Variations in Paleodrainage and Depositional Style:

Underfilled and Overfilled Foreland (Deep Basin) Western Canada Sedimentary Basin

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Outline

- Key Points
- Geologic Setting
- WCSB Drilling Activity
- Underfilled vs. Overfilled Foreland Basin
  - Underfilled FB: e.g. Nordegg, Nikinassin, BQ and equivalents, Spirit River
  - Overfilled FB: e.g. Dunvegan, Belly River Formations
- Summary and Conclusions
- Acknowledgements
Key Points

- Four key plays actively being pursued presently in the WCSB
  - Duvernay, Montney, Spirit River (Wilrich), Viking

- WCSB Foreland Basin is divisible into:
  - Underfilled Foreland Basin sequence
  - Overfilled Foreland Basin sequence
  - Pre-Foreland Basin sequence

- Paleodrainage:
  - South to north for the underfilled foreland basin
  - West to east for the overfilled foreland basin

- Shoreline geometry
  - East - west for the underfilled foreland basin - Prograding to the north
  - North – south for the overfilled foreland basin - Prograding to the east
“….. best strategy ….. is to focus on growth companies with the lowest cost structures in the best basins and ‘cash harvesters’ with low sustaining capital requirements.” BMO Capital Markets O&G: North America Jan 16, 2017

- 5 Main areas

Questions:

1- Is the Western Canada Sedimentary Basin a “best in class basin”?

2- What are the active plays presently in the WCSB?
Oil and Gas in the WCSB

**Alberta**
Area: 661,848 km²

**Texas**
Area: 696,241 km²

Source: NGI’s Map of North American Shale/Resource Plays
Western Canada Sedimentary Basin
Tectonic Evolution

Edmonton Group
Belly River
Cardium
Dunvegan
Second White Specks
Viking
Joli fou/Basal Colorado

Mannville
Spirit River
(Wilrich/Falher/Notikewan
Glaucolithic
Ostrocod
BQ-Ellerslie
Fernie, Poker Chip Rock Creek
Nordegg

Figure 2.3
Geologic evolution of Alberta

Phase 1: 1.5 billion – 170 Ma Deposition
5.4 billion – 170 million years ago

Phase II: 170 – 59 Ma Tectonic Uplift, Loading & Deposition
170 – 59 million years ago

Present Structural Domains in the Canadian Cordillera to Plains

Williston Basin
Intramountain Basins
Alberta Basin
Precambrian Shield
Williston Basin

ERCB ST-98-2011
Burial History Curves
Compartmentalization of the WCSB Shear Zone “Piano Key” Effect

Key - Major Source Rocks in the WCSB

- 16+ Source Rock Intervals on WCSB
- Key Source Rocks
  - SWS
  - Colorado Group Source Rocks (e.g. 1st Specks, Fish Scales, Joli Fou)
  - Ostracod
  - Fernie/Poker Chip
  - Nordegg
  - Pardonet
  - Baldonnel
  - Doig Phosphate
  - Montney
  - Banff
  - Exshaw
  - Calmar/Ireton
  - Duvernay
  - Elk Point

USGS Fact Sheet - Assessment of Undiscovered Conventional Oil and Gas Resources of the Western Canada Sedimentary Basin, Canada, 2012
3 Stacked Deep Basin Systems

Jurassic - Cretaceous Foreland “Deep Basin”

Mississippian – Devonian “Deep Basin”

Edmonton Group
Belly River
Cardium
Dunvegan
Second White Specks
Viking
Joli fou/Basal Colorado

U Mannville
Spirit River
(B) Wilrich/Father/Notikewan
Glaucolithic
Ostrocdo
BQ-Ellerslie
Fernie, Rock Creek
Nordegg

Techniques for Defining the Deep Basin

Ward, unpublished

Burnie et al., 2005
Western Canada Sedimentary Basin (WCSB)

**Pre-Foreland Basin**

- Edmonton Group
- Belly River
- Cardium
- Dunvegan
- Second White Specks
- Viking
- Joli fou/Basal Colorado
- Mannville
- Spirit River
- (Wilrich/Falher/Notikewan
- Glaucolithic
- Ostrocod
- BQ-Ellerslie
- Fernie, Poker Chip Rock Creek
- Nordegg

**Overfilled Foreland Basin**

- Underfilled Foreland Basin

**Accommodation Cycles**

**USGS Fact Sheet - Assessment of Undiscovered Conventional Oil and Gas Resources of the Western Canada Sedimentary Basin, Canada, 2012**
WCSB Drilling Activity - Rig Count

