IDENTIFICATION AND EVALUATION OF NEW RESOURCE OIL PLAYS, NEBC

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Attract mineral and oil & gas investment to British Columbia through generating, interpreting, and publicly distributing geoscience data in collaboration with First Nations, communities, government, and industry
The NEBC portion of the Western Canada Sedimentary Basin has traditionally been dominated by gas production.

Existing oil pools are typically small and tightly bounded.

Is there tight / unconventional / "resource" oil potential that we have overlooked?
Historical Oil Production

Large pools are old and in decline
Heritage (Montney) is the only recent significant addition
Resource Oil Play Types

TIGHT OIL
- Clastic or carbonate reservoirs with low permeability, requiring high-density drilling and multi-stage fracs to produce oil at economic rates (Montney Fm, Bakken Fm)

SHALE OIL
- Oil accumulations hosted by shales / mudrocks, perhaps some interbedded coarser material (Duvernay Fm, Eagle Ford Shale)

HALO OIL
- Lower permeability fringes flanking conventional oil reservoirs (Cardium Fm)
Reviewed >20 potential resource oil targets throughout the stratigraphic column (excluding Montney), assessing high / medium / low prospectivity
Identification and Evaluation Process

Stratigraphic and production / maturity review
  • Potential for extensive tight / halo / shale facies ?
  • Existing oil production or shows (tight / halo), or oil-prone maturity levels (shale) ?

Reservoir geology analysis and mapping

Assess geochemistry / maturity / geomechanical data, and complete sampling / analytical work to address data gaps

Reservoir engineering analysis
  • Do existing production / test data suggest presence of significant oil volumes in low-permeability reservoirs ?
Compiling Analytical Data

Analytical data are submitted to BC OGC – historically in hard copy, more recently as digital image files

- Source rock analysis
- Adsorption / desorption
- X-ray diffraction, X-ray fluorescence, SEM
- Standard petrography
- Geomechanical testing and analysis
- Capillary pressure, special core analysis

Only routine core analysis data have been routinely compiled and made available through vendor databases
Project team reviewed .pdf files from OGC
  • Identified tests completed and verified stratigraphic assignments
  • Built on existing compilation work (open file reports)

Created master database listing all test / analytical data
  • Searchable by formation, test type, WA#

Used for Resource Oil project data compilation

OGC is using the database to facilitate digital submission of core data, and will make it publicly available
Acquiring New Analytical Data

Focused on addressing existing data gaps – generally units that have not been considered as resource oil targets

Identify rock properties
  • Mineralogy, geochemistry, TOC, $T_{\text{max}}$, porosity, permeability

Identify remaining hydrocarbons
  • TOC, $T_{\text{max}}$, $S_1$ (pyrolysis testing)

Identify rock strengths
  • Petrography – rock fabric
  • Brittleness
Muskwa Source Rock

Generally regarded as a rich source rock

- Moderate-high TOC values in major embayments
- Distinctive high-gamma / resistivity section on logs

Lower TOC values between basins – in part because section is thin and poorly sampled
Muskwa Source Rock

Muskwa maturity ($T_{\text{max}}$) difficult to map – many invalid values

Highly mature in Horn River Basin and Cordova Embayment, where it produces gas

Oil tests in Shekilie area demonstrate lower maturity – liquids and oil potential

Oil shows and limited oil production in overlying Devonian and Mississippian carbonates point to area of tight oil potential
# Muskwa – Analytical Data

## Husky Bivouac a-55-B/94-I-8 - Unconfined Porosity and Crushed Permeability

<table>
<thead>
<tr>
<th>Sample</th>
<th>Core Depth (m)</th>
<th>Formation</th>
<th>Total Bulk Density (g/cc)</th>
<th>Total Skeletal Density (g/cc)</th>
<th>Total Porosity (%)</th>
<th>GRI Matrix Permeability (mD)</th>
<th>Avg</th>
<th>Std Dev</th>
<th>Avg</th>
<th>Std Dev</th>
<th>Avg</th>
<th>Std Dev</th>
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</table>
Muskwa – Mineralogy

