Codell Sandstone, DJ Basin*

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Summary

- Codell has historically been a major contributor in the DJ Basin. The “First Burrowed SS Play”!
- Codell SS is primary driver of Wattenberg being extended to the North into Laramie County, WY.
- We believe the Codell is eastern sourced but do not have a good handle on depositional environment.
- Unconformity at the Base of Ft. Hayes LS is primarily responsible for Codell thinning.
- Core Data is essential to understanding the Codell Play due to poor log response. NMR Logs are the next best thing.
- Clays are not the only minerals that bounds water in the Codell.
- Log density porosity is a good match to core porosity.
- MICP is essential to understanding pore throat distribution and injection pressures.
- Don’t forget about thermal maturity and charge!
- Oil has been typed back to Niobrara source

References Cited


Codell Sandstone
DJ Basin
Kevin H. Smith
Paleogeographic Setting

*Western Interior Cretaceous Seaway (85 Ma)*

- Western Interior Cretaceous Seaway (WIC) is an asymmetric foreland Cretaceous seaway from Arctic to Gulf of Mexico
  - Following regional Codell Sandstone deposition in low stand conditions, the Niobrara deposition occurred during high sea level conditions resulted in coccolith-rich carbonate sedimentation.

- Codell deposition took place in the eastern portion of the seaway and is preserved today in the northern and southern DJ Basin.
- Codell SS/Greenhorn FM is age equivalent to the Eagle Ford Shale.
Lower 48 states shale plays

Shale plays
- Current plays
- Prospective plays
- Stacked plays
  - Shale youngest/ shallowest
  - Intermediate depth/age
  - Deepest/oldest

Basins
- Mixed shale & chalk play
- Mixed shale & limestone play
- Mixed shale & tight dolostone-siltstone-sandstone

Source: Energy Information Administration based on data from various published studies.

Updated: May 9, 2011
Asymmetrical basin with thrust contact on the western margin against the Laramide orogeny (Rocky Mountains)

- Steep western dip and gentle eastern dip.

- Top of Codell ranges from ~6,000’ TVD to ~9,000’ TVD across productive area
DJ Basin Stratigraphy

- Cretaceous Petroleum System is most prolific
- Niobrara/Codell is the focus of present day activity by most operators in DJ Basin
- Originally drilled as tightly spaced vertical wells with fracs and refracs
  - Refrac and downspacing built many mid-cap companies in the late 1990’s:
    - Snyder
    - HS Resources
    - Kerr McGee
- Present day horizontal and multi-stage frac has revitalized the play
DJ Basin Drilling as of 2009

- Wattenberg had been primarily a vertical Niobrara/Codell play with down spacing and refracing
- Silo Field had been drilled with horizontal Niobrara B Bench wells in the early 1990’s with open hole, unstimulated completions
- Noble drilled a horizontal Niobrara B Bench well in Wattenberg
- Encana drilled two horizontal Niobrara B Bench and two horizontal Codell laterals from a common pad.
- EOG drilled the Jake 02-1H resulting in the discovery of the Hereford Field and setting off the Niobrara “boom” outside of core Wattenberg
DJ Basin
2009 - 2010 Drilling

5 Horizontal Rigs running

- Hereford Field begins to get developed (Niobrara)
- Several Niobrara Wildcats drilled north and northeast of Wattenberg Field
- Wattenberg Horizontal Niobrara programs take off
DJ Basin
2009 - 2011 Drilling

~10 horizontal rigs running

- Hereford Niobrara Field development continues
- Mineral Belt/Wattenberg extension begins to develop
- Fringe Wattenberg begins to take off
DJ Basin

2009 - 2012 Drilling

~20 horizontal rigs running

• Mineral Belt/Wattenberg extension development continues
• Fringe Wattenberg development continues
• First Horizontal Codell wells are drilled between Silo and Hereford Fields outside of Wattenberg
DJ basin
2009 - 2013 Drilling

> 25 horizontal rigs running

- Mineral Belt/Wattenberg extension development continues
- Fringe Wattenberg development continues
- Fairway/Brennsee Codell Field development starts
DJ Basin

**2014 Drilling and Permits**

- 30 Horizontal rigs running
  - Brennsee and Fairway Codell Fields defined between Silo and Hereford Fields
  - Mineral Belt/Wattenberg extension development continues
  - Fringe Wattenberg development continues
  - Codell, Niobrara C, Niobrara A & B are all exploration targets north and northeast of Wattenberg

2015?
DJ Basin

- Gas Oil ratio shown on wells
- Gas window in center of Wattenberg Field
  - Historically Vertical Wells
- Edge of Wattenberg Field wells get into Oil Window
  - Horizontal Wells
- Silo, Hereford, Mineral Belt/Wattenberg Extension, Fairway/Brennsee in Oil Window
  - Horizontal Wells

- Historical DJ Basin Production

The DJ Basin produced over 2.2 Bboe from Cretaceous reservoirs, primarily from Codell and Niobrara, before horizontal drilling began.
Codell Sandstone- DJ Basin

Where Burrowed SS Pay Was Found!

