Geologic Reservoir Characterization of the Codell Sandstone: Wattenberg Field, Colorado

John Stamer
Outline

• Purpose
• Wattenberg Field
• Codell Sandstone
• AOI
• Facies Identification
• Cores
• XRD
• Micro-porosity in Thin Section
• Production
• Forward Thinking
• Preliminary Conclusions
• Future Work
Hypothesis and Purpose

**Hypothesis:** The ever increasing production within the Codell Sandstone in the Wattenberg Field is greatly influenced by the micro-porosity, mineralogy, temperature, and over pressured nature of the formation in the region.

**Purpose:**
- Characterize the depositional environment of the Codell Sandstone
- Better understand the mineralogy of the system within the Wattenberg Field
  - Study the clay composition
- Porosity and Permeability
  - Detail the pores
- Attempt to determine the cause of increased production rates from the Codell due to re-hydraulic fracture stimulation
Middle-Late Turonian
Wattenberg Field

Denver Basin Structure
Top Niobrara

PAY ZONE(S)

Typical Depth

Formation or Group

Stage

Maestrichtian

Campanian

Santonian

Coniacian

Turonian

Cenomanian

Albian

Sonnenberg, 2002
• Located in the Denver-Julesburg (DJ) Basin in Northeast Colorado
  • 81 Townships
• ~35,000 Total wells
• Discovered in the 1970s
• Original Estimated Ultimate Recovery 1.3 Tcf
• Over 35,000 wells drilled:
  – 7th Largest gas field in the United States (largest in Colorado)
  – Cumulative production to date is over ~320 MMbo & 4.5 Tcf
• Depth, MD 6,900 – 7,300
• BHT, Degrees F 240
• BHP, psig 4,600
• Gross Sand, ft 10 – 30
• Net Pay, ft 5 – 20
• Porosity, % 8 – 12
• Permeability, md 0.05 – 0.005
• Original Spacing, acres 80
• Rule 318A Spacing, acres 20
• Horizontal Wells, acres 100-120
AOI – Central Wattenberg Field

- 16 Townships
- ~17,000 Wells drilled
- ~4,000 Codell production wells
  - ~54 MMBo
  - ~500 Bcf
- 3 Cores to be used
Cross Section Structure

Niobrara

Codell

Carlile
Isopach – Codell Sandstone

Feet

Miles

35 30 25 20 15 10

0 3 Miles 6 Miles
Codell Sandstone – Pay (Porosity > 10%)
Temperature & Pressure Anomaly

Modified From Birmingham, 2001
Facies A: Gray to light-gray; very fine- to fine-grained; bioturbated, clayey to silty, sandstone

Facies B: Gray to light-gray; very fine- to fine-grained; bioturbated, ripple-laminated sandstone with discontinuous clay laminae containing sand-filed burrows
Facies C: Light-brown to light-gray; fine-grained; moderately- to well-sorted; low-angle hummocky cross-stratified sandstone
• Petro Quest State B-41-36 Core Photos
• 4N-64W-36
• Weld County
• Composition is silty, shaly, fine to very fine grained, clay-cemented sandstone
• 2 Identified Core Facies:
  1. Facies A: Bioturbated
  2. Facies B: Clay laminae
• Absence of Facies C may be due to the 8’ of core missing
Codell Sandstone Core

- Dome Petroleum Frank #1-13 Core Photos
- 4N-65W-13
- Weld County
- Shows contact with the overlying Ft. Hayes
- 3 Identified Core Facies
  1. Facies A: Bioturbated
  2. Facies B: Clay laminae
  3. Facies C: Hummocky cross-stratified
Brooks Exploration Harrington 2-30 Core Photos
- 6N-66W-30
- Weld County
- 3 Identified Core Facies:
  1. Facies A: Bioturbated
  2. Facies B: Clay laminae
  3. Facies C: Hummocky cross-stratified
# X-Ray Diffraction Analysis – Codell

## X-Ray Diffraction Analysis Codell Sandstone

<table>
<thead>
<tr>
<th>Well Number:</th>
<th>Dome Franks #1-13</th>
<th>Petroquest B-41-46 State</th>
<th>Brooks Harrington #2-30</th>
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</thead>
<tbody>
<tr>
<td></td>
<td>7030’ 7031.5’ 7037’</td>
<td>6815’ 6816’ 6825’</td>
<td>7096’ 7102’ 7106’</td>
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<tr>
<td><strong>Sample Depth:</strong></td>
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<td><strong>Whole Rock Mineralogy</strong></td>
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<tr>
<td>Quartz</td>
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<td>Potassium Feldspar</td>
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<td>Pyrite</td>
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<tr>
<td>Illite-Smectite</td>
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<tr>
<td>Kaolin</td>
<td>tr</td>
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<tr>
<td>Chlorite</td>
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## Relative Clay Abundance

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Micro-porosity – Frank #1-13

- Plain polarized light photomicrographic
- Note fine-grained nature of sandstone, and porosity development in blue
- Facies A (Bioturbated)

“More than 80% of the porosity has pore throats smaller than 0.25 μm in diameter, which by all standards, is a microsized pore throat. Traditional sandstone pore throats are larger than 5 μm, while siltstone pore throats are larger than 2 μm”
Pagano, 2006
Production – Oil & Gas

- ~1,500 Wells with quality data
- IP’s: 10-140 Bopd
- Average IP: ~35 Bopd
- Expected: 26 Bopd

= Area of Thermal Maturity
(%R₀ (J Ss) greater than 1.0)

Oil Production

- ~1,500 Wells with quality data
- IP’s: 2-8,148 Mcfd
- Average IP: 207 Mcfd
- Expected: 155 Mcfd
• Due to low permeabilities
  – Codell wells barely bleed oil and gas into wellbore
    • Hydraulic fracturing is needed
  – Wells will never fully drain their spacing
    • According to Boone et al. (1998) usually drain 15-30 acres

• Operators can either:
  – Infill drill
  – Re-stimulate the reservoir by hydraulic refracture of existing wells
Production – Hydraulic Re-fracturing

Pagano, 2006
Forward Thinking

• Re-stimulation of reservoir adds on average 25 Mboe reserves per well (~9 Bopd & 150 Mcfpd per well)
• Noble drilling horizontals on 120 acre spacing
  • In between existing vertical producing wells
  • Average EUR: 310 Mboe
  • Increases EUR from 1.5% to 6% OOIP
• Possibly drill laterals off existing 5-Spot Infill vertical wells
• PDC and Noble have reported little to no interference from existing vertical wells

Directional Drilling and Well Density

Noble Energy, 2011

¼ Section

¼ Section

5-Spot Infill Wells

Modified From Encana, 2013

Noble Energy, 2011
Preliminary Conclusions

• Codell Sandstone in the Wattenberg field was deposited in an inner shelf environment
• Low permeability in the Codell is due to clay content
• Temperature and pressure are major factors for success of the Codell in the Wattenberg field
• Re-Hydraulic fracture stimulation success likely due to pressure depletion and loss of connection with micro-porosity
  – Little to no interference with existing wells
• New horizontal wells will see new reserves
Future Work

• Continue studying other research efforts
• Petrographic thin sections
• FESEM
• Select samples for MICP
• Continue correlation mapping
• Research economics of Codell vertical vs. horizontal wells