Finely-laminated siliceous, organic-rich shale

Illitic clay, neomorphic microcrystalline quartz, mica and pyrite
Muskwa – Mineralogy / Organics

Substantial TOC values – good source rock potential
Substantial porosity, but very small pores
**Muskwa – Hydrocarbon Analysis**

- **C₈ peak related to invert mud system**
- **Range of residual HC’s reflects liquids-rich maturity**

### Hydrocarbon Analysis Summary Table

<table>
<thead>
<tr>
<th>Sample Depth</th>
<th>Formaion</th>
<th>Sample Type</th>
<th>% Light Condensate</th>
<th>% Heavy Condensate</th>
<th>% Naphthen</th>
<th>% Aromatics</th>
<th>% Biomarkers</th>
<th>Range &gt;2%</th>
<th>Peak</th>
<th>Initial Boiling Point (°C)</th>
<th>Carbon Number</th>
<th>Final Boiling Point (°C)</th>
<th>Carbon Number</th>
<th>Calculated Specific Gravity</th>
<th>Calculated API gravity</th>
<th>Chromatogram Quality</th>
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<tbody>
<tr>
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<td>solid</td>
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<td>C₈, m,p.xylene, C₁₀-C₂₂</td>
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<td>62</td>
<td>&lt;C₆</td>
<td>456</td>
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<td>1819.98</td>
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<td>19.10</td>
<td>65.58</td>
<td>0.31</td>
<td>3.22</td>
<td>11.79</td>
<td>C₈, C₁₁-C₂₆</td>
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<td>85</td>
<td>C₇</td>
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<td>C₆</td>
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<td>C₇</td>
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<td>C₃₄</td>
<td>0.825</td>
<td>40.0</td>
<td>Best</td>
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</table>

**Averages**

|               |          |             |             |           |           |             |             |          |     |             |             |               |             |                   |               |             |
| 30.01         | 55.47    | 0.35        | 2.53        | 11.65     | 80        | 475         | 0.837       | 37.5     |     | Best        |               |               |               |                   |               |

**Note:** Oil-based mud

- Light Condensates
- Heavy Condensates
- Aromatics
- Biomarkers

**Range:**

- Light Condensates: nC₆ through nC₁₂
- Heavy Condensates: nC₁₃ through nC₄₀
- Naphthenes: Cyclopentane, Methylcyclopentane, Cyclohexane, Methylcyclohexane
- Aromatics: Benzenes, Toluene, Ethylbenzene, Xylenes
- Biomarkers: Pristane & Phytane

**Simulated Distillation:**

- Peak Indicators
- Initial Boiling Point (°C)
- Carbon Number
- Final Boiling Point (°C)
- Carbon Number
- Calculated Specific Gravity
- Calculated API gravity
- Chromatogram Quality

**Ranges:**

- C₈ peak related to invert mud system
- Range of residual HC’s reflects liquids-rich maturity
### Husky Bivouac a-055-B 094-I-08 - Triaxial

<table>
<thead>
<tr>
<th>Depth (m)</th>
<th>Confining Pressure (MPa)</th>
<th>Axial Strain at Failure (%)</th>
<th>Compressive Strength (MPa)</th>
<th>Residual Strength (MPa)</th>
<th>Static Young's Modulus (GPa)</th>
<th>Static Poisson's Ratio</th>
<th>Static Bulk Modulus (GPa)</th>
<th>Static Shear Modulus (GPa)</th>
<th>Strain Brittleness</th>
<th>Stress Brittleness</th>
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</thead>
<tbody>
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<td>137.94</td>
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<td>1824.89</td>
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<td>15.91</td>
<td>13.03</td>
<td>0.86</td>
<td>0.26</td>
</tr>
</tbody>
</table>

Values consistent across formation:
- Average Young’s modulus
- Low Poisson’s ratio

Very little plastic deformation, with moderate energy release at failure

Low to average compressive strength
Muskwa Engineering Analysis

Oil tests in Shekilie area demonstrate liquids and oil potential

8 hz / multi-frac wells completed in Muskwa (Alberta) 2009 – 2014
- Maximum liquid (oil+water) rate is 20.4m$^3$/d (monthly basis)
- Production data are erratic
- Only one well shows normal decline behaviour
- Strong indicators of non-reservoir problems (production related) – so we don’t yet know whether this reservoir has economic potential
Oil-bearing shales are confirmed, but initial horizontal / multi-frac campaign has failed

Root cause?
- Reservoir (low perm)
- Completion / production issues

Approach: Drill lower-cost vertical test well, designed to clarify potential issues not fully addressed by existing data sets
Approach: Drill lower-cost vertical test well to identify potential issues
- Core completely
- Comprehensive logging suite
- Test fluid / rock compatibility
- Diagnostic Fracture Injection Test (DFIT) to establish effective perm
- Execute standard frac job
- Set pump close to perfs
- Produce well, analyze results to decide whether modified horizontal program can be reasonably designed
Muskwa – Summary

Highly mature and productive gas shale in Horn River Basin and Cordova Embayment

Lower maturities suggest good oil source rock, and shale oil potential to the southeast

Substantial porosity, but very small pores; high clay content and geomechanical properties suggest Muskwa may be difficult to frac

Engineering analysis indicates poor performance in 8 horizontal wells drilled to date

New vertical wellbore with extensive testing recommended to identify better completion techniques
Tight Oil – Tetcho Formation

Wabamun regional carbonate platform – outer shelf to basinal setting in NEBC

Open marine skeletal lime mudstones and wackestones, not dolomitized

Halbertsma, 1994

Devon Helmet
c-A46-K/94-P-1
889.25 - 890.17m
Platform limestones 60-100m thick, shale out westward

DST’s and scattered vertical tests produced only small gas shows

Six horizontal wells drilled in Helmet area
  – 3 oil, 3 gas
No evidence for systematic development of higher-quality reservoir along specific stratigraphic or structural trends.

Horizontal completions in clean limestone facies.
Standard core analysis data show low porosity and low-moderate permeability.

Seven wells with existing petrographic / geochemical analyses.

New geomechanical data acquired from two cores near oil producers.
## Tetcho – Analytical Data

### Czar Venus d-13-C/94-P-9 Unconfined Porosity and Crushed Permeability

<table>
<thead>
<tr>
<th>Sample</th>
<th>Core Depth (m)</th>
<th>Formation</th>
<th>Total Bulk Density (g/cc)</th>
<th>Total Skeletal Density (g/cc)</th>
<th>Total Porosity (%)</th>
<th>GRI Matrix Permeability (mD)</th>
<th>GRI Matrix Permeability (nD)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>Avg</td>
<td>Avg</td>
<td>Std Dev</td>
<td>Avg</td>
<td>Std Dev</td>
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<tr>
<td>811.84</td>
<td>811.84</td>
<td>Tetcho</td>
<td>2.66</td>
<td>2.722</td>
<td>0.001</td>
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<td>833.53</td>
<td>Tetcho</td>
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</table>
Tetcho – Mineralogy

Stylolitic wackestone, microspar cement

Interlocking microcrystalline calcite, rare quartz
Tetcho – Pore Size Distribution

Low porosity, tight distribution of larger pores

Czar Venus d-013-C 094-P-09 - Mercury Intrusion Capillary Pressure

<table>
<thead>
<tr>
<th>Sample</th>
<th>Core Depth (m)</th>
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<th>Porosity (%)</th>
<th>Conformance Corrected Porosity (%)</th>
<th>Peak Range (nm)</th>
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<td>23</td>
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# Tetcho – Hydrocarbon Analysis

## Hydrocarbon Analysis Summary Table

**Czar Venus d-13-C/94-P-9**

<table>
<thead>
<tr>
<th>Sample</th>
<th>Formation</th>
<th>Sample Type</th>
<th>% Light Condensate</th>
<th>% Heavy Condensate</th>
<th>% Naphthenes</th>
<th>% Aromatics</th>
<th>% Biomarkers</th>
<th>Peak Indicators</th>
<th>Peak</th>
<th>Initial Boiling Point (°C)</th>
<th>Carbon Number</th>
<th>Final Boiling Point (°C)</th>
<th>Carbon Number</th>
<th>Calculated Specific Gravity</th>
<th>Calculated API gravity</th>
<th>Chromatogram Quality</th>
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**Averages**

<table>
<thead>
<tr>
<th>% Light Condensate</th>
<th>% Heavy Condensate</th>
<th>% Naphthenes</th>
<th>% Aromatics</th>
<th>% Biomarkers</th>
<th>Peak Indicators</th>
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<th>Initial Boiling Point (°C)</th>
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<td>&lt;C6</td>
<td>452</td>
<td>C30</td>
<td>0.846</td>
<td>35.8</td>
<td>no good</td>
</tr>
</tbody>
</table>

**837.21m**

**Heavy Condensates**

**Substantial range of heavier condensates API gravities 30-32**

**C20**

**C36**

**Phytane**
### Geomechanics

#### Data Table

<table>
<thead>
<tr>
<th>Depth (m)</th>
<th>Confining Pressure (MPa)</th>
<th>Axial Strain at Failure (%)</th>
<th>Compressive Strength (MPa)</th>
<th>Residual Strength (MPa)</th>
<th>Static Young’s Modulus (GPa)</th>
<th>Static Poisson’s Ratio</th>
<th>Static Bulk Modulus (GPa)</th>
<th>Static Shear Modulus (GPa)</th>
<th>Strain Britteness</th>
<th>Stress Britteness</th>
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<td>61.75</td>
<td>23.55</td>
<td>0.79</td>
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</tr>
</tbody>
</table>

#### Graph

- **Deviation Stress (MPa)** vs. **Strain (%)**
- **816.25**
- **834.28**

### Observations

- **Values consistent across formation**
  - Very high Young’s modulus
  - Average Poisson’s ratio
- **Moderate plastic deformation, with moderate energy release at failure**
  - Spl 816.25 showed drop in stress prior to max load, indicating multiple failure events
- **Average compressive strength**
Tetcho – Summary

Broad, homogeneous carbonate platform presents a consistent, widespread, tight reservoir

Existing hydrocarbon shows and production demonstrate charge, but insufficient data to characterize hydrodynamics

Maturity of deeper Muskwa source rocks a key to understanding oil distribution in this and other carbonate platform reservoirs – Kotcho, Kakisa, Jean Marie

Rock and geomechanical properties suggest a reservoir that can be effectively stimulated, but more work needs to be done to optimize completion methodologies
Charlie Lake Formation

Numerous oil pools in discrete aeolian sands sharply bounded by evaporitic facies

- High-quality reservoir, but thin and limited extent
- Generally < 10 MMBOIP
- Larger accumulations at:
  - Inga (125 MMBOIP)
  - Boundary Lake (540 MMBOIP)
  - Brassey (28 MMBOIP)

Almost all oil pools are found south of the Gordondale subcrop edge
Charlie Lake Stratigraphy

Complex Charlie Lake stratigraphy controls distribution of individual reservoir trends

Davies, 1997
Charlie Lake – Brassey Field
Charlie Lake – Brassey Field

Thin, high-quality sandstone reservoir, sharply bounded both vertically and laterally
Charlie Lake – Conventional Reservoirs

Artex Member, Brassey Field
6-1-77-19W6
Fefchak and Zonneveld, 2010

Φ 25%, K 1 Darcy
Charlie Lake – Production Analysis

~75 oil pools, most <5 MMBO in place, only larger pools have secondary recovery (generally waterflood) in operation

Reservoirs are generally thin, very sharply bounded laterally and vertically, by tightly-cemented facies

Horizontal drilling has been undertaken at Rigel Cecil ‘A’ pool

- 33.3 MMBOIP, 24 hz wells drilled pre-2011
- Partial waterflood complicates analysis
- IP rates 8 to 30m³/d fluid, wide range of water cuts
- Wells are ‘non-optimal’ in terms of current technology, but offer encouraging results for other large Charlie Lake pools
- But while recovery may be enhanced, we don’t see strong evidence that new halo oil volumes are being accessed
Upper Charlie Lake tight oil fairway has been developed in Alberta using horizontal / multifrac wells

- Tourmaline and Birchcliff have booked >125 MMBO reserves and hundreds of potential horizontal locations

Can we extrapolate upper Charlie Lake tight oil prospectivity into BC?

