The Graneros-Greenhorn Petroleum System, a Possible New Resource Play, Rocky Mountain Region, USA*

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Abstract

High total organic carbon content (TOC) in the Graneros and Greenhorn formations and limestone reservoirs in the Greenhorn suggest potential for a new resource play in the Rocky Mountain region. Operators are currently testing new horizontal wells in the play. The source rocks are dominantly Type II with a mixture of Type III. The Greenhorn is a pelagic carbonate deposit and consists of three members: Bridge Creek, Hartland, and Lincoln. Pelagic constituents consist of nannofossils (coccoliths and calcispheres) and foraminifera (mainly planktonic). The formation ranges in thickness in the northern Denver Basin from 200 to 290 feet. The Bridge Creek and Lincoln are largely chalk units or chalky marl units (40-85% CaCO₃). The Hartland is a chalky marl (20-80% CaCO₃). TOC in the Bridge Creek, Hartland, and Lincoln members ranges from 0.5 to 5 wt. %). The Hartland contains the high levels of organic carbon and has the lowest levels of fossil diversity and abundance, suggesting low oxygen or anoxic conditions during deposition. Depositional depths for the chalk units is probably 100 to 300 feet.

The Graneros interval occurs between the Greenhorn and the D Sandstone over much of the Denver Basin. Where the D pinches out the Graneros terminology is extended down to the top of the Mowry Shale. The Graneros to Mowry interval ranges in thickness from 150 to 400 feet across the northern Denver Basin. TOC in the Graneros ranges from 0.5 to 5.3 wt. %. The overall all distribution of the TOC in the Graneros is more consistent (not as cyclic) than in the Greenhorn. Production from vertical Greenhorn wells has been encountered in the general Denver Basin area. Production comes mainly from the Lincoln member.

References Cited


Gilbert, G.K., 1895, Sedimentary measurement of geologic time: J. Geol., v. 3, p. 121-127.


Nakamura, K., 2015, Chemostratigraphy of the late Cretaceous western interior (Greenhorn, Carlile, and Niobrara Formations), Denver Basin, CO, USA: Thesis submitted to Colorado School of Mines.


The Graneros-Greenhorn Petroleum System, A Possible Resource Play

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• Regional geology
• Graneros-Greenhorn Petroleum System
• Analysis of Greenhorn
  – XRF
  – Petrophysics
  – Geomechanics
• Shows and Greenhorn completions
• Screening criteria for unconventional plays
• Summary
<table>
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<th>STAGE</th>
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<th>FORMATION</th>
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Modified from Eicher, 1969
Peak transgression, Cretaceous epeiric sea, Greenhorn marine cycle, from Kauffman, 1969
Greenhorn

- Greenhorn was named by Gilbert (1896) for exposures near Greenhorn Station, 28 miles south of Pueblo
- Subdivided into Bridge Creek, Hartland, and Lincoln members
- ~ 95 ft thick in Kansas; 153 ft Rock Canyon anticline
- Carbonates predominantly of pelagic origin (i.e., coccoliths & forams)
- Water depths less than 600 ft (90 to 300 ft)
- Inoceramid bivalves are ubiquitous Greenhorn macroinvertebrates, almost everywhere represented by prismatic shell layer
GRANEROS-GREENHORN
PETROLEUM SYSTEM
ROCK CANYON AREA
modified from Eicher and Diner, 1985
Pay Zone(s)

Typical Depth

- PIERRE FM
- L-RR MBR.
- TERRY MBR.
- HYGIENE MBR.
- DAKOTA SAND
- SHALE CREEK FM.
- JUANA LOPEZ
- MOWRY MBR.
- PIERRE FM.
- CARLILE FM
- GREENHORN FM
- BRIDGE CREEK L S MBR
- HARTLAND SHALE
- LINCOLN L S MBR
- GRANEROS FM
- D FM
- JFM J S S
- SKULL CREEK FM.
- DAKOTA SAND

Typical Depth:
- 4300'
- 4800'
- 6800'
- 7100'
- 7600'
- 7800'
- 7100'
- 7600'
- 7800'
- 7800'
• Late-Cretaceous shales, marls and chalks
• Bridge Creek Member
  – Low GR, Elevated resistivity,
  – Elevated Neutron-Density porosity readings
  – Similar to Niobrara Chalks