- Codell Type Log
  - Gamma looks like a dirty sand / shaley
  - Resistivity usually between 4 and 6 ohmms
  - Porosity 12% to 16%
  - Perm generally increases to greater than 0.01md
  - Oil saturation increases
• 23 Codell Cores identified in study area
  – Some at CRC and some proprietary
• 8 Codell Cores laid out today
  – 4 in the Fairway/Brennsee Field Area
  – 2 on the far end of the Mineral Belt/Watteneberg Trend
  – 2 in Wattenberg Field
Break to Look at Core

Things to think about:

• Depositional Environment?
• Key Surfaces – Unconformities, Etc…?
• Porosity Distribution?
• Permeability Distribution?
• Facies Changes?
Codell Depositional Environment

- Shallow water?
- Bioturbation
  - Paleontologists are resistant to pigeon hole trace fossils into water depth and specific environments now!
- Hummocky Cross-Strat = Storm beds
- Does not follow a typical shore face model

We don’t have it figured out yet. Anyone want to go to Kansas?
Codell Paleogeography

- The DJ Basin is bound by the Front Range of Colorado, Laramie Range of Wyoming, Chadron Arch and Las Animas Arch
- **Codell**
  - Deposition occurred along the eastern margin of the Cretaceous Epeiric Seaway
  - Represented by sandstones deposited in a shallow marine setting
  - Composition is silty, shaly, fine-grained, clay-cemented sandstone
  - Common structures include mud drapes, planar horizontal bedding and thin planar to hummocky cross-bedding and bioturbation
  - Thought to be sourced from the North American craton east of the epeiric seaway.
Restored stratigraphic section for lower part of the Cretaceous from central Wyoming to central Kansas.

Modified from Weimer, 1986, Relationship of Unconformities, Tectonics, and Sea Level Change in Cretaceous Western Interior, United States.
Codell Sandstone

• Sourced from the East found throughout the Northern Colorado and Southern Wyoming
• The heart of Codell is 25 to 30 feet thick
• Codell gets less than 5 feet and pinches out to the north and south east
• Average depth ~8,500' and porosity between 12% and 17% in productive trend
- Codell SS pinches out in southern Goshen Co, WY
- Emigrant Gap? Member of the Frontier FM develops in Goshen County
- Mistaken for Codell SS in Goshen Co
Regional Unconformity in the Codell

- Sage Breaks preserved to the North
- Unconformity at base of Ft Hayes cuts out Sage Breaks and eventually erodes into Codell as you go south
- Basal Ft Hayes unconformity is the primary reason for thinning in the Codell
- The farthest north cores actually have ~1’ of Juana Lopez preserved
Facies Changes

- **Laminated Facies**
  - Best reservoir characteristics
  - Usually in middle of the Codell section
  - Ranges from <1 to 8 feet in thickness
  - Not apparent on logs

- **Bioturbated Facies**
  - Lower permeability than laminated but significant oil in place and 8.0% to 14.0% porosity
Codell Sandstone, Laguna 8-8-2CH, DJ Basin
Codell Sandstone, Child VO30-09, DJ Basin
• Codell sandstone is dominated by quartz with other major minerals being clays and feldspars
• Minor minerals include Calcite, Apatite, Glauconite, and Pyrite
• Mineral assemblages are consistent whether in Bioturbated or Laminated Facies
• Clays are mostly illite with minor mixed layers

Averages:
- Quartz ~ 60-70%
- Feldspars ~ 10-20%
- Clay ~ 20%
- Pyrite Varies

Mineral Percentage

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Mineral Percentage
Laguna XRF

- 1” measurements
- Very little variation between Laminated and Bioturbated Facies
- Surfaces are hard to pick out even at this resolution
Codell Thin Section Analysis

- Thin Sections show porosity in both plain and epiflourescent light
- Under epiflourescent light intergranular microporosity is apparent in Feldspars
- Very difficult to differentiate facies in thin section
- Both facies show comparable amount of porosity in thin section
- Grains are very angular and Feldspars are only partially weathered indicating low transport distance from source
Codell Porosity and Permeability

- Laminated zone has better slightly reservoir characteristics than bioturbated zone
- Both Facies contain oil
- 2 reservoir system?

Core Porosity vs Permeability

Laminated
Bioturbated
Fractured Samples

Core Porosity vs Permeability

RCA Core Air Permeability (md)

Core Porosity (Ambient) (Percent)
The laminated zone has larger pore throats and accepts mercury under lower pressures.

This is likely the main pathway for oil migration in the Codell.

Production and core data suggests a mix matrix and fractured reservoir system?

Ft Hayes contribution?
Mercury Injection-Capillary Pressure Injection Pressure

- The Bioturbated zone has a range of pressure that it will accept mercury injection, showing a variety of pore throat sizes.
- Injection pressure can be estimated when plotting 1-Sw (x-axis) on the injection pressure line for the same sample as MICP was run.
- No cores have the same injection pressure.

Noble Energy: Child VO 30-9

Cirque Resources: Laguna 8-8-2CH
Codell Porosity vs Saturation

- Codell Sw decreases as porosity increases
  - Core data ranges from 9-15% Phi and 25-80% Sw
- No cores have the same regression equation
**Petrophysics / Log Analysis**

**Analysis Assumptions**

- Used Modified Simandoux due to clay content within sand
- Rw determined from lowest measured produced water salinity
- Porosity calibrated to core measurements
- Low Resistivity Pay can be evaluated only with correlation to core data, then extrapolated to older wells

**Modified Simandoux Equation**

\[
\text{If } (Vshl[] < 1) \\
\quad \text{SwMS[]} = \left( \frac{\sqrt{Vshl[]/Rshl}^2 + 4*PHIE[]^m/(a*Rw*(1-Vshl[])*RT[])}{2*PHIE[]^m/(a*Rw*(1-Vshl[]))} \right)
\]

\[
\text{ElseSwMS[]} = 1
\]

End If

Rw = 0.055 (48K ppm 200 deg F)
Rsh = 1.2 ohm
Mat Den= 2.68
m= 1.85
n= 1.87

**Noble Energy: Child VO 30-9**

![Diagram showing SwMS values with depth and other logs]
Log Calculated Saturation Vs. Core
Lazy D ZN 03-09 MRIAN Log – Core Corrected

Total Porosity 15%, Effective 4-7%

- Core Porosity lines up well with both Density Porosity and MRIL Porosity
- Most of the water is bound in clays and Feldspars
- Very little moveable water seen on the NMR log
- Saturations from NMR log approximate core saturations
- Only drawback - this log does not see fractures
Fluid Analysis

- Oil gravity = 38° API
- GOR = 900 scf/bbl average
- Water cut ranges from a low of 20% to a high of 45%
- Reservoir pressure has not been directly measured but DFIT & DST indicates a range of .51 to .58 psi/ft gradient
- Niobrara sourced oil in Codell
Regional Thermal Maturity

Niobrara $T_{\text{max}}$ Contours and Burial Histories

Tmax Contours for the Niobrara

- Brennsee/Fairway area lies within a favorable Thermal Maturity fairway for the cretaceous petroleum system
- $T_{\text{Max}}$ values in Niobrara of 435 to 441 show Thermal Maturity for oil in Project Area

Modified from Landon, Longman, Luneau, 2001
Regional Thermal Maturity
Vitrinite Reflectance (Ro) for J Sand Interval

- Samples were analyzed using vitrinite reflectance in the J Sand due to problematic vitrinite populations in the Niobrara.
- Thermal maturity is responsible for injection pressure and charge.

CODELL SANDSTONE Injection Pressure vs Mercury Saturation
MERCURY INJECTION CAPILLARY PRESSURE

RCA 1-Sw data points
Codell Wells

Samson Energy (Cirque)
Brennsee Field
11 Codell Wells Producing

EOG
Jubilee 103-0433H
IP30d: 1,366 boe/d (1280)

EOG
Windy 508-1806H
IP30d: 1,192 boe/d (1280)

EOG
Jubilee 553-1034H
IP30d: 1,157 boe/d (1280)

EOG
Jubilee 584-1705H
IP30d: 1,169 boe/d (1280)

Samson Energy (Cirque)
Rimrock 33-4-6-1CH
First Production: 2/2014
IP30d: 620 boe/d (960)

Samson Energy (Cirque)
Magee 9-16-2-1CH
First Production: 11/2014
IP30d: 1,216 boe/d (1280)

Cirque
Laguna 8-8-2CH
First Production: 06/2014
IP30d: 151 boe/d (640)
Drilled in Fault Zone

Cirque
Railay 28-3-1CH
First Production: 09/2014
IP30d: 110 boe/d (640)
Drilled in Fault Zone

Source: HPDI.
Summary

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