Tight Gas Reservoirs of the Western Canada Deep Basin*

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Abstract

The prolific Deep Basin parallels the western edge or structural "foredeep" of the Western Canada Sedimentary Basin (WCSB) and forms a regionally extensive area of hydrocarbon-saturated, abnormally pressured, thermally mature, Mesozoic to Paleozoic rocks characterized by multiple, stacked, “permeability challenged” gas and oil reservoirs, characterized by little to no water production. This Deep Basin fairway has produced >10 TCF of gas with up to 1750 TCF OGIP, and remains relatively undrilled by American standards.

The initial Deep Basin reservoirs in the Elmworth-Wapiti area targeted aggradationally-stacked Lower Cretaceous high permeability shoreface conglomerates encased within lower reservoir quality “tight” sandstones, siltstones, organic shales, and coals. Until recently, these “sweetspots” of High Permeability Basin Centered Gas (HP-BCG), have been the traditional reservoir targets.

Exploration over the last 30 years has expanded both the areal extent of the Deep Basin parallel to the overthrust belt and, stratigraphically, to include Devonian carbonates through Mesozoic fluvial and paralic siliciclastics. In the late 1980’s and into the 1990’s exploration in the Deep Basin began to focus on interbedded HP-BCG systems and lower-permeability (Kmax <1 md), basin-centered gas systems (LP-BCGS), resulting in the exploitation of dual-transmissivity reservoirs, analogous to plays occurring in the US Rocky Mountains. However, the WCSB has predominantly undergone only tectonic compression and subsequent unroofing since Late Jurassic, restricting fracture permeability in elastic reservoirs to isolated zones of basin suturing and subsequent transpressional motion. An understanding of resulting tectonics, pore-geometry, and multi-phase permeability in interbedded HP - LP-BCG systems is key to realizing the enormous gas potential of the Deep Basin.
Tight Gas Reservoirs of the Western Canada Deep Basin

“Focusing on the Lower Cretaceous Cadomin Fm.”

Thomas F. Moslow
Midnight Oil Exploration Ltd.

Brian A. Zaitlin
Suncor Energy Inc

(AAPG 2008)
Tight gas reservoir production

- A product of $Kh$
- Function of permeability type, origin and distribution determined by facies on a primary level
- Strong modification from diagenesis on a secondary and tertiary level
- Controlled by tectonics and burial history
- Demonstrate the above from examination of Deep Basin history and Cadomin Fm. facies
• WCSB “Deep Basin”
  – Pressure Regime (Hydrodynamics)
  – Tectonic Compartmentalization and Burial History
  – Reservoir Quality and Performance

• Cadomin Formation
  – Reservoir Model (Outcrop)
  – Facies, Petrography (Subsurface)
  -- Permeability Origin and Character

• Summary and Conclusions
Distribution of U.S. BCGA and WCSB Deep Basin

- Low permeability
- Pervasive gas saturation
- Abnormally pressured
- No downdip water leg
- Gas prone source rocks

(sensu Masters, 1979, 1984)

(Canadian Discovery Strategy 2005)
Cadomin Fm. – Deep Basin (DST Data)

Sea Level
Depth (m)
-500
-1,000
-1,500

Regional Hydraulic System
(Up-dip Water)

700+ m of Gas Column
In Separate Compartments

Lower Pressure Deep Basin Gas Columns

“Overpressured Cell”

Pressure (kPa)
5,000
15,000
25,000

(modified after Canadian Discovery Digest & Rakhit, 2005)
Stacked Deep Basin Systems

Jurassic - Cretaceous “Deep Basin” (Tight Gas)

Triassic “Deep Basin” (High TOC Tight Gas)

Mississippian - Devonian “Deep Basin” (Shale Gas)

Cadomin & Nikanassin

Montney Fm.
Burial Histories

Shear Zone “Piano Key” Effect

Study Area

GSLSZ

British Columbia

SnowBird Tectonic Zone

Vulcan Suture

Controls on the distribution of the Gas-Saturated Deep Basin Type Burial History Curve, WCSB