• Hartland Shale
  – Relatively homogeneous

• Lincoln Member
  – lower resistivity and Neutron-Density separation
  – Indicates higher clay content
  – Thin interbeds

Durkee, 2016
Lincoln Member 
(Hattin, 1979)

Abundant coccoliths

Compacted fecal pellets & forams
Relatively homogeneous, Foraminifera-rich, laminated calcareous mudstone

Fine-grained chalks with laminar organic-rich calcareous shale and marl

Finely laminated, calcareous shales and marls with interbedded carbonate-rich chalk beds
Lincoln Member

• 3 Facies:
  – Light-grey foraminifera-rich grainstone with little Qz/clay
    • Laminated, cryptic bioturbation, scour and fill
    • Offshore, deep water active currents
  – Interbedded calcareous mudstone and foraminifera-rich packstone/grainstone
    • Offshore quiet water conditions near the edge of clay transport
  – Dark-grey, calcareous, homogeneous mudstone with low fossil content
    • Offshore conditions in quiescent water

• 70-90 feet thick in Wattenberg

Durkee, 2016
• First called Lincoln Marble (Logan, 1897)
• Renamed Lincoln Limestone Member (Rubey and Bass, 1925)
• Shaley chalk with thin beds of skeletal limestone seams (inoceramids and oyster valves), seams of bentonite
Hartland Shale

- 2 Facies:
  - Laminated foraminifera-rich mudstone
  - Fossiliferous mudstone

- Well-laminated
  - Abundant foraminifera, fossil fragments, and fecal pellets concentrated into laminae
  - Graded beds/ turbidites

- Foraminifera “white specks”
- Inoceramid Bivalves and oyster fragments
- Relatively low energy, pelagic sedimentation
- Remaining TOC values 2-4 wt. %
  - Type II marine Kerogen
  - Lowest near basin axis

Durkee, 2016
Hartland Shale

- Named by Bass (1926)
- Finely laminated calcareous shale
- High levels of organic carbon
- Low levels of fossil diversity and abundance
- Non-bioturbated
- Probable low oxygen or anoxic event (Sageman, 1985)
• 4 main Facies:
  1) Bioturbated chalk intervals
     • *Planolites, Thalassinoides*
     • transgressive phases with less clay
  2) Fossiliferous Marly Chalk
     a. Bioturbated Marly Chalk
     b. Laminated Marly chalk
  3) Chalky Marl
  4) Marl
     a. Laminated foraminifera-rich marl
     b. Lenticular bedded ripple marl

• Chalks considered reservoirs, Calcareous marlstone facies considered sources
  – Chalk: TOC <1%
  – Marl: TOC 4-5 wt. %

• Less than 40 to over 90 ft thick

Durkee, 2016
Bridge Creek Limestone

- Rhythmic limestone-shale cycles in response to Milankovitch orbital cycles 20,000 to 100,000 years Barron et al., 1985
- Encompasses Cenomanian-Turonian extinction event and a major Cretaceous oceanic anoxic event
- Named by Bass (1926) for a series of beds at top of Greenhorn limestone near Medway, Kansas
- Bridge Creek correlates to upper Hartland Member, Jetmore Chalk and Pfeifer Shale Member as defined in central Kansas
USGS # 1
Portland
~ 23 cycles in the Bridge Creek
Bridge Creek Limestone Parasequence Model

- Oscillations between mud-rich and carbonate-rich facies

- Earth Orbital variations:
  - Axial precession about 21 Ka
  - Axial obliquity 41 Ka
  - Orbital eccentricity 100 Ka and 413 Ka

- Greenhorn Cycles correspond to Milankovitch cycles
  - appear to be 41 Ka obliquity cycles

- Periods of stratified and mixed water columns explain benthic and redox cycles
The Graneros-Greenhorn Petroleum System

- Reservoirs: Bridge Creek LS., Lincoln LS.
- Source Beds: Graneros, Lincoln LS., Hartland Shale
- Seals: Carlile and Greenhorn shales
- Overburden: Tertiary beds, Laramie, Fox Hills, Pierre and Niobrara formations
Hartland Mbr. Carlile

