Petroleum Systems Modelling for Unconventional Play Analysis in the Cooper Basin, Australia*

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Abstract

The Cooper Basin is a late Carboniferous - Middle Triassic intracratonic basin in north-eastern South Australia and south-western Queensland. The basin is currently Australia's premier onshore hydrocarbon producