Geologic Factors Controlling Production in the Codell Sandstone, Wattenberg Field, Colorado*

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Abstract

The Upper Cretaceous Codell Sandstone is a major pay in the giant Wattenberg Field of the Denver Basin. Vertical well completions in the Codell date back to 1981. The vertical wells have a history of successful hydraulic refracturing. New horizontal wells (2011 to P) with initial production of 100 to 700 BOPD (GOR ~10,000 cf/bbl) indicate substantial remaining reserves in the formation. Geologic factors important for production include: proximity to thermally mature source beds; thickness; geothermal gradients; pressure gradients; fault bounded reservoir compartments; gas-oil ratios; sufficient reservoir quality (phi-h). The Codell in Wattenberg is characterized by low porosity (<10%) and permeability (< 0.1 md). The Codell is 5 to 20 ft thick across the Wattenberg Field and has formation pressure gradients that range from 0.45 to 0.66 psi/ft. Geothermal gradients range from 1.8 to 2.5°F/100 ft. The highest GORs in the field correspond to the highest geothermal gradients. The sandstone is very fine to fine grained and bioturbated. Thin (< one ft thick) hummocky cross stratified beds are present in the Codell. Depositional environment is interpreted to be a shallow marine shelf setting. Clay content within the pay interval is approximately 20% and consists of 40–45% mixed layer illite-smectite, 30–40% illite, 10–30% chlorite, and up to 7% glauconite. The Codell is a low-resistivity, low-contrast pay. The fault-bounded reservoir compartments form mainly from a well-developed polygonal fault system. Polygons are generally about 1.5 square miles in size. The orientation of the polygons is influenced by pre-existing basement fault systems. The Codell unconformably overlies the Fairport chalk member of the Carlile Formation and is unconformably overlain by either the Juana Lopez or the Fort Hays Limestone Member of the Niobrara Formation.
ABSTRACT

The Upper Cretaceous Codell Sandstone is a major pay in the giant Wattenberg Field of the Denver Basin. Vertical well completions in the Codell date back to 1981 and were hydraulic fracture stimulated. The vertical wells have a history of successful hydraulic refracturing. New horizontal wells (2011 to P) with initial production of 100 to 700 BOPD (GOR ~10,000 cfd/bbl) indicate substantial remaining reserves in the formation.

Geologic factors important for production include: proximity to thermally mature source beds; thickness; geothermal gradients; pressure gradients; fault bounded reservoir compartments; gas-oil ratios; sufficient reservoir quality (phi-h). The Codell in Wattenberg is characterized by low porosity (<12%) and permeability (< 0.1 mD). The Codell is 5 to 20 ft thick across the Wattenberg Field and has formation pressure gradients that range from 0.45 to 0.66 psi/ft. Geothermal gradients range from 1.8 to 3°F/100 ft. The highest GORs in the field correspond to the highest geothermal gradients. The sandstone is very fine to fine grained and bioturbated. Thin (< one ft thick) hummocky cross stratified beds are present in the Codell. Depositional environment is interpreted to be a shallow marine shelf setting. Clay content within the pay interval is approximately 20% and consists of 40-45% mixed layer illite-smectite, 30-40% illite, 10-30% chlorite, and up to 7% glauconite. The Codell is a low-resistivity, low-contrast pay.

The fault-bounded reservoir compartments form mainly from a well-developed polygonal fault system. Polygons are generally about 1.5 square miles in size. The orientation of the polygons is influenced by pre-existing basement fault systems. The Codell unconformably overlies the Fairport chalk member of the Carlile Formation and is unconformably overlain by either the Juana Lopez or the Fort Hays Limestone Member of the Niobrara Formation.

Source rock maturity map for the Niobrara Formation from Smagala et al., 1984. Ro values greater than 0.6 indicate probable areas of mature source rocks.

Isopach of the Codell Sandstone, Denver Basin (modified from Weimer and Sonnenberg, 1983). Map shows current Codell producers.

Type 1 Sandstone: Marine shelf or shoreline bars; good porosity and permeability; sheet-like distribution

Type 2 Sandstone: Impermeable, bioturbated, fine-grained marine shelf sandstone; contains thin hummocky cross stratified beds; no central bar facies present (eroded?); most of the existing production comes from this sandstone type

Type 3 Sandstone: Fine-grained, parallel to cross stratified to ripple cross stratified; contains sparse burrows; deposited in intertidal to marine environments, contains abundant authigenic clays that reduce porosity and permeability
TYPE 2 SANDSTONE

Isopach Type 2 Sandstone, central Denver Basin

Cross-section Type 2 Sandstone, central Denver Basin

Type log, Niobrara and Codell, Wattenberg Field

TYPE 3 SANDSTONE

Isopach Type 3 Sandstone, northern Denver Basin

Cross-section Type 3 Sandstone, northern Denver Basin

Structure map top Codell Sandstone, Wattenberg Field area (well control not shown). Contour interval is 100 ft. Outline of wells assigned to Wattenberg shown by dashed outline. Wattenberg is regarded as a basin-center accumulation which straddles the synclinal axis of the Denver Basin.

Wattenberg Faulting

Location map of seismic line shown below. Red outline is Greater Wattenberg area.

2-D seismic line from Wattenberg Field, from Davis 1985.

Structure map top Codell Sandstone for T3N, R66W. Contour interval is 10 ft. Axes of structural highs and lows shown by red and blue lines. Note somewhat random orientation of axes.

2-D seismic line with interpreted faults. Kn = Niobrara; Kd = Dakota Sandstone; Kp = Pierre marker.

Wattenberg Field Structure

Drilling activity map northern Denver Basin. New drilling activity is occurring in SE Wyoming part of Denver Basin. Wells are being drilled horizontally and fracture stimulated.
**Wattenberg Field Stratigraphy**

Isopach map of net sandstone in Codell interval defined by porosity great than 10 percent. The highest net values occur on west side of map area.

West to east cross section across Wattenberg Field showing the Codell Sandstone and adjacent units.

**Petrographic Analysis**

- Moderately well sorted, very fine-to fine-grained sublitharenites and subarkose
- Slight to moderate compaction
- Ductile deformation of incompetent grains
- Partial dissolution of chert, and mica
- Porosity and permeability inhibiting cements include: Mixed layer illite/smectite, illite, chlorite, quartz overgrowths, and calcite

Plain polarized light photomicrograph, Codell Sandstone. Note fine-grained nature of sandstone, and porosity development in blue.

"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

Core photos of from the Dome #1-13 Frank core. The Codell Sandstone is a bioturbated, silty, clay-rich sandstone. From USGS CRC, 2013.

Outcrop description of Codell Sandstone, HW 36, north of Boulder, CO.
**Wattenberg Thermal Anomaly**

- Related to igneous masses in basement (?)
- Located where CMB intersects Denver Basin
- Direct temperature measurements
- Ro values
- GORs

**Bottom hole temperature map, J Sandstone, Wattenberg Field.**

**Vitrinite reflectance map, J Sandstone, from Higley and Cox, 2007**

**Gas oil ratio map for Codell producers. Note the high GOR area south of Greeley.**

**Location of some of the new horizontal Codell wells drilled from 2011 to P. Most wells are located in liquid-rich areas or areas flanking the high GOR area.**

**SUMMARY**

The Codell Sandstone in the Wattenberg Field is a tight unconventional reservoir. Geologic factors important for production include:

- Proximity to thermally mature source beds;
- Geothermal gradients; pressure gradients; fault bounded reservoir compartments; gas-oil ratios; sufficient reservoir quality (phi-b).
- Drainage areas for Codell wells is quite small. Refracs of the Codell have proven to be highly successful in many areas of Wattenberg Field. Horizontal drilling and multistage fracture stimulation is now being utilized in Wattenberg development.

**REFERENCES CITED**


The Codell Regressive Sandstone Event
Thrust belt movement, sea level changes, paleogeography diagrams

Thrust Belt Tectonics
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- Unconformities, Weimer, 1983
- Niobrara Codell Greenhorn
- Transgressions and regressions, from Longman et al., 1998 after Kauffman & Caldwell, 1993
- Weimer and Sonnenberg, 1983

Major Thrust sheets, RMAG, 1972
Stratigraphic sections in thrust sheets, RMAG, 1972
Estimated principal movement of thrust sheets, RMAG, 1972
Kauffmann, 1977

RMAG, 1972
Codell Refracs
Over 4,000 in Wattenberg Field

REFRACS
Concepts advanced to why refracs work in the Codell
1. Improved completion and stimulation practices
2. Extension of existing fracture half-lengths leading to increased reservoir drainage
3. Reorientation of hydraulic fractures leading to increased reservoir drainage
4. Combination of 2 and 3 above

Why do refracs work? (mechanisms)
From Vincent, 2014
- Enlarged frac (more reservoir contact)
- Improved pay coverage in vertical wells
- Better lateral coverage in horizontal wells
- Increased frac conductivity
- Restore conductivity lost – frac degradation
- Address unpropped poorly propped portions
- Improved wellbore-to-frac connection/conductivity
- Reorientation
- Use of more suitable frac fluids
- Re-energizing natural fissures
- Other mechanisms

Extension of existing fracture half-lengths
Typical refrac design: 260,000 lbs proppant and 135,000 gals cross-linked gel performed to reduce screen-out risk and maximize fracture half-length; From Birmingham et al., 2001

Reorientation of hydraulic fractures

REFERENCES


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