(Shona M. Ness* and Ian Hutcheon ASRG Website 2006)
Slot K - Conceptual Grain Expansion and Contraction

1. At Deposition

Open, Inter-connected pore system

2. At Maximum Burial

Grain crushing, pressure solution isolate inter-granular pores

3. After Partial Uplift

Inter-granular pores again connected through grain bounding tabular pores

(Billingsley et al., 2005)
Cadomin Paleogeography

Elmworth

Outcrop

Deep Basin

Fluvial

Continental area

Alluvial

BC

W6

Alberta

T80

T60

T40

T20

0 100 200 km

Calgary

Deep Creek Escarpment

Pembina High

Spirit River Channel

Spirit River Channel

Corden

Outcrop
Cadomin Outcrop Lithofacies – Mount Allen, Alberta

- medium - very coarse pebbly sandstone
- sand matrix chert pebble conglomerate
- carbonaceous silty-shale
- coal

MA - 07  MA - 08  MA - 04  MA - 03  MA - 02  MA - 01

30 m

0 m

900 m.
Cadomin Reservoir Model
Deep Basin Multi-Zone Gas Completions

- Cadotter
  - High combined flow rates

- Notikewin
  - Large reserve base
  - Evolving completion techniques

- Falher
  - High and low permeability reservoirs combined

- Cadomin
Cadomin Fm. - Deep Basin Depositional Model

Cutbank, BC
Coalescing Alluvial Fans

Elmworth, AB
Braided Fluvial/Alluvial

(after Gies, 1984)
Cadomin Formation - Elmworth, AB (Deep Basin)

- **IP** = 1.5 MMcf/d
- 12 Mo = 600 Mcf/d
- Cum 1.6 BCF (14 yrs)

7-23-69-13W6

- **GR**
- **Density Ø**
- 2650m

**Cadomin (7m)**

- **Ø h** = 0.45 (logs)
- 2675m

**Fractures**

- **Kh** = 110 md • m (core)

LSE
Clast-Supported Polymodal Sand Matrix Conglomerate

2660m

4% Ø
2.4md Kmax
Cadomin Fm – Elmworth Deep Basin  (7-23-69-13W6)

(Pebble Conglomerate with Matrix)

- sand matrix
- chert clast
- microfracture

Plane Light
Cadomin Fm. - Elmworth Deep Basin (7-23-69-13W6)

Flourescence (Moslow, 2005)

microfracture cross-cutting clasts and sandy matrix

1 Intg. Ø

2

3 slot
Slot K - Conceptual Grain Expansion and Contraction

1. At Deposition
   - Open, Inter-connected pore system

2. At Maximum Burial
   - Inter-granular pores again connected through grain bounding tabular pores
   - Grain crushing, pressure solution isolate inter-granular pores

3. After Partial Uplift
   - Inter-granular pores again connected through grain bounding tabular pores

(Billingsley et al., 2005)
Deep Basin “Tight” Gas Reservoir Material Balance
(Dual or Tri Transmissivity System)

IP 8.0 MMCF/D (April/82)

10-33-67-7W6 Cadomin

High Perm. Conventional Reservoir Rock

Low Perm./Tight Reservoir Matrix

10.5 BCF (Nov/02)

18.9 BCF (July/07)

 Cum. Gas Production (BCF)

10 BCF (Initial RGIP)

33 BCF (Ultimate RGIP)
Summary and Conclusions – Deep Basin

- Regionally pervasive gas saturation
- Abnormally (over/under) pressured
- Gas prone source rocks
- Compressional tectonics with isolated/spaced zones of wrenching
- Unconventional R.Q.* with “sweetspots” of conglomeratic and/or fracturing
- “Continuous” Foredeep with shear “piano key” segmentation
- Potential dual or tri transmissivity systems with slot K
- Progressing to multizone completions & horizontals
Evolving (“Pioneer”) Tight Gas Play in Deep Basin

- Technically not “tight” (<0.1 md), interbedded low and high perm. lithofacies
- Facies Heterogeneity → $K_{max}$ Variability (lateral and vertical)
- Microfracture and slot K
- Good Hzl Candidate
Acknowledgements