- 5 Year Average
- 2015 vs. 2016 activity
- Increase mid 2016 into 2017
- Top Plays based on activity:
  - Viking
  - Spirit River Group
  - Montney
  - Duvernay
Top Wells - 2015 Drilling Activity

BMO Oil and Gas: E&P – Canada Report
Top Wells – Alberta (January-December 2015)

- Top 40 wells (one-month, three-month and twelve-month cumulative basis) organized:
  - 20 best oil/condensate rate and 20 best raw natural gas rate
  - bbl/d, mmcf/d and boe/d (calendar day rate)
  - Location, Producing formation, Spud and On Production Date, TVD, bbl/d, mmcf/d, boe/d, % oil, % gas

- Caveat:
  - Useful screening tool; however these are just rates, and aren’t necessarily indicative of:
    - relative economics, including IRRs, NPVs, payouts, etc. and
    - returns from a corporate perspective

- This study then took BMO data, re-classified by:
  - Overfilled Foreland Basin
  - Underfilled Foreland Basin
  - Pre-foreland Basin

Kwan and van Bolhuis, 2016
Top 2015 Drilling Activity

Last 12 Months Top 20 Monthly Oil/Condensate Wells (Calendar Day Rate)

4 wells - Deep Basin – Overfilled Foreland Basin – (1 Belly River and 3 Dunvegan)
1 well - Deep Basin – Underfilled Foreland Basin – (1 Gething)
15 wells - Deep Basin - Pre-foreland Basin – (Doig, Montney, Bakken, Swan Hills, Halfway, Dulwood, Charlie Lake)

Exhibit 6: Last 12 Months Top Oil/Condensate Wells by Operator (Calendar Day Rate)

