Arthur Creek “Hot Shale”: A Bakken Unconventional Oil Analogy in the Georgina Basin of Northern Territory, Australia*

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Abstract

The Southern Georgina Basin is a Neoproterozoic/Paleozoic basin located in the the Northern Territory, Australia. The Arthur Creek Formation is a Middle Cambrian coarsening-upward sequence comprised of dolomitic sands/silts, shales, dolomites and black anoxic “hot shale.” High Total Organic Carbon percentages (TOC’s) are reported from core data throughout the basin within the Arthur Creek. TOC’s from the “hot shale“ interval range from 3 to 16% and average on the order of 5.5% in the central part of the Southern Georgina Basin. The kerogen is predominantly Type II and is currently thermally oil mature. Porosity and permeability are on the order of 8 to 15% and 10 to 100 mD, respectively, in the dolomitic sand units that are encased in the organic-rich shale.

Live oil shows in the Arthur Creek are ubiquitous in the 18 exploratory wells drilled in the basin to-date. The basal “hot shale” unit of the Arthur Creek formation ranges up to 130 meters in thickness and has up to four sections of tight oil-stained sands/silts separated by high TOC% shale. The shale is both the trap and source of the light oil recovered to-date. Resource estimates for the Arthur Creek “hot shale” made by Ryder Scott range up to 9BBl recoverable.

The Devonian/Mississippian Bakken Formation of the Williston Basin is productive in fields in the northern USA and southeastern Saskatchewan. The Bakken ranges in thickness from 25 to 30 meters in the main play area in Saskatchewan, has TOC averaging 7% (14.2% maximum),and is part of a large carbonate ramp complex. The productive dolomitic silt/sand unit in the middle Bakken is usually less than 5 meters thick. Porosity and permeability in the Saskatchewan Bakken averages 4 to 8% and 0.01 to 0.20mD, respectively. Modern completion techniques that employ horizontal drilling and small multi frac stimulation programs have allowed the tight Bakken dolomitic sand/silt units to produce at rates averaging nearly 80bpd. The presence of overlying and underlying water wet units restrains the use of large fracs.
The extension of the production techniques pioneered in the Bakken in southeastern Saskatchewan to the Arthur Creek Formation in Australia are projected to allow for flow rates well in excess of those reported in Canada. The thicker and cleaner sands of the “hot shale” play in the Southern Georgina Basin should allow for larger frac stimulation programs than in the Bakken, and possibly production from vertical wells without the expense of horizontal drilling.

Selected References


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AAPG International Convention
September 14, 2010
Calgary, Alberta Canada

Paul J. Bennett (presenter), Peter Philipchuk, Annelise Freeman
Australia Energy Corp., Calgary, AB, Canada.
Southern Georgina Basin – Centralian Superbasin

- Neoproterozoic “sag” basin formed the locus for the deposition of thick Cambrian sediments in a restricted anaerobic environment.
- “Hot” black shales formed in a ramp setting in lower parts of the Cambrian section.
- Clastic and carbonate intercalations within the “Hot Shale” are potential Bakken-like reservoirs.

Neoproterozoic Sub-basins of the Great Centralian Superbasin, after P. Haines et al., 2001
The intracratonic Williston Basin is the setting for the deposition of the black radioactive ("Hot") Devonian/Mississippian Bakken Formation.
South Georgina Basin Northern Territory, Australia

Stratigraphy

Cambrian lithostratigraphy, southern Georgina Basin (Dunster, J.N., et al., 2007)
South Georgina Basin Northern Territory, Australia
Arthur Creek Formation

Well log based W-E cross section through the S. Georgina Basin showing the detail of the carbonate ramp setting implied by Dunster et al. (above).

Note the widespread nature of the “Hot Shale” unit in the Lower Arthur Creek Formation.
Log comparison Arthur Creek Fm, Australia and Devonian/Mississippian Bakken

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Bakken Fm. N. Dak</th>
<th>Arthur Cr. Hot Shale</th>
</tr>
</thead>
<tbody>
<tr>
<td>Porosity (Ave)</td>
<td>4%-8%</td>
<td>8%-15%</td>
</tr>
<tr>
<td>Permeability (Ave)</td>
<td>0.01-0.20 mD</td>
<td>10-100 mD</td>
</tr>
<tr>
<td>Thickness</td>
<td>26 meters</td>
<td>95 meters</td>
</tr>
<tr>
<td>TOC Max</td>
<td>13.9% (7% Min)</td>
<td>14.2% (5% Ave.)</td>
</tr>
<tr>
<td>Resistivity Peak</td>
<td>1,000 ohms</td>
<td>10,000 ohms</td>
</tr>
<tr>
<td>Source</td>
<td>AAPG Vol 93. Sonnenberg &amp; Pramudito</td>
<td>JN Dunster, PD Kruse, ML Duffett and GJ Ambrose</td>
</tr>
</tbody>
</table>

Arthur Creek “Hot Shale” is 4 to 5 times thicker than the Bakken in SE Saskatchewan
Log Comparison – Arthur Creek & Bakken
Petrophysical Hot Shale Evaluation: Baldwin Well

