Unlocking potential for unconventional petroleum resources in the frontier greater McArthur Basin, NT

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Overview

• Basin overview – greater McArthur Basin
• Petroleum Exploration History
• Conventional to Unconventional Thought
• Legacy Data and Newly Acquired Data
• DIP 014 dataset release
• Application of New Data
• Moving Forward in data compilation
The greater McArthur Basin

- The greater McArthur Basin is a regional correlation between the existing Palaeo- to Mesoproterozoic McArthur and Birrindudu basins.

- Approximate area within the Northern Territory is 550,000 km$^2$ in the northern section of the NT, extending through to QLD and WA borders and to the Tomkinson Province in the south.

- Overlain by Neoproterozoic and Phanerozoic basins.
Stratigraphy of the greater McArthur Basin

WILTON PACKAGE – ROPER GROUP

- Bukalara Sandstone
- Hayfield Mudstone
- Jamison Sandstone

- Bukelokami Sandstone
- Kyalla Formation
- Sherwin Formation
- Moroak Sandstone
- Velkerri Formation
- Bessie Creek Sandstone

- Corcoran Formation
- Hodgson Sandstone
- Jalbri Formation
- Arnold Sandstone
- Crawford Formation
- Mainoru Formation
- Limmen Sandstone
- Mantungula Formation

Abner Sandstone

Northern Territory Government

AGES2015
Stratigraphy of the greater McArthur Basin

GLYDE PACKAGE – McARTHUR GROUP
Stratigraphy of the greater McArthur Basin

REDBANK PACKAGE
- TAWALLAH GROUP
Petroleum Exploration History

- Intermittent exploration since the 1960’s, increased interest through the 1980-90’s.
- Exploration was for conventional trap and seal style targets for hydrocarbons.
- Information gains on source rock geochemistry, identifying five potential source rock units in the southern McArthur Basin.

- An example of middle Velkerri Formation shale intersected in BMR Urapunga 3, (drilled 1985).
Unconventional Petroleum Exploration History

- Mid-2000’s interest turned to shale gas potential, riding on the successes of shale gas and oil developments in the USA

- 2007 Shenandoah-1 is drilled, followed by a deepening and fracture-stimulation in 2010 as Shenandoah-1A. This targeted the organic carbon-rich middle Velkerri Formation and flared gas. Proven active petroleum system present

- How much of this potential can be revealed by studying legacy cores?
Greater McArthur Basin Legacy Data

- 2822 data points from 71 open file cores have been interrogated.

- Mostly basic source rock analysis.

- Limited data exists from X-ray diffraction, gas chromatography, kerogen analysis, porosity, permeability, maturity analyses.

- Vertical sample spacing very large, up to 20m between intervals.
Basin wide sampling on legacy cores

Sampling program:

- 649 additional sample points from 44 wells
- Mainly Roper Group, limited sampling from the Tawallah Group and Limbunya Group
- Specifically targeting the shales for source rock and reservoir properties
- A wealth of information contained minerals holes
Digital Information Package: DIP 014

- DIP 014: shale resource data from the greater McArthur Basin.
- MS Excel format
- Contains 3700 datapoints encompassing:
  - TOC & Programmed Pyrolysis
  - Shale Rock Properties
  - XRD Data
  - Elemental Kerogen Data
  - Whole Rock Geochemistry

- No interpretation of the results contained in the dataset

DIP014 is now available at the Dept. of Mines and Energy booth!
Results coming for addition to the dataset include:

- 195 CHONS elemental kerogen analyses, incorporating Fe and organic Sulfur content analysis
- 192 XRD Bulk and Clay fraction analyses
- 20 GC biomarker analyses
- 10 Shale Rock Properties analyses
- 8 Mechanical rock properties analyses – Young’s modulus and Poisson’s ratio.
- 30 Whole rock geochemistry analyses
Minimum requirements for high volume shale gas systems

- TOC >2% (non-residual organic carbon)
- Maturity over 1.1%, under 3.5%
- Over-pressedured (>0.45 psi/ft)
- Brittle mineral content >40%, clay mineral content <30%
- Air porosity over 2%, permeability over $0.1 \times 10^{-3}$ mD
- Effective thickness of organic–rich shale over 30-50 m

Adapted from Zou (2013)
Desirable qualities for shale gas systems

Desirable properties of the shale source rock:

- Type I, II or IIs kerogen (marine/lacustrine)

- S1 >2 mg HC/g rock
  - Free hydrocarbons present in rock

- S2 >10 mg HC/g rock
  - Potential to generate hydrocarbons if buried deeper

- Sand-rich facies within the shales
  - High micro-fracture content in quartz
Total Organic Carbon

- TOC needs to be at least 2% for gas generation in economic quantity
Total Organic Carbon

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Total Organic Carbon

• TOC needs to be at least 2% for gas generation in economic quantity
2D TOC mapping

- 2D subsurface mapping of the Kyalla Formation TOC content based on legacy reported data
- Incorporation of new data into grid in 2015
- Sub-surface mapping to be incorporated into 3D structural model
- TOC, maturity isotherms, mineral tenacity, euxinia/anoxia facies mapping, isopach thickness maps to be derived from dataset

2D sub-surface map of maximum TOC of the Kyalla Formation in the Beetaloo sub-basin area.
Mineralogy of the shales

- Brittle mineral content (quartz, carbonates, feldspars) over 40%
- Clay mineral content under 30%

Sample numbers (n =) are low
Mineralogy of the shales

- Sample numbers (n =) are low

Average mineralogy (wt%) of the Velkerri Formation middle

- Brittle mineral content (quartz, carbonates, feldspars) over 40%
- Clay mineral content under 30%

n = 66
Mineralogy of the shales

- Brittle mineral content (quartz, carbonates, feldspars) over 40%
- Clay mineral content under 30%
- Sample numbers (n =) are low
Mineralogy of the shales

- **Brittle mineral content** (quartz, carbonates, feldspars) over 40%
- **Clay mineral content** under 30%

- **Sample numbers** ($n =$) are low

**Average mineralogy (wt%) of the Kyalla Formation**

- **Clays**: 44%
- **Carbonates**: 43%
- **Quartz**: 11%
- **Other**: 2%

$n = 14$
Mineralogy of the shales

- Brittle mineral content (quartz, carbonates, feldspars) over 40%
- Clay mineral content under 30%
- Sample numbers (n =) are low

Average mineralogy (wt%) of the Mainoru Formation

- Clays: 60%
- Carbonates: 31%
- Quartz: 9%
- Other: 0%

n = 14
Mineralogy of the shales

- Brittle mineral content (quartz, carbonates, feldspars) over 40%
- Clay mineral content under 30%

Sample numbers (n =) are low
Mineralogy of the shales down hole

Walton 2 mineralogy by weight %

>30% CLAY

Velkerri Formation - middle
Mineralogy of the shales

HyLogger results can provide increased resolution to infill the gaps between XRD sampling, deriving the tenacity of the shales through mineral composition.
Mineralogy of the shales

Velkerri Formation

Sample Depth m

412
422.9
423
423.4
Maturity 1.1% to 3.5%

Histogram of Velkerri Formation calculated vitrinite reflectance equivalence values

Formula computation from (Jarvie et al, 2001)
Maturity 1.1% to 3.5%

- Challenge of maturity data in Proterozoic basins
- Bituminite and alginate reflectance can yield some excellent direct measurement data
- Most calculations used to derive equivalent values are based on data for younger sediments.
- Sulfur content affects maturation of kerogens, eg Monterey Shale in the USA has generated low-maturity oils at 0.35% Ro due to presence of high-sulfur kerogens.
How are the shales comparing?

<table>
<thead>
<tr>
<th>Formation</th>
<th>TOC weight %</th>
<th>S1 mg HC/g rock</th>
<th>S2 mg HC/g rock</th>
<th>Clay mineral %</th>
<th>Brittle mineral %</th>
</tr>
</thead>
<tbody>
<tr>
<td>Chambers River Formation n = 24</td>
<td>0.35%</td>
<td>0.01</td>
<td>0.03</td>
<td>0%</td>
<td>100%</td>
</tr>
<tr>
<td>Hayfield Mudstone n = 2</td>
<td>0.12%</td>
<td>0.12</td>
<td>0.18</td>
<td>no data</td>
<td>no data</td>
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<tr>
<td>Kyalla Formation n = 442</td>
<td>1.25%</td>
<td>0.56</td>
<td>3.36</td>
<td>43%</td>
<td>57%</td>
</tr>
<tr>
<td>Velkerri Formation upper n = 346</td>
<td>1.12%</td>
<td>0.73</td>
<td>2.26</td>
<td>43%</td>
<td>57%</td>
</tr>
<tr>
<td>Velkerri Formation middle n = 803</td>
<td>3.69%</td>
<td>2.01</td>
<td>9.54</td>
<td>26%</td>
<td>74%</td>
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<tr>
<td>Velkerri Formation lower n = 314</td>
<td>0.75%</td>
<td>0.31</td>
<td>0.89</td>
<td>40%</td>
<td>60%</td>
</tr>
<tr>
<td>Corcoran Formation n = 155</td>
<td>0.28%</td>
<td>0.03</td>
<td>0.09</td>
<td>no data</td>
<td>no data</td>
</tr>
<tr>
<td>Mainoru Formation n = 27</td>
<td>0.26%</td>
<td>0.47</td>
<td>0.70</td>
<td>60%</td>
<td>40%</td>
</tr>
</tbody>
</table>

* TOC = Total Organic Carbon  
** S1 free hydrocarbons present in shale  
*** S2 hydrocarbons cracked from kerogen by heating to 600°C
Moving forward

• Data still to come:
  • 572 further data points
  • High-end geochemistry and mechanical rock properties
  • Focus moving to Favenc and Glyde Packages of the McArthur Basin and equivalents

• Products:
  • Organic Geochemistry dataset
  • XRD mineral dataset
  • Elemental Kerogen dataset
  • Porosity and Permeability dataset
  • Summary report and data interpretation on Roper Group and equivalents
References:

THANKS FOR YOUR ATTENTION!