<table>
<thead>
<tr>
<th>Unique Well ID</th>
<th>Current Operator Name</th>
<th>Formation</th>
<th>Spud Date</th>
<th>On Prod</th>
<th>Field Name</th>
<th>Pool Name</th>
<th>TVD (m)</th>
<th>Peak Mthly boe/d</th>
<th>Cum. Oil &amp; Gas Cond. (bbbl)</th>
<th>Cum. Gas (mcf)</th>
<th>% Oil</th>
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<tbody>
<tr>
<td>101/15-06-075-086/W00</td>
<td>Surge Energy Inc</td>
<td>Tri-low</td>
<td>6/27/2015</td>
<td>2015/07</td>
<td>VALHALLA</td>
<td>TD UND</td>
<td>1,990</td>
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<td>Tri-low</td>
<td>3/18/2015</td>
<td>2015/04</td>
<td>DOUG V</td>
<td>TD UND</td>
<td>2,002</td>
<td>2,495</td>
<td>175,579</td>
<td>542,089</td>
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<td>RMP Energy Inc</td>
<td>Tri-ronny</td>
<td>1/13/2015</td>
<td>2015/02</td>
<td>ANTE CREEK NORTH</td>
<td>TRASSIC E</td>
<td>1,920</td>
<td>1,488</td>
<td>125,031</td>
<td>888,564</td>
<td>46%</td>
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<td>102/04-15-047-15/W5</td>
<td>Boulder Energy Ltd</td>
<td>Khelby rv</td>
<td>1/3/2015</td>
<td>2015/02</td>
<td>BRAZEAU RIVER</td>
<td>BELLY RIVER PGP</td>
<td>1,925</td>
<td>901</td>
<td>123,177</td>
<td>269,504</td>
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<td>TRASSIC E</td>
<td>1,954</td>
<td>1,206</td>
<td>110,373</td>
<td>440,907</td>
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<td>100/09-19-003-16/W4</td>
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<td>FERGUSON</td>
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<td>1,283</td>
<td>404</td>
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<td>83%</td>
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<td>Agapenfield Corp</td>
<td>Oswee_hl</td>
<td>12/11/2014</td>
<td>2015/02</td>
<td>SWAN HILLS</td>
<td>COMMINGLED POOL 001</td>
<td>2,337</td>
<td>341</td>
<td>84,505</td>
<td>62,714</td>
<td>89%</td>
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<td>2015/02</td>
<td>BIGSTONE</td>
<td>MONT UND</td>
<td>2,668</td>
<td>1,462</td>
<td>81,175</td>
<td>1,159,541</td>
<td>30%</td>
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<td>Kduvegan</td>
<td>10/24/2014</td>
<td>2015/03</td>
<td>KAWKA</td>
<td>OLVENAG CC</td>
<td>2,699</td>
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<td>80,009</td>
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<td>100/01-24-003-17/W4</td>
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<td>1/3/2015</td>
<td>2015/02</td>
<td>FERGUSON</td>
<td>WB BANTF-EXPON-BW</td>
<td>1,305</td>
<td>414</td>
<td>76,367</td>
<td>186,718</td>
<td>74%</td>
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<td>Tri-ronny</td>
<td>2/9/2015</td>
<td>2015/07</td>
<td>KAYBOB</td>
<td>TRASSIC B</td>
<td>1,791</td>
<td>1,185</td>
<td>75,569</td>
<td>630,638</td>
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<td>2015/02</td>
<td>PROGRESS</td>
<td>HALFWAY C</td>
<td>1,919</td>
<td>556</td>
<td>70,915</td>
<td>142,756</td>
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<td>Whitcap Resources Ltd</td>
<td>Kduvegan</td>
<td>1/7/2015</td>
<td>2015/02</td>
<td>SIMONETTE</td>
<td>OLVENAG F</td>
<td>1,977</td>
<td>565</td>
<td>68,584</td>
<td>343,838</td>
<td>54%</td>
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<tr>
<td>100/13-13-062-07/W6</td>
<td>Jupiter Resources Inc</td>
<td>Kduvegan</td>
<td>12/6/2014</td>
<td>2015/02</td>
<td>KAWKA</td>
<td>OLVENAG CC</td>
<td>2,766</td>
<td>601</td>
<td>67,886</td>
<td>286,431</td>
<td>59%</td>
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<td>100/13-34-066-24/W5</td>
<td>RMP Energy Inc</td>
<td>Tri-ronny</td>
<td>7/15/2015</td>
<td>2015/08</td>
<td>ANTE CREEK NORTH</td>
<td>TRASSIC E</td>
<td>1,936</td>
<td>1,437</td>
<td>67,689</td>
<td>408,018</td>
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<td>100/02-20-063-19/W5</td>
<td>Trilogy Resources Ltd</td>
<td>Korthin</td>
<td>1/5/2015</td>
<td>2015/07</td>
<td>KAYBOB</td>
<td>GETING C</td>
<td>1,836</td>
<td>1,148</td>
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<td>611,102</td>
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<td>Arsenal Energy Inc</td>
<td>Dghwood</td>
<td>12/2/2014</td>
<td>2015/02</td>
<td>EVI</td>
<td>GULWOOD AAA</td>
<td>1,590</td>
<td>209</td>
<td>64,683</td>
<td>13,658</td>
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<td>Tri-hallway</td>
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<td>2015/02</td>
<td>PROGRESS</td>
<td>HALFWAY F</td>
<td>1,923</td>
<td>533</td>
<td>64,554</td>
<td>70,523</td>
<td>85%</td>
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<td>100/07-15-077-07/W6</td>
<td>Exshaw Oil Corp</td>
<td>Tri-hly. tk</td>
<td>12/5/2014</td>
<td>2015/02</td>
<td>VALHALLA</td>
<td>CHARLIE LAKE F3</td>
<td>1,598</td>
<td>497</td>
<td>64,416</td>
<td>324,881</td>
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<td>Glencoe Energy Inc</td>
<td>Tri-dog</td>
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<td>2015/02</td>
<td>DOE</td>
<td>COMMINGLED POOL 001</td>
<td>1,576</td>
<td>382</td>
<td>63,576</td>
<td>302,644</td>
<td>56%</td>
</tr>
</tbody>
</table>

Source: geoSCOUT, BMO Capital Markets.