Suncor Energy – Prospect Generation Services
Midnight Oil Exploration Ltd.
Canadian Hunter Exploration Ltd.
Discovery Digest – Strategy 2005
Penta Graphix Ltd.
Cadomin Paleocurrent Transport
(Alberta and BC Front Ranges)

N

90°

270°

180°

90°

N=25

N=25
Key Points – Similarities WCSB and RMB Deep/BCA Basins

- Considered to have regionally pervasive gas saturation
- Abnormally (over/under) pressured
- Gas prone source rocks
Tertiary & Upper Cretaceous Sands

Green River Basin - Wyoming

Projected Recharge 7000'

Depth Sub-Sea (ft.)

Pressure data in regional water system
Pressure data in gas saturated zone

Regional up-dip water

4,000' of Gas Column in Separate Compartments

Under-and Over-Pressured Gas Zones

Sea Level

Pressure (psig)

(Davis, 1984)
### Evolving/Emerging “Tight” Gas Plays In Western Canada Deep Basin

<table>
<thead>
<tr>
<th>Formation/Age</th>
<th>Gas Saturation</th>
<th>Subnormal H₂O Sat</th>
<th>High TOC</th>
<th>Fracture Perm</th>
<th>Lateral Continuity (Hz Candidate) Low k•h/“High” Kmax</th>
<th>Vertical Continuity High k•h/Low Kmax</th>
</tr>
</thead>
<tbody>
<tr>
<td>* Cadinom (Lower K)</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>Nikanassin (Jurassic)</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>Montney (Triassic)</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
</tr>
</tbody>
</table>
## Summary and Conclusions

### Deep Basin – BCG Systems

<table>
<thead>
<tr>
<th>WCSB Deep Basin</th>
<th>U.S. Rocky Mountain BCG Basins</th>
</tr>
</thead>
<tbody>
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<td>• Regionally pervasive gas saturation</td>
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<td>• “Continuous” Foredeep with shear “piano key” segmentation</td>
<td>• Segmented” Basins</td>
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<tr>
<td>• Thick succession with isolated thin low net:gross reservoirs</td>
<td>• Thick succession with stacked high net:gross reservoirs</td>
</tr>
<tr>
<td>• Relatively deep* (2000 - 3000+ m)</td>
<td>• Spectrum of depths (300 - 4000+ m)</td>
</tr>
<tr>
<td>• Compressional tectonics with isolated/spaced zones of wrenching</td>
<td>• Wrench / extensional tectonics dominate</td>
</tr>
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<td>• Unconventional R.Q.* with “sweetspots” of conglomeratic and/or fracturing</td>
<td>• Tight RQ with fractured sweetspots</td>
</tr>
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<td>• Potential dual or tri transmissivity systems with slot K</td>
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<tr>
<td>• Chert to sublithic arenite</td>
<td>• Quartz arenites</td>
</tr>
<tr>
<td>• Non-marine to shallow marine deposits (deepwater)</td>
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</tr>
<tr>
<td>• Progressing to multizone completions</td>
<td>• Commingling of production from multiple reservoirs common</td>
</tr>
</tbody>
</table>
Summary and Conclusions – Deep Basin

- Regionally pervasive gas saturation
- Abnormally (over/under) pressured
- Gas prone source rocks
- Thick succession with isolated thin low net: gross reservoirs
- Relatively deep* (2000 - 3000+m)
- Compressional tectonics with isolated/spaced zones of wrenching
- Unconventional R.Q.* with “sweetspots” of conglomeratic and/or fracturing
- Chert to sublithic arenite
- Non-marine to shallow marine deposits (deepwater)
WCSB Gas Production History
All Areas – All Formations – By On-Production Date
Decline Rate Increasing

(data from AJM 2002; Zaitlin, 2003)
*Nickels Oil and Gas Statistical Quat. Q1 2006*
Montney Turbidite Sandstone

Range:
0.1 - 1.0 mD
5 - 8% Ø
Montney Depositional Model

Lowstand Turbidite Complex

(Moslow & Davies, 1997)
Example of Slot and Fracture Ø and K - Triassic Example
Nikanassin - Wapiti (15-27-66-10W6)

