Wattenberg Field Area, A Near Miss & Lessons Learned After 35 Years of Development History

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Diagrammatic Cross-Section Denver Basin

Basin Center Accumulation with:
Six Potential Reservoirs
Main Pays: J Sandstone with Codell commingle
Secondary Objectives: Dakota, Niobrara, Sussex, Shannon

Gustason and Sonnenberg, 2003
A Near Miss!
- All DSTs or cores taken in the J indicated shows of gas
- Core analyses of the J compared with those of the Dakota in the SJB
- Old wells in area remarkably similar
- Earlier discovery at Roundup - 1967
- Wattenberg discovered - 1970

Original Est. EUR 1.3 TCF

Matuszczak, 1973
Conventional & Unconventional Reservoirs & The Resource Triangle

Conventional reservoirs
Small volumes that are easy to develop

Unconventional
large volumes difficult to develop

Holditch, 2005
Currently Productive Areas-GWA

Wright, 2005; Modified after Ladd, 2001
Cumulative Production GWA

Cumulative Production GW:

- Sussex/Shannon: 786
- Other: 180
- Codell/Niobrara: 1302
- D SS: 1524
- J SS: 220

Cum: 4012 BCFe (34%)

Modified from Wright, 2005
• 1970: 320 acre units for drilling & spacing of J Sand
• 1979: Additional J Sand well allowed per 320 acre unit
• 1980: Section 29 tax credit; Tight gas sand designation (exp. 2002)
• 1983: Codell spaced on 80 acre
• 1984,85: Niobrara added to Codell spacing order
• 1991: J Sand wells can be recompleted to C-N & commingling of all downhole zones allowed
• 1998: Rule 318A allows 5 wells per quarter section in GWA for all Cretaceous age formations (81 townships)
• 2005: Rule 318A modified to allow for section line & quarter section line wells (~ 20 acre spacing 27 townships)

Modified from Wright, 2005 & Weimer, 2005
Oil & Gas Field Growth

- Step outs
- Infill drilling
- New horizons
- Improved economics
- Improved geologic model
- Improved reservoir model
- Improved technologies
- Fracture stimulation
- Drilling & completion
- Recompletions
- Changing operator
- Enhanced recovery

Level of technology required:
- Low
- High

Resource quality:
- High
- Low

Sonnenberg, 04
The Wattenberg Geothermal Anomaly

Vitrinite Reflectance Values, %Ro

Higley & Cox, 2005
Wattenberg Thermal Anomaly

- Related to igneous masses in basement
- Located where CMD intersects Denver Basin
- Direct temperature measurements in wells
- Ro values
- GORs

Modified from Weimer, 1995
HYDROSTATIC GRADIENT (0.43 psi/ft)

Migration Paths

Source Rock

Weimer, 1995
Overpressuring in Rockies Basins

INCREASING THERMAL METAMORPHISM

VOLUME OF ORIGINAL UNMETAMORPHOSED "IMMATURE ORGANIC MATERIAL (KEROGEN)"

ASSUMES GENERATED HYDROCARBONS ARE RETAINED IN SYSTEM & CONVERT TO STABLE SPECIES

VOLUME OF METAMORPHOSED ORGANIC MATERIAL

"MATURE"

VOLUME OF GENERATED FLUID HYDROCARBONS

Modified from Spencer, 1987 and Meissner, 1980
Structural Overview

- North-trending structural axis
- Northeast trending right lateral wrench faults
- Antithetic and synthetic horsts and grabens

Contours represent subsea depths to top J SS

Weimer, 2000
Codell Faulting Density is Greater than J Sand

Ladd, 2001
Isopach Map of J Sand

Weimer & Sonnenberg, 1989
J Sandstone
Stratigraphic Nomenclature

Huntsman Shale
Mowry Shale

Skull Creek ‘A’
Skull Creek Marker
Skull Creek Ash

Gustason and Sonnenberg, 2003
Sequence Stratigraphy of J Sandstone

J Sandstone

Skull Creek ‘A’

Skull Creek

Skull Creek Ash

Huntsman Shale

Mowry Shale

D Sand

Horsetooth Member (LST/TST)

Fort Collins Member (HST)

FC1

FC2

TSE / LSE

TSE

LSE

Sec 9 2N 67W

Sec 31 1N 65W

Gustason and Sonnenberg, 2003
J Sandstone
Original Gas in Place

EUR
Red > 15 Bcf / sec.
Green 10 - 12 Bcf / sec.
Blue < 8 Bcf / sec.

Hu, 2002
Sequence Stratigraphy of Fort Collins Member

Huntsman Shale
(Graneros)

Mowry Shale

Fort Collins 1

Skull Creek A

Skull Creek

W
SE2 2N 67W
SW7 2N 66W
SW8 2N 66W
SW9 2N 66W
SW10 2N 66W
SW11 2N 66W
SW12 2N 66W
SE2 2N 67W
SE7 2N 66W
SE8 2N 66W
SE9 2N 66W
SE10 2N 66W
SE11 2N 66W
SE12 2N 66W
E

Gustason and Sonnenberg, 2003
J Gas Trap Is Stratigraphic (Facies Pinch-out & Muddy Valley-fill)

modified from Hu, 2002; Gustason and Sonnenberg, 2003

J %Ro > 1 (blue line after Higley & Cox, 2005)
## Pertinent Data – Muddy J Sandstone, Wattenberg Field

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
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<tbody>
<tr>
<td>Depth</td>
<td>7,600 – 8,400 ft</td>
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<tr>
<td>BHT, °F</td>
<td>260</td>
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<tr>
<td>BHP, psig</td>
<td>2,900</td>
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<tr>
<td>Gross sand, ft</td>
<td>50 to 100</td>
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<tr>
<td>Net pay, ft</td>
<td>10 to 50</td>
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<tr>
<td>Porosity, %</td>
<td>8 to 12</td>
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<tr>
<td>Permeability, md</td>
<td>0.05 – 0.005</td>
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<tr>
<td>Original spacing</td>
<td>320</td>
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<tr>
<td>Est. original reserves</td>
<td>1.3 TCF</td>
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<tr>
<td>Current Est. Cum</td>
<td>1.3 TCF</td>
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*modified from Matuszczak, 1976*
Codell Sand

Production "Sweet Spot"

GWA

H. Panigoro, 1988
Codell Pressure Gradient

- Based upon P-buildups
- Range: 0.366-0.669 psi/ft.
- Coincident with basin axis
- Most north of “Wattenberg High”
- Follows J Ro =1% outline (blue)
- High GOR, sweet spot (gray area) coincident with temperature anomaly

Birmingham, 2000
### Pertinent Data – Codell Sandstone, Wattenberg Field

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<td>Porosity, %</td>
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<td>Original spacing</td>
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<td>Est. original reserves</td>
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Lessons Learned

• Bypassed pay
• Technology
• Field growth
• Long range migration
• Reservoir compartmentalization
• LRLC pays
• Geothermal anomalies