Petroleum Systems Modelling for Petroleum Prospectivity Analysis in the Cooper Basin, Australia

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Cooper Basin

- Australia’s largest onshore conventional gas and oil producer
- Unconventional exploration targets: shale gas, basin centred gas, deep coal seam gas plays
- Principal source rocks: Permian coals and coaly shales of the Gidgealpa Group
- Mapping the petroleum generation potential of these source rocks, together with describing the resulting fluid composition, is critical for understanding the hydrocarbon prospectivity of the basin
Project Aims

• To use basin and petroleum systems modelling as a tool to investigate the petroleum prospectively of Permian source rocks in the Cooper Basin.

• Workflow:
  • Basin architecture and evolution:
    – 3D regional basin model (structure surfaces, isopachs, lithofacies)
  • Source rock geochemistry:
    – Source distribution, thickness, type, quality, kinetics
  • Integrated basin and petroleum systems modelling:
    – Maturity maps, source rock yield, oil and gas generation potential

➤ Improve understanding of basin scale hydrocarbon prospectivity
➤ Underpin future resource assessment studies
Structural Elements & Tectono-stratigraphy
Cooper Basin Source Rocks

10 key Permian source rocks:
- Toolachee Fm coal
- Toolachee Fm coaly shale
- Daralingie Fm coal
- Daralingie Fm coaly shale
- Roseneath Shale
- Epsilon Fm coal
- Epsilon Fm coaly shale
- Murteree Shale
- Patchawarra Fm coal
- Patchawarra Fm coaly shale
Regional 3D Basin Model

- Cooper Basin structure surfaces and isopachs:
  - Better integration of datasets across the state border
  - Incorporation of new open file well picks and seismic interpretation

- Eromanga and Lake Eyre Basin surfaces:
  - Modeled from existing seismic interpretation and well picks

- Unconformities (with uplift and erosion)
  - Based on existing studies; consistent with regional tectonic evolution

- Stratigraphic ages:
  - Updated to GTS 2012, inclusion of revised spore pollen zone ages
Source Rock Distribution

- Source rock extent and gross formation thickness from 3D model.
- Toolachee/ Patchawarra Fms thickest and most extensive units.
- Daralingie, Roseneath, Epsilon and Murteree restricted to the southern part of the basin.
Source Rock Net Thickness

- Toolachee, Daralingie, Epsilon and Patchawarra Formations mixed lithology
- SA: Sun and Camac (2004) electrofacies mapping, with updated coal thicknesses
- QLD: new electrofacies maps consistent SA methodology
Source Richness

- Present day TOC maps by lithology:
  - Coal: average TOC ~ 70%
  - Shales and coaly shales: TOC maps formation.

- Good – excellent source potential across all formations (TOC> 2%)

- Highest TOCs associated with the Toolachee and Patchawarra coaly shales

- Original HI and TOC maps also generated for input into the petroleum systems modelling

**Present day TOC (%)**

<table>
<thead>
<tr>
<th>TOC (%)</th>
<th>Legend</th>
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<tr>
<td>0 - 0.5</td>
<td>0 - 0.5</td>
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<tr>
<td>0.6 - 1</td>
<td>0.6 - 1</td>
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<tr>
<td>1.1 - 2</td>
<td>1.1 - 2</td>
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<td>2.1 - 3</td>
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<td>3.1 - 4</td>
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<td>5.1 - 7</td>
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<td>7.1 - 10</td>
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<td>60.1 - 70</td>
<td>60.1 - 70</td>
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<tr>
<td>70.1 - 100</td>
<td>70.1 - 100</td>
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Source Characterisation

- Coals/ coaly shales. TOCs: 2 – 80%; (coals > 50%)
- HI > 250 mg/gC (little variation by lithology – highest HI values found in coals)
- Kerogen type II/III (non-marine) - Good gas to oil + gas source potential.
- Toolachee, Daralingie, Epsilon and Patchawarra formations show similar source characteristics

- “Shales”. TOC: 2 - 12 %;
- HI’s < 200 mg/gC
- Kerogen type III/IV (non-marine) - Gas prone
- No “sweet” lacustrine shales observed
Source Rock Kinetics

- Cooper basin kinetics (Malhstedt et al., 2015).
  - Consistent with Pepper and Corvi DE – F (Type II/III – IV; non-marine)
  - Potential for late primary gas generation
- Calibration with natural maturity sequence from new sampling

Malhstedt et al. (2015) GA Record
Download from www.ga.gov.au
Expulsion/ Retention & Oil/ Gas Windows

- Petroleum retained: free + adsorbed
  - Arco model (includes saturation of organic and inorganic porosity)
  - Calibration with observed data (BI vs Ro)
  - Need to better understand adsorption in coals
- Cooper specific maturity windows

<table>
<thead>
<tr>
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<th>Cooper Basin</th>
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<tbody>
<tr>
<td>Ro (%)</td>
<td>Tmax (°C)</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>
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Burial and Thermal History Modelling Set Up

- 1D models for > 90 wells
- Model setup:
  - Thermal boundary conditions: transient heat-flow from base lithosphere.
  - Crustal thickness and radiogenic heat production properties from published studies
- Model calibration:
  - Present day corrected temp. and maturity indicators (Ro, Tmax) (all wells).
  - Lithology calibration: velocity, density, thermal conductivity (key wells)
- Integration with 3D basin model to generate maturity maps
Maturity Modelling Results

- Major variation in thermal history between depocentres.
- Key influences: Big Lake Suite Granodiorites, Late Cretaceous uplift and erosion, thermal blanketing effect of thick Permian coals.

Windorah Trough (Marengo-1)

Nappamerri Trough (Burley-2)
Hydrocarbon Generation

- Integration with source rock properties and 2-component kinetics => hydrocarbons generated

![Map showing hydrocarbon generation in the Cooper Basin]

Total hydrocarbons generated from the Permian Gidgealpa Group

HCs Generated (Mmboe/km²)

- Toolachee Fm
- Daralingie Fm
- Roseneath Shale
- Epsilon Fm
- Murteree Shale
- Patchawarra Fm

Total hydrocarbons generated from the Permian Gidgealpa Group

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Petroleum Systems Modelling for Play Analysis in the Cooper Basin – AAPG ICE 2015
Hydrocarbons Generated by Source Rock

No distinction is made for HCs adsorbed vs expelled.

Total Hydrocarbons generated from the Permian Gidgealpa Group > 2x10^6 MMboe
Fluids Expelled/ Retained & GOR

- Test case: Patchawarrra Formation coals
- GOR: instantaneous/ in situ fluid vs cumulative expelled
- Need to calibrate with observed data

Outputs modified depending on the play type being assessed

Work in progress – Patchawarrra coal
Conclusions

• Map of cumulative hydrocarbons generated from all Gidgealpa Gp source rocks highlights the broad extent of the source kitchen

• Largest contribution from Toolachee and Patchawarra coals and coaly shales.

• Results show the importance of BPSM as a predictive tool for understanding the regional petroleum resource potential.

• Work in progress:
  • improve expulsion models to map hydrocarbons expelled and retained, along with fluid composition
  • application of Monte Carlo simulations to capture model uncertainty
Please visit us at the following locations:

• Basin Modeling Poster Session, Wed 10am - # P20
• Australian Government Petroleum Booth - # 529

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