Bridge Creek
CaCO₃: 40-85 %
TOC: 0.5 – 3.4 wt. %

Hartland Shale Member
CaCO₃: 20-80 %
TOC: 0.7 – 4.1 wt. %

Lincoln LS. Member
CaCO₃: 20-80 %
TOC: 2.2 – 4.7 wt. %

Graneros Formation
TOC: 1.6 – 4.03 wt. %

Kaiser, 2012
Reservoir Rock Thicknesses

Bridge Creek Member Isopach

≈80-110 ft. thick

Lincoln Member Isopach

≈70-90 ft. thick

Kaiser, 2012
Source Rock Thicknesses

Hartland Member Isopach

≈100-130 ft. thick

≈40–90 ft. thick

Kaiser, 2012

Lower Graneros Isopach

≈100-130 ft. thick

Kaiser, 2012
XRF DATA

Detrital indicators
Al, Ti, K

Ca, Si

Organic Elements
Cr, Zn, Mo, V, Ni, U

Anoxic Suite (Redox)
Mo, U, Ni
Fe, S (pyrite)

Oxic Suite
Mn

Organic Suite

Gr TOC Cr Zn V Mo U Ni Fe S Al Ti K Si Ca

Figure 1-14: Thermo Scientific Niton XRF analyzer (Niton XL3 GOLD+) (Thermo Fisher Scientific, 2010)

Table: R² values for Niton-ICP/LECO relationships.
Nakamura, 2015.
**XRF**

**Detrital indicators:**
- Associated with terrigenous materials

**Carbonate indicators:**
- Associated with carbonate production

Durkee, 2016
**XRF**

- **Organic suite:**
  - Redox conditions, organic matter

- **Anoxic Suite:**
  - Anoxic conditions associated with redox reactions

- **Oxic Suite:**
  - Oxic to Suboxic conditions

Durkee, 2016
Calculated Geomechanics

Elastic moduli and brittleness:

\[
PR = \frac{1}{2 \left(\frac{DTS}{DTC}\right)^2} - 1
\]

\[
YM = 1000 \cdot \rho \left(\frac{1}{DTS} \left(\frac{1}{DTC} \left(\frac{1}{DTC} - 4 \cdot \frac{1}{DTS}\right)\right)\right)
\]

\[
BI = \frac{YM}{PR}
\]

Durkee, 2016
### Elastic Moduli

Average Geomechanical properties for each member in each of the study wells

<table>
<thead>
<tr>
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<td>0.28</td>
<td>5.38</td>
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<td>0.28</td>
<td>3.20</td>
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<td>0.26</td>
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<td><strong>EOG Big Sandy 132-33M</strong></td>
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<td>2.46</td>
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**Durkee, 2016**
Mechanical Stratigraphy

- **Zone 1: Carbonate Zone**
  - Alternating chucks and marls (Facies 1-4)
  - Fluctuating YM, PR, and BI
  - Low clay
  - Brittleness: >15

- **Zone 2: Mudstone Zone**
  - Mudstone facies (Facies 5 a, b and c)
  - YM, PR, BI homogeneous
  - Increased TOC and Clay
  - Brittleness: 10-12

- **Zone 3. Bentonite Zone**
  - Bentonite (Facies 8)
  - Increased PR, Lowest YM and BI
  - Brittleness: <10
Lincoln DST Recoveries

- DST’s
  - Largest in southeast Wyoming
    - >7,000 ft. Oil

- Multiple wells >1,000 ft. oil recovered
  - In areas with low resistivity
    - <10 Ohms

Kaiser, 2012
Other Shows of Interest

- Greenhorn
  - Rec. 5280 GCO
  - Rec. 7700 O&G
- Niobrara
- Codell
- Fort Hays
- Bridge Creek LS
- Hartland Shale
- Lincoln LS
- Graneros
- Mowry
- J SS
Greenhorn Producers
(some mislabeled wells)
• Continuous-type hydrocarbon accumulation in Greenhorn
• Abundant shows (Type I) and/or production
• Areally pervasive
• Sapropelic source beds
• TOC > 2.5 wt. %
• Thickness > 50 ft
• Abnormally pressured
• Lacks water and a downdip water contact
• Low $\phi$ (<10%) & k (<0.1 md)
• Bridge Creek is recommended target in GWA
• Tectonically quiet