Cooper Basin Unconventional Gas Prospectivity

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Acknowledgements:
3D Geo, Andrew Murray, Andrew Stacey, Bruce Radke, Jim Preston, Russell Korsch, Sandy Menpes, Steve le Poidevin and many more…
Cooper Basin

- Australia’s largest onshore conventional gas and oil producer (Queensland, South Australia)
- Infrastructure: pipelines to East Coast gas market/Gladstone LNG
- Increase in unconventional hydrocarbon exploration over the last 5 years
- Permian targets: shale gas, basin centred gas, deep coal seam gas plays
- Unconventional gas resources potential across all basin remains poorly defined
Project Aims

Review of basin geology and petroleum systems elements, focusing on unconventional gas plays in the Permian

1. Review of regional basin architecture:
   • Structure surfaces, isopachs, lithofacies

2. Evaluation of Permian source rocks:
   • Source distribution, type, quality, maturity

3. Predict the possible extent of Permian unconventional gas plays:
   • Play fairway / chance of success maps

- Improve understanding of basin scale prospectivity
- Australia petroleum source rock mapping study
- Underpin future resource assessment studies
Structural Elements & Tectono-stratigraphy
Cooper Basin Unconventional Gas Plays

Continuous Gas Play types:
- Basin centred gas
- Shale gas
- Deep coal seam gas

➢ Gidgealpa Gp composite resource play

Basin centred gas accumulation +/- shale +/- deep coal seam gas +/- natural fracture play (Menpes et al., URTec, 2013)
## Selection Criteria for Defining Continuous Gas Plays

<table>
<thead>
<tr>
<th>Typical US Shale Gas Play</th>
<th>Typical US Tight Gas Play</th>
<th>Typical Deep Coal Gas Play</th>
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<tr>
<td>• TOC &gt; 2 %; Type II marine kerogen</td>
<td>• Source rock</td>
<td>• Coal thickness?</td>
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<tr>
<td>• Net shale thickness &gt; 15-20 m</td>
<td>• Net reservoir thickness &gt;100 m</td>
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<td>• Overpressured (&gt;0.45 psi/ft)</td>
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Unconventional Gas Prospectivity Cooper Basin – APPEA 2015
## Selection Criteria for Defining Continuous Gas Plays

### Typical US Shale Gas Play
- TOC > 2%; Type II/IIIs marine kerogen
- Net shale thickness > 15 - 20 m
- Maturity: vitrinite reflectance > 1.1%; < 3.5%
- Gas in matrix/organic storage ✓
- Overpressured (>0.45 psi/ft) ✓
- Relatively low water saturation ✓

### Typical US Tight Gas Play
- Source rock
- Net reservoir thickness >100 m
- Maturity: vitrinite reflectance > 0.8%
- Low permeability matrix (< 0.1 mD) ✓
- Abnormal pressure (mostly overpressure) ✓
- Relatively low water saturation ✓

### Typical Deep Coal Gas Play
- Coal thickness ?
- Maturity ?
- Other factors (e.g. permeability)?

> Remains poorly defined!
### Selection Criteria for Defining Continuous Gas Plays

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| • Maturity: vitrinite reflectance > 1.1 %; < 3.5 % ? | • Maturity: vitrinite reflectance > 0.8% ? | • Other factors (e.g. permeability) ?
| • Gas in matrix/organic storage ✓ | • Low permeability matrix (< 0.1 mD) ✓ | ✓ Remains poorly defined! |
| • Overpressured (>0.45 psi/ft) ✓ | • Abnormal pressure (mostly overpressure) ✓ | |
| • Relatively low water saturation ✓ | • Relatively low water saturation ✓ | |

> What screening criteria should be applied to the Cooper Basin?
Basin Architecture

- Regional update of key structure surfaces and isopachs
- Better integration of datasets across the state border
- Update to incorporate new public domain well picks (April, 2015) and seismic interpretation
Formation Isopachs

- Further strat review of Weena Trough underway (SA)

- Toolachee/ Patchawarra Fms thickest and most extensive units.