Kwan and van Bolhuis, 2016
Top 2015 Drilling Activity
Last 12 Months Top 20 Monthly Gas Wells (Calendar Day Rate)

0 wells - Deep Basin – Overfilled Foreland Basin
20 wells - Deep Basin – Underfilled Foreland Basin – Spirit River Group
0 wells - Deep Basin - Pre-foreland Basin

Exhibit 7: Last 12 Months Top Gas Wells by Operator (Calendar Day Rate)

<table>
<thead>
<tr>
<th>Unique Well ID</th>
<th>Current Operator Name</th>
<th>Formation</th>
<th>Spud Date</th>
<th>On Prod</th>
<th>Field Name</th>
<th>Pool Name</th>
<th>TVD (ft)</th>
<th>Peak Mthly bbl/d</th>
<th>Cum. Oil &amp; Cond. (bbl)</th>
<th>Cum. Gas (MMcf)</th>
<th>% of</th>
</tr>
</thead>
<tbody>
<tr>
<td>100/16-19-063JW5/00</td>
<td>Jupiter Rces Inc</td>
<td>Kowlch</td>
<td>6/4/2014</td>
<td>2015/02</td>
<td>KAKWA</td>
<td>COMMINGLED POOL 041</td>
<td>3,762</td>
<td>2,090</td>
<td>1</td>
<td>2,836,576</td>
<td>0%</td>
</tr>
<tr>
<td>100/16-02-062JW6/00</td>
<td>Jupiter Rces Inc</td>
<td>Kowlch</td>
<td>1/1/2015</td>
<td>2015/02</td>
<td>KAKWA</td>
<td>WILD UND</td>
<td>3,237</td>
<td>2,338</td>
<td>428</td>
<td>2,820,721</td>
<td>0%</td>
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<td>100/09-17-062JW5/00</td>
<td>Turnerine Oil Corp</td>
<td>Kowlch</td>
<td>2/16/2015</td>
<td>2015/06</td>
<td>KAKWA</td>
<td>SPRT &amp; UND</td>
<td>3,358</td>
<td>3,456</td>
<td>147</td>
<td>2,453,049</td>
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<td>102/14-11-063JW5/00</td>
<td>ConocoPhillips Gsa Optics</td>
<td>Kowlch</td>
<td>9/2/2014</td>
<td>2015/02</td>
<td>KAKWA</td>
<td>COMMINGLED POOL 005</td>
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<td>2,140</td>
<td>166</td>
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<td>5/15/2015</td>
<td>2015/02</td>
<td>SUNDANCE</td>
<td>COMMINGLED POOL 034</td>
<td>3,222</td>
<td>3,917</td>
<td>54</td>
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<td>102/13-23-054JW5/00</td>
<td>Turnerine Oil Corp</td>
<td>Kowlch</td>
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<td>2015/09</td>
<td>MASH</td>
<td>NOT UND</td>
<td>3,722</td>
<td>3,369</td>
<td>7,263</td>
<td>2,206,478</td>
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<td>Kowlch</td>
<td>1/6/2015</td>
<td>2015/02</td>
<td>WAPITI</td>
<td>COMMINGLED MFP529</td>
<td>2,259</td>
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<td>Perpetual Exploit Operating</td>
<td>Kowlch</td>
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<td>EODON</td>
<td>UPPER MANNIVILLE QQ</td>
<td>2,670</td>
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<td>2015/08</td>
<td>WILD RIVER</td>
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<td>2,798</td>
<td>2,958</td>
<td>2,023</td>
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<td>Kowlch</td>
<td>6/7/2015</td>
<td>2015/08</td>
<td>MINEHEAD</td>
<td>TD UND</td>
<td>3,349</td>
<td>2,814</td>
<td>216</td>
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<td>1/9/2014</td>
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<td>11/17/2014</td>
<td>2015/08</td>
<td>KAKWA</td>
<td>MESSIT</td>
<td>3,078</td>
<td>2,685</td>
<td>1,422</td>
<td>1,951,471</td>
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<td>2015/08</td>
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<td>UPPER MANNIVILLE ZZ</td>
<td>3,136</td>
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<td>1,975,648</td>
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<td>TAOA</td>
<td>MARSH</td>
<td>2,590</td>
<td>1,118</td>
<td>6</td>
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<td>MASHER</td>
<td>UND</td>
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<td>COMMINGLED MFP529</td>
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<td>1,515</td>
<td>86</td>
<td>1,888,021</td>
<td>0%</td>
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<td>Kowlch</td>
<td>1/4/2015</td>
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<td>BRAZEAU RIVER</td>
<td>COMMINGLED POOL 028</td>
<td>2,596</td>
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<td>21</td>
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<td>IHELLD</td>
<td>UND</td>
<td>3,043</td>
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Source: geoSCOUT, BMO Capital Markets.

Kwan and van Bolhuis, 2016
Top 2015 Drilling Activity Distribution of Top AB Gas Wells (based on IP 30)

- Top 20/20 gas wells
- Spirit River Reservoir Trends (yellow)
- Underfilled FB

5/20 Top Oil Wells
- Overfilled FB
- Underfilled FB

C. Stephens, CSUR Luncheon Presentation, 2016
Production and Well Count
IP90 Average Rate – Wells on Stream in 2016

- **Viking**
  - N ~960 wells
  - IP90 ~ 90boepd

- **Spirit River**
  - N ~ 390 wells
  - IP90 ~ 850 boepd

- **Montney**
  - N ~ 840 wells
  - IP90 ~ 800 boepd

- **Duvernay**
  - N ~ 140
  - IP ~ 475boepd
Foreland Basin
Axial Drainage vs. Transverse Drainage
Underfilled FB vs. Overfilled FB

- Zone of Max. Subsidence and Sedimentation Rate
- Zone of High Subsidence and Sedimentation Rate
- Hinge Zone
- Stable Eastern Platform Zone

Cordilleran Fold-Thrust Belt
Foreland Basin: Loading Subsidence
Axial Drainage and Sedimentation Rate
Isostatic Rebound in Hinge Zone

Edmonton Group
Belly River
Cardium
Dunvegan
Second White Specks
Viking
Joli fou/Basal Colorado

Mannville
Spirit River
(Wilrich/Falher/Notikewan
Glaucolithic
Ostrocod
BQ-Ellerslie
Fernie, Poker Chip Rock Creek
Nordegg

Transverse Drainage

modified after Kauffman, 1984
Underfilled Foreland Basin
Drainage to north

Blum et al., 2015

Continental Scale
Paleodrainage Reorganization

Mid-Cretaceous

Paleocene-Early Eocene

to Boreal Sea
to GoM

Atlantic

to GoM
Coastal Classification – along strike variation

Boyd, Dalrymple and Zaitlin, 1992
Shoreline Depositional Model of along strike variation for a wave dominated shoreline, deltas and associated facies

(modified after Armitage, Pemberton and Moslow, 2004 for the Falher C)
Delta Models

Sandbody Prediction Made Easy?

Describe facies

Compare with models

Fit into the Ternary Diagram

River

Wave

Tide

Infer delta morphology

Predict sandbody geometry, width-thickness ratios, etc.

Figure 7

Updrift: wave-dominated

Downdrift: river- and/or tide-dominated

Junaid Sadeque, March, 2016
Asymmetric Wave-Influenced Delta Model

Figure-5

After Bhattacharya & Gieson 2003

Figure-6

Clean reservoir quality sand

More heterolithic, muddy sand

Junaid Sadeque, March, 2016
Western Canada Sedimentary Basin
Underfilled Foreland Basin Examples

Edmonton Group
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Joli fou/Basal Colorado
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USGS Fact Sheet - Assessment of Undiscovered Conventional Oil and Gas Resources of the Western Canada Sedimentary Basin, Canada, 2012
Foreland Basin
Axial Drainage vs. Transverse Drainage
Underfilled FB

Cordilleran Fold-Thrust Belt

Foreland Basin: Loading Subsidence
modified after Kauffman, 1984

Axial Drainage

Isostatic Rebound in Hinge Zone

Zone of High Subsidence and Sedimentation Rate

Hinge Zone

Stable Eastern Platform Zone

Mannville
Spirit River
(Wilrich/Falher/Notikewan
Glaucnonitic
Ostrocod
BQ-Ellerslie
Fernie, Poker Chip Rock Creek
Nordegg

Zone of Max. Subsidence and Sedimentation Rate

Axial Basin: Subduction-Induced Subsidence

Underfilled Foreland Basin
Jurassic Nordegg FM - Foreland Basin

Axial Paleodrainage
Jurassic Nikinassin Fm

Axial Paleodrainage
Lower Cretaceous – Aptian (120-115 Ma)  
(Cadomin, Gething, Basal Quartz)

Paleodrainage
Lower Cretaceous Aptian (120-115 Ma)

Isopach Map
Jurassic to Ostracod and equivalents

(modified from Cant and Abramson; Zaitlin et al, 2002)
Stratigraphy – Fort St. John – Spirit River Groups

Modified after Masters, 1984
Lower Cretaceous Depositional Cycles

Parasequence Sets

CDD

(Jackson, 1984)
Example Log – Hoadley Barrier

(modified after Rosenthal, 1998)
Glaucanitic Hoadley Type Schematic Cross Section SE-NW