- “Lower Charlie Lake / Montney A” oil pool at Chinchaga River
Stacked sandier-upward successions produce oil in the SE but grade out northwestward

- FSJ Graben provided accommodation space for deposition

4-6-88-9W6

6-21-90-11W6
Upper Charlie Lake, Worsley
10-21-87-9W6

\[ \Phi 25\%, K 1 \text{ Darcy} \]

Worsley Mbr
Upr CL tight sst
Charlie Lake – Summary

Discrete, narrow aeolian sand reservoirs are thin and abruptly bounded by evaporitic facies

- No positive indication of halo oil potential, although horizontal drilling may improve recovery factor in larger pools
- Most pools are so small that potential upside is very limited

Upper Charlie Lake tight oil play in Alberta occurs in stacked, low- to moderate-permeability sandier-upward successions

- Excellent horizontal / multi-frac development targets, still being aggressively pursued
- Reservoir trends cannot be mapped into B.C.; depositional limits appear to be imposed by residual relief on Fort St John Graben
Shale Oil – Gordondale Member

Regionally-extensive, high-quality source rock

Phosphatic, organic-rich shale, distinctly radioactive

Ross and Bustin, 2007

Asgar-Deen et al, 2004
Gordondale Total Isopach

Uniform package up to 30m thick, thinning abruptly at NE subcrop edge

Many source rock analyses and some geomechanical testing
Gordondale

TOC (%)

Very rich source rock, becoming leaner at depth where hydrocarbons have been expelled
Gordondale

Maturity ($T_{\text{max}}$)

Mature for oil in northeast, becoming overmature southwestward
Gordondale – Summary

Only two completion attempted in NEBC to date, both in areas where Gordondale is gas-prone

– Poor gas rates in one well, information confidential in the other

More concerted development efforts in Alberta have not been successful – but light oil has been produced locally from naturally-fractured Gordondale shales

NEBC (and adjacent Alberta) has a broad, prospective Gordondale shale fairway, but we have not yet figured out how to produce from it
Chinkeh Formation

Regionally extensive basal Cretaceous sandstones deposited in shallow marine to channelized settings in the Liard Basin; up to 50m thick

Maxhamish Lake Chinkeh ‘A’ pool
– 208 BCF original marketable reserves hosted in higher-quality basal sands

9 oil wells (4 horizontals) credited with 5.6 MMBO in place (BCOGC)
-- Regional exploration work indicates potential for >200 MMBOIP
Regional continuity of reservoir sands not well understood away from dense well and core control at Maxhamish

Frank, 2002
Chinkeh Fm, c-95-J/94-O-11
## Chinkeh – Analytical Data

### ECA Maxhamish d-48-B 094-O-11 Unconfined Porosity and Crushed Permeability

<table>
<thead>
<tr>
<th>Sample ID</th>
<th>Core Depth (m)</th>
<th>Formation</th>
<th>Total Bulk Density (g/cc)</th>
<th>Total Skeletal Density (g/cc)</th>
<th>Total Porosity %</th>
<th>GRI Matrix Permeability (md)</th>
<th>GRI Matrix Permeability (nd)</th>
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<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>Avg</td>
<td>Avg</td>
<td>Std Dev</td>
<td>Avg</td>
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<td>1466.95</td>
<td>Chinkeh</td>
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<td>2.696</td>
<td>0.001</td>
<td>5.12</td>
<td>1.39E-04</td>
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<td>1467.85</td>
<td>Chinkeh</td>
<td>2.55</td>
<td>2.697</td>
<td>0.001</td>
<td>5.40</td>
<td>3.96E-05</td>
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</table>
Chinkeh – Mineralogy