2995m

6% Ø
0.5md Kmax

fractures

slot

Ch

Q

Ø
Lower Cretaceous – underfilled with axial drainage

(Isopach Values
- No Data
- 0 - 40m
- 40 - 80m
- 80 - 120m
- 120 - 160m
- 160 - 200m
- > 200m)

(Modified after Cant and Abrahmson, 1996; Zaitlin et al., 2002)
Nikanassin - Wapiti (15-27-66-10W6)

2995m

fracture

slot

Auth. Clays

6% Ø

0.5md Kmax
Lower Cretaceous Depositional Cycles - Deep Basin

Cadomin

(Jackson, 1984)
Conceptual Grain Expansion and Contraction

At Deposition

Open, Inter-connected pore system

At Maximum Burial

Inter-granular pores again connected through grain bounding tabular pores

(Unloading)

After Partial Uplift

Grain crushing, pressure solution isolate inter-granular pores

(Mechanical / Chemical Compaction)

(Billingsley et al., 2005)
Cadomin - Wapiti (9-11-65-13W6)

Alluvial - Fluvial Conglomerate

3247m

3250m
Regional Cadomin Reservoir Quality Summary (Core)
Idealized Structural Elements Foreland Basin

- Lower Cretaceous – underfilled with axial drainage
- Mid-Upper Cretaceous – filled with transverse drainage

(A')

Cordilleran Fold-Thrust Belt

Axial Basin: Subduction-Induced Subsidence

Foreland Basin: Loading Subsidence

Isostatic Rebound in Hinge Zone

(Kauffman, 1984)
<table>
<thead>
<tr>
<th>Formation</th>
<th>Rock Fabric</th>
<th>Tectonic/Diagenetic History</th>
<th>Permeability</th>
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</thead>
<tbody>
<tr>
<td><strong>Cadomin</strong></td>
<td>Polymodal Sand - Matrix Conglomerate</td>
<td>• Transpression (Compression + Shear)</td>
<td>• Primary • Secondary • Fracture • Slot</td>
</tr>
<tr>
<td><strong>Nikanassin</strong></td>
<td>V.F. – F. Sandstone • 90% Quartz + Clays (~ Lance Fm.)</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Montney</strong></td>
<td>• Coarse Siltstone - V.F. Sandstone • Dolomite Matrix</td>
<td>• Extension • Compression</td>
<td></td>
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Slot K - Conceptual Grain Expansion and Contraction

1. At Deposition
   Open, Inter-connected pore system

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   Inter-granular pores again connected through grain bounding tabular pores
   Grain crushing, pressure solution isolate inter-granular pores

3. After Partial Uplift
   (Billingsley et al., 2005)
Cadomin Formation – Cutbank Ridge, BC (Deep Basin)

IP = 1.2 MMcf/d
12 Mo = 200 Mcf/d
Cum 0.43 BCF (8 yrs)

Polymodal Clast-Supported Sand Matrix Conglomerate

a-57-C / 93-P-07

GR

Density Ø

2800m

3%

2825m

Fractures

Kh = 36.7 md • m (core)

(Moslow, 2005)
Cadomin Fm. – B.C. Deep Basin

Plane Light

- Chert
- Quartz
- Sand matrix
- Bitumen

Clast
Cadomin Fm – B.C. Deep Basin

microfractures

Chert matrix

Slot K?

Q

Fluorescence

400 µm
Cadomin Outcrop – Mount Allen, Alberta

MA-3
gamma ray

0 15 150

Gething

30 m

"Upper"
Cadomin

20 m

"Lower"
Cadomin

10 m

Nikanassin

0 m

Braided Fluvial

Alluvial Fan

medium - very coarse pebbly sandstone
sand matrix chert pebble conglomerate
carbonaceous silty-shale
carbonaceous silty-shale coal
Selected References


Gies, R.M., 1984, Case history for a major Alberta deep basin gas trap; the Cadomin Formation, in Elmworth; case study of a deep basin gas field: AAPG Memoir 38, p. 115-140.