By J. Hogan, B.J. Services, Calgary

- Ductile
- Brittle

Crossover: Neutron-Density
Tracking: Neutron Sonic
Thermal Maturity Comparison

Major structural elements of the Bakken Fm. Bakken $T_{\text{Max}}$ in light blue. Chen, Z., et al., 2009

$T_{\text{Max}} = \text{approx. } 450^\circ\text{C}$

Overall average $T_{\text{Max}}$ from wells. Dunster, J.N., et al., 2007

$T_{\text{max}}$ average maximum = approx. $460^\circ\text{C}$ within basin section
Arthur Creek “Hot Shale” Thickness

Seismic interpretation of “Hot Shale” thickness – implies thickness > 100m

Isopach from well and seismic data – implies thickness > 50 m
## Arthur Creek “Hot Shale” TOC%

<table>
<thead>
<tr>
<th>Source Rock</th>
<th>Ave TOC (%)</th>
<th>Age</th>
<th>Lithology</th>
<th>Kerogen Type</th>
<th>BOE (x 10⁹)</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>Arthur Creek Hot Shale</td>
<td>&gt; 5.0</td>
<td>Middle Cambrian</td>
<td>shale sandstone</td>
<td>I, II</td>
<td>937</td>
<td>Ryder Scott Report (Sept. 2009)</td>
</tr>
<tr>
<td>AEC Lands</td>
<td>Max. 14.2</td>
<td></td>
<td>siltstone</td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>Southern Georgina Basin</td>
<td></td>
<td></td>
<td>dolomite shoals</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Bakken Shale</td>
<td>8.0 - 10.0***</td>
<td>Devonian Mississippian</td>
<td>shale sandstone</td>
<td>I, II**</td>
<td>200 - 400*</td>
<td>***Peters &amp; Co. (2009)</td>
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<tr>
<td><strong>Mississippian</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>*Manoyan, J.M., &amp; Frodl, M.G.</td>
</tr>
<tr>
<td><strong>sandstone</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>(2009)</td>
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<td><strong>siltstone</strong></td>
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<td></td>
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<td><strong>dolomite shoals</strong></td>
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<tr>
<td>Niger Delta</td>
<td>2.6</td>
<td>Cenozoic</td>
<td>shale</td>
<td>II</td>
<td>25 100</td>
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<tr>
<td><strong>Kimmeridgian 'hot' Shale - Brent</strong></td>
<td>&gt; 6</td>
<td>Jurassic - Cretaceous</td>
<td>shale</td>
<td>II</td>
<td>54 000</td>
<td>after, Dunster, J.N., et al. (2007)</td>
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<td>NW European shelf</td>
<td></td>
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<tr>
<td>Hanifa and Tuwaig Mountain</td>
<td>3</td>
<td>Upper Jurassic</td>
<td>shale</td>
<td>II</td>
<td>57 000</td>
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<td>Arabian/Iranian Basin</td>
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<td>Smackover-Tamman</td>
<td>2 - 4</td>
<td>Upper Jurassic</td>
<td>shale</td>
<td>II, III</td>
<td>21 300</td>
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<td>Gulf of Mexico</td>
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<tr>
<td>Brown-Duwi Member, Sudr Fm</td>
<td>2.6</td>
<td>Upper Cretaceous</td>
<td>uraniferous limestone</td>
<td>II</td>
<td></td>
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<td>Red Sea Basin</td>
<td></td>
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<tr>
<td>Qusaiba 'hot' Shale</td>
<td>4.1</td>
<td>Silurian</td>
<td>shale</td>
<td>II</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Arabian Peninsula</td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>Proven source rock</td>
<td>0.47</td>
<td>various including Cambrian</td>
<td>carbonate rocks</td>
<td>II, III</td>
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<tr>
<td>Russian Platform</td>
<td>1.37</td>
<td>Cambrian</td>
<td>shale</td>
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</tbody>
</table>

Comparison of world class source rocks with the high TOC% levels of the South Georgina Basin “Hot Shale “ zone. Rich and widespread source potential. Max TOC% -- 14.2 %
Core Photos Arthur Creek “Hot Shale”

Notes by Presenter:
Hot Shale is laminated, there is an abrupt transition from the Thortonian carbonates to the Hot Shale
Core Play Area

- **Southern Georgina Basin** (Northern Territory Australia)
- EP 103, 104, 127 & 128 (13.9 million acres)
- **50% W.I.**
- Under-explored Palaeozoic basin
- World class rich Cambrian age source rocks (>5%TOC)
- Huge Un-risked, Undiscovered, Best Prospective (Recoverable) Oil Resources (gross acreage):
  - Unconventional oil shale prospects **8.9 BBL**
  - Conventional Carbonate ramp prospects **2.4 BBL**
- Relatively close to infrastructure and oil and gas market (paved roads to Alice Springs)
- Low (onshore) exploration costs
- Shallow target depth 600-1,200 meters
Summary – Georgina Basin

• Untapped oil reservoirs in Cambrian-aged rocks
• Analogous to the North American Bakken Formation
• Carbonate and clastic reservoirs – ductile / brittle sandwich ideal for fracture treatment
• Oil/Wet gas mature
• Potential recoverable resources (p50) of 9 Billion barrels in the “Hot Shale” – Ryder Scott 2009