- Wider extent than previously mapped in QLD

Formation Thickness (m)

- Toolachee Fm
  - ~280m max thick
  - Halifax 1

- Daralingie Fm
  - ~130m max thick
  - Halifax 1

- Roseneath Shale
  - ~240m max thick
  - Halifax 1

- Epsilon Fm
  - ~195m max thick
  - Moonta ST1

- Murteree Shale
  - ~90m max thick
  - Holdfast 1

- Patchawarra Fm
  - >680m max thick
  - Kirby 1
**Lithofacies**

**Inputs:**
- SA: Sun and Camac (2004) electrofacies mapping, with updated coal thicknesses
- QLD: new electrofacies maps consistent SA methodology

**Results**
- Sand, silt, shale, coal isoliths & isopachs
- Toolachee, Daralingie, Epsilon & Patchawarra Fms

- **Net source thickness** (coal/shale)
- **Net reservoir thickness**

**Toolachee Formation**

**Patchawarra Formation**

**Net thickness by lithology by formation**

**Net Thickness By Lithofacies (m)**

- 0 - 2
- 2 - 5
- 5 - 10
- 10 - 15
- 15 - 20
- 20 - 30
- 30 - 40
- 40 - 50
- 50 - 70
- 70 - 100
- 100 - 150
- 150 - 200
- 200 - 300
- 300 - 400
- 400 - 500
- 500 - 700
- 700 - 1000
- 1000 - 1500
- 1500 - 2000
- 2000 - 3000
- 3000 - 4000
- 4000 - 5000
- 5000 - 7000
- 7000 - 10000
- 10000 - 15000
- 15000 - 20000
- 20000 - 30000
- 30000 - 40000
- 40000 - 50000
- 50000 - 70000
- 70000 - 100000
- 100000 - 150000
- 150000 - 200000
- 200000 - 300000
- 300000 - 400000
- 400000 - 500000
- 500000 - 700000
- 700000 - 1000000
Source Rock Analysis

• Geochemical data analysis:
  • Source amount and distribution (TOC maps by formation)
  • Source quality and oil vs gas potential (HI, kerogen type)
• Compilation/ QC of source rock geochemistry data (TOC, Rock Eval, vitrinite reflectance).
• New sampling – changes in source rock characteristics with maturity

➢ Australia petroleum source rock mapping study
Source Rock Distribution

- TOC maps by formation and lithology: good – excellent source potential (TOC > 2%)
- Highest TOCs associated with the Toolachee and Patchawarra coals and coaly shales
- Source rock with remaining generation potential (TOC > 2%; S1+S2 > 3 mg/gRock)

Source rocks with remaining generation potential are abundant at multiple intervals across the basin

Toolachee Coals
Patchawarra Coal
Roseneath Shale
Toolachee Shale/coaly shale
Patchawarra Shale/coaly shale
Murteree Shale

Present day TOC

TOC %
- Poor < 2
- Good - excellent

RE Data: remaining HC generation potential

TOC %
- 2 - 3
- 3 - 5
- 5 - 7
- 7 - 10
- 10 - 20
- 20 - 30
- 20 - 30
- 30 - 40
- 40 - 50
- 50 - 70
- > 70
Source Rock Characterisation

- Coals - shales
- TOCs: 2 – 80%; HI > 250 mg/gC
- Kerogen type II/III (non-marine) - Good gas to oil + gas source potential

- “Shales”
- TOC: 2 - 12 %; HI’s < 200 mg/gC
- Kerogen type III/IV (non-marine) - Gas prone

- Shales
- TOC: 2-12 %; HI > 300-500 mg/gC
- Kerogen type II, and some Type I (marine)

Toolachee/ Patchawarra coals and shales are the best quality source rocks, not the Roseneath/ Murteree ‘shales’
Kinetics for Petroleum Generation & Oil/ Gas Windows

- Cooper basin kinetics (Malhstedt et al., in press).
  - Consistent with Pepper and Corvi DE – F (Type II/III - IV)
  - Potential for late primary gas generation
- Adsorption exerts a major control on ratio of oil vs gas expelled
- Cooper specific maturity windows

<table>
<thead>
<tr>
<th>Cooper Basin</th>
<th>Barnett Shale (Jarvie et al., 2005)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Vr</td>
</tr>
<tr>
<td>Early oil</td>
<td>0.75 - 0.9</td>
</tr>
<tr>
<td>Peak oil</td>
<td>0.9 - 1</td>
</tr>
<tr>
<td>Late oil</td>
<td>1 – 1.3</td>
</tr>
<tr>
<td>Wet gas</td>
<td>1.3 - 2</td>
</tr>
<tr>
<td>Dry gas</td>
<td>2 – 3.5</td>
</tr>
<tr>
<td>Over-mature</td>
<td>&gt; 3.5</td>
</tr>
</tbody>
</table>

➢ Later onset of oil and gas generation compared with US shales
Maturity Modelling

- Multi-1D basin modelling study in progress
- 91 1D models. Calibration: corrected temperatures, vitrinite reflectance etc.
- Source characteristics based on lithofacies, geochem evaluation (original TOC and HI)

- Large areas of the key source rock intervals are gas mature
Cooper Basin Unconventional Gas Plays

- Tight gas/ deep coal gas plays are more important than the shale gas plays:
  - thicker, more extensive intervals
  - contain larger amounts of better quality source rocks

- For quick screening, we will apply the composite resource gas play model (Menpes et al., 2013).
Selection Criteria for Defining Continuous Gas Plays

**Typical US Shale Gas Play**
- TOC > 2%; Type II/ IIIs marine kerogen ✓
- Net shale thickness > 15-20 m ✓
- Maturity: vitrinite reflectance > 1.1%; < 3.5% ✓
- Gas in matrix/organic storage ✓
- Overpressured (>0.45 psi/ft) ✓
- Relatively low water saturation ✓

**Typical US Tight Gas Play**
- Source rock ✓
- Net reservoir thickness >100 m ✓
- Maturity: vitrinite reflectance > 0.8% ✓
- Low permeability matrix (< 0.1 mD) ✓
- Abnormal pressure (mostly overpressure) ✓
- Relatively low water saturation ✓

**Typical Deep Coal Gas Play**
- Coal thickness ✓
- Maturity ✓
- Other factors ✓
- Remains poorly defined!

➢ What screening criteria should be applied to the Cooper Basin?
Selection Criteria for Defining Continuous Gas Plays

**Cooper Shale Gas Play**
- TOC > 2%; ✓ Type III non-marine kerogen ✓
- Net shale thickness > 15-20 m ✓
- Maturity: vitrinite reflectance > 1.3%; < 3.5% ✓
- Gas in matrix/organic storage ✓
- Overpressured (>0.45 psi/ft) ✓
- Relatively low water saturation ✓

**Cooper Tight Gas Play**
- Source rock ✓
- Net reservoir thickness >100 m ✓
- Maturity: vitrinite reflectance > 0.8% ✓
- Low permeability matrix (< 0.1 mD) ✓
- Abnormal pressure (mostly overpressure) ✓
- Relatively low water saturation ✓

**Cooper Deep Coal Gas Play**
- Coal thickness > 5m ✓
- Maturity vitrinite reflectance > 1.3%; < 3.5% ✓
- Other factors – still to be considered

> Most criteria are met BUT
> Adjustments to the shale gas selection criteria required to account for differences in kerogen type.
> Selection criteria for deep dry coal gas need to be defined.
Gidgealpa Gp Composite Resource Play (Gas)

Play elements missing:
- Reservoir permeability
- Seal quality
- Migration distance
- Overpressure
+ uncertainty due to variable data quality/level of knowledge across the basin
Conclusions

• Plenty of good quality, mature source rock across the basin.
• Main source rocks are the Toolachee and Patchawarra coal and coaly shales: not the Roseneath and Murteree shales.
• The composite gas resource play fairway shows there is potential for significant amounts of unconventional accumulations in the Permian section across the basin.
• Cooper shales are different from typical US examples so application of US analogues requires more careful consideration
• Next steps: move away from COS maps by play type, towards a modelling approach which maps the distribution and amounts of hydrocarbons generated/ expelled.

➢ Highlights the significance of the Cooper Basin as a world class unconventional gas province.
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