

Number of wells

DST data indicates every new well is lower in reservoir pressure.

Field results indicates the drill spacing should be greater than 40 acres.
Great Plains Field

East – West Cross-section through the Great Plains Field
Great Plains Field
- John Craig 7-2 original Cherokee A discovery;
- John Craig 6-2 600+ BOPD from Cherokee;
- Both wells had technical problems;
- Complex structures.
Middle Mist Prospect

- Hansen 8-10: Mississippian Discovery;
- 240 BOPD for two months;
- No decline so far;
- Project defined by surface geochemistry (Atoka);
- 3D seismic acquired by Running Foxes defined a complex structure.
Structure on Mississippian;
Complex horst and graben;
Aeromagnetics very useful.
Discovered in 1984;
- 25 MMCF, 5 MBO form a Atoka sandstone;
- 3D survey indentified a Morrow channel system;
- Surface geochemical survey supportive.
Running Foxes in 2007 approached the area as a potential play in the Atoka and Cherokee Shales;

Drilled 19 wells, numerous attempts at vertical completions in the Excello, V, Tebo and Atoka shales;

Refocused on the Marmaton and Cherokee “A” and “B” porosity zones;

Marmaton is a “teaser” – requires structural closure, all wells calculate lots of oil in place;

Unit Drilling drills horizontal well in Atoka – fails do to poor frack,

“Shale Play” becomes non-commercial at this time.

Wepkking-Fullerton discovers Great Plains Field and does a recompletion program on several of its plugged wells targeting the Cherokee;

Southwestern, Devon (Auburn), Pine Ridge, Pioneer, Cascadia, Anadarko, etc. all in the play;

Two marginal Marmaton horizontals;

Focus is Marmaton and Cherokee carbonates;

No fracking required;

Becoming an independents conventional oil play.
Summary

- Marmaton, Cherokee “A” and “C” reservoirs represent discrete thin carbonate reservoirs.
- Large area extent.
- Good source rocks
- Structural and stratigraphic traps
- Other reservoirs potentially present – Mississippian and Morrow.
- Under pressured.
The End

Thank you for coming