Upper MNVL Channels  
Regional Deltaic Sands  
Hoadley Shoreface  
Offshore Hoadley

Regional Deltaic Sands  
Upper MNVL Channels

Hoadley Shoreface

Wave ravinement surface

POST GLCC CHANNEL/FLHR CHANNELS  
Regional Sheet Sands  
GLCC Age CH  
Middle HOADLEY Shoreface  
Lower HOADLEY Shoreface

LEGEND

- Upper Glaucanitic/Marronville Felsispathic Litharenite
- Glaucanitic Arenite & Quartz arenite Arenites
- Brackish-lacustrine Shales & Limestones
- Regional Brackish-High Marine (Coal, Rooted Palosols, Floodplain Muds & Splay & Muddy Estuarine Channel fill (N10-P10))
- Conglomerate Reservoir
- Felsispathic Sublitharenite & Litharenites
- Marine Shale
- Coal

Top 2015 Drilling Activity

C. Stephens,
CSUR Luncheon
Presentation, 2016

Oil
★ **Overfilled** Foreland Basin
★ **Underfilled** Foreland Basin

Spirit River Reservoir Trends in yellow

CDD
Spirit River – Wilrich EURs
Facies, Depositional model vs. Technology

Lenko, 2016
Wilrich A – Gross Isopach

Kakwa (T65)
Simonette (T44)
Resthaven (T58)
Wildriver (T54)
Edson/Ansell (T50)
Ferrier (T44)

LEGEND
- Wells with Cores Logged
- Wells with Petrophysical Analysis

Color Grid
- 0
- 30
- 60 m

Figure 6
Clean reservoir quality sand
More heterolithic muddy sand

B. Hayes, PRCL, 2013
Wilrich A – Net Porous Sand (6% Ø cutoff)

B. Hayes, PRCL, 2013

LEGEND
- Wells with Cores Logged
- Wells with Petrophysical Analysis

Color Grid
0 20 40 m

Kakwa (T65)
Simonette (T64)
Resthaven (T58)
Wildriver (T54)
Edson/Ansell (T50)
Ferrier (T44)
Shoreline Depositional Model of along strike variation for a wave dominated shoreline, deltas and associated facies

(modified after Armitage, Pemberton and Moslow, 2004 for the Falher C)
High Øh Low Kh
Conglomerate Reservoir (“Natures HZ”)

Low Øh High Kh
HPBCGA “Sweet Spots” act as a HZ well
Dual Transmissivity System

High Øh Low Kh “Tight”
Tight Sandstone Reservoir - HZ

Falher A & B Reservoirs
Wilrich Reservoirs

HPBCGA “Sweet Spots” require a HZ well
Dual Transmissivity System

Conglomeratic (Falher) vs. Fine Grained Sandstone (Wilrich) Shoreface Reservoirs

“Gas Deliverability” (K_h)

“Gas Storage” (Øh)

Slope

“Gas Storage” (Øh)

Slope

Modified after Zaitlin and Moslow, 2004
### Western Canada Sedimentary Basin

#### Overfilled Foreland Basin Examples

<table>
<thead>
<tr>
<th>Era</th>
<th>System</th>
<th>Series</th>
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</table>

#### Assessment of Undiscovered Conventional Oil and Gas Resources of the Western Canada Sedimentary Basin, Canada, 2012

- Edmonton Group
- Belly River
- Cardium
- Dunvegan
- Second White Specks
- Viking
- Joli fou/Basal Colorado
- Mannville
- Spirit River
- Wilrich/Falher/Notikewan
- Glaucocitic
- Ostrocod
- BQ-Ellerslie
- Fernie, Poker Chip Rock Creek
- Nordegg

Accommodation Cycles

USGS Fact Sheet
Foreland Basin

Axial Drainage vs. Transverse Drainage

Overfilled FB

Foreland Basin: Loading Subsidence

Axial Basin: Subduction-Induced Subsidence

modified after Kauffman, 1984

Cordilleran Fold-Thrust Belt

Overfilled Foreland Basin

Edmonton Group
Belly River
Cardium
Dunvegan
Second White Specks
Viking
Joli fou/Basal Colorado

Isostatic Rebound in Hinge Zone

Hinge Zone

Stable Eastern Platform Zone

Zone of Max. Subsidence and Sedimentation Rate

Zone of High Subsidence and Sedimentation Rate

Transverse Drainage

modified after Kauffman, 1984
Basal Belly River Prograding Shorelines
Overfilled Foreland Basin

(After Hamblin, 1996a, 1997a/b)
FACIES AND LITHOLOGY

- Non-marine sandstone & siltstone with coal
- Shoreline-related sandstone
- Shallow marine siltstone/shale
- Fluvial channel or valley-filled estuarine ss

PLAY TYPES

1. Basal Belly River shoreface sandstones
2. Belly River Gp. Fluvial channel sandstones (Foremost, Oldman and Dinosaur Park Fms.)
- Productive Reservoirs - Gas/Oil

Datum: Milk River Shoulder (Disconformity/Condensed Section)

(After Hamblin, 1996a, 1997a/b)
Western Canada Sedimentary Basin (WCSB)

- Edmonton Group
- Belly River
- Cardium
- Dunvegan
- Second White Specks
- Viking
- Joli fou/Basal Colorado
- Mannville
- Spirit River
- (Wilrich/Falher/Notikewan Glauconitic
- Ostrocod
- BQ-Ellerslie
- Fernie, Poker Chip Rock Creek
- Nordegg

Accommodation Cycles

Pre- Foreland Basin

Overfilled Foreland Basin

Underfilled Foreland Basin

Foreland Basin

USGS Fact Sheet - Assessment of Undiscovered Conventional Oil and Gas Resources of the Western Canada Sedimentary Basin, Canada, 2012
Foreland Basin

Axial Drainage vs. Transverse Drainage

Underfilled FB vs. **Overfilled FB**

- Zone of Max. Subsidence and Sedimentation Rate
- Zone of High Subsidence and Sedimentation Rate
- Hinge Zone
- Stable Eastern Platform Zone
- Isostatic Rebound in Hinge Zone

**Cordilleran Fold-Thrust Belt**

**Foreland Basin: Loading Subsidence**

**Axial Basin: Subduction-Induced Subsidence**

**Edmonton Group**

**Belly River**

**Cardium**

**Dunvegan**

**Second White Specks**

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(Wilrich/Falher/Notikewan)

**Glaucolithic**

**Ostrocod**

**BQ-Ellerslie**

**Fernie, Poker Chip Rock Creek**

**Nordegg**

**modified after Kauffman, 1984**
**Conglomeratic (Falher) vs. Fine Grained Sandstone (Wilrich) Shoreface Reservoirs**

- **High $\Omega_h$$**
- **Low $K_h$$**
  Conglomerate Reservoir ("Natures HZ")

- **Low $\Omega_h$$**
- **High $K_h$$**
  Tight Sandstone Reservoir

**HPBCGA “Sweet Spots”**
- Act as a HZ well
- Dual Transmissivity System

**Gas Deliverability** ($K_h$)

**Gas Storage** ($\Omega_h$)

Falher A & B Reservoirs

Wilrich Reservoirs

Modified after Zaitlin and Moslow, 2004
Jurassic-Cretaceous Foreland Basin Unconventional Plays Underfilled vs. **Overfilled** Foreland Basin

**Overfilled FB**
- Edmonton Group
- *Belly River*
- Cardium
- *Dunvegan*
- Second White Specks
- Viking
- Joli fou/Basal Colorado

**Underfilled FB**
- Upper Mannville
- *Spirit River - Wilrich*
- Glaucocitc - Bluesky
- Ostrocod
- *BQ-Ellerslie*
- Fernie - Nikinassin
- Rock Creek
- Nordegg
Summary

- **WCSB Foreland Basin** is divisible into:
  - Underfilled Foreland Basin sequence
  - Overfilled Foreland Basin sequence
  - Pre-Foreland Basin sequence

- **Paleodrainage:**
  - South to north for the underfilled foreland basin
  - West to east for the overfilled foreland basin

- **Shoreline geometry**
  - East-west for the underfilled foreland basin - Prograding to the north
  - North – south for the overfilled foreland basin - Prograding to the east
  - Asymmetric Wave-dominated Delta model = “sweetspots”
Acknowledgements

- Dr. Brad Hayes
  - (Petrel Robertson Consulting Ltd.)
- Dr. Zeev Berger
  - (Ittech, Inc.)
- Many Past Colleagues from:
  - Esso/Exxon
  - PanCanadian/Encana
  - Suncor
  - Enerplus
  - EOG
  - Daylight/Midnight/Pace

One last thought:
“Once you understand that water flows downhill, then everything makes sense”