Mineralogy in wt-%

TOC in wt-%

Tmax: 445-450°C

- Quartz
- Feldspars
- Carbonates
- Clays
Chinkeh – Pore Size Distribution

ECA Maxhamish d-48-B 094-O-11 - Mercury Intrusion Capillary Pressure

<table>
<thead>
<tr>
<th>Sample</th>
<th>Core Depth (m)</th>
<th>Formation</th>
<th>Density</th>
<th>Porosity (%)</th>
<th>Conformance Corrected Porosity (%)</th>
<th>Peak Range (nm)</th>
<th>Stem Volume Used %</th>
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<tbody>
<tr>
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<td>1466.95</td>
<td>Upper Chinkeh</td>
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<td>1467.85</td>
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<td>3.46</td>
<td>&lt;3 - 190</td>
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</table>

Low porosity, intermediate pore sizes
Chinkeh – Hydrocarbon Analysis

Broad mix of condensates

% Normalized Fractions Summary

Heavy Condensates

Biomarkers

Aromatics

Light Condensates

- b-49-J (1616.8)
- d-48-B (1467)
- d-48-B (1467.9)
- c-95-J (1505.6)
- c-95-J (1510.8)
- c-95-J (1514.2)
- a-64-B (1293.6)
- a-64-B (1295)
**Chinkeh – Geomechanics**

<table>
<thead>
<tr>
<th>Depth (m)</th>
<th>Confining Pressure (MPa)</th>
<th>Axial Strain at Failure (%)</th>
<th>Compressive Strength (MPa)</th>
<th>Residual Strength (MPa)</th>
<th>Static Young’s Modulus (GPa)</th>
<th>Static Poisson’s Ratio</th>
<th>Static Bulk Modulus (GPa)</th>
<th>Static Shear Modulus (GPa)</th>
<th>Strain Brittleness</th>
<th>Stress Brittleness</th>
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<td>31.64</td>
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<td>1478.76</td>
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<td>0.94</td>
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<td>0.14</td>
<td>19.79</td>
<td>18.50</td>
<td>0.10</td>
<td>0.67</td>
</tr>
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</table>

Values variable across formation
- Low Poisson’s ratio

Spl 1478.76 and 1473.5 had large release of energy at failure (high “stress brittleness”)

Spl 1478.76 showed a drop in stress prior to max load, indicating multiple failure events

Low to very high compressive strengths
Gas pool east of the oil leg is mature and depleted

More widely spaced gas wells to the south show:

– Generally low rates
– Transient radial flow (!!)
– Significant energy in area
Western oil leg:

- 5 vertical wells, exhibiting 10 years linear flow, no boundaries
- 8 horizontal wells (drilled 2010-2012) – linear flow, no boundaries
  - No record of fracturing, peak oil rates ~11m³/d
- Production appears not to be affected by gas wells
Horizontal wells have produced up to 7000m$^3$ oil with inefficient completions.

Suggests considerable upside for appropriate well design, including modern multi-stage fracturing.

Mapping indicates large potential oil fairway.
Chinkeh – Summary

Broad prospective fairway has potential to host large oil in place, although reservoir continuity is not firmly established

– Existing well control and outcrop correlations support large prospective area

Reservoir energy appears adequate for oil production; not depleted by gas production

Geomechanics indicate fracture propagation should be good, although initiation pressure may be relatively high

Considerable upside for economic oil production using modern drilling / completion techniques
Gas-prone source rocks limit oil prospectivity over many areas

A liquids-rich window in the Muskwa supports tight oil potential in overlying tight carbonate reservoirs like the Tetcho, but more work is required to establish Muskwa oil production

Halo and tight oil potential in the Charlie Lake in BC appears to be limited (but may exist in the Halfway)

The Gordondale has disappointed to date (in Alberta and BC), despite favourable organic richness and maturity

Chinkeh sandstones (and the underlying Toad/Grayling) in the Liard Basin may hold significant resource oil potential
IDENTIFICATION AND EVALUATION OF NEW RESOURCE OIL PLAYS, NEBC

Brad J. Hayes, Petrel Robertson
Raphael Wust, Trican Geological Solutions
Robert Bachman, CGG Geoconsulting
Jason S. Clarke, Petrel Robertson
Brent Nassichuk, Trican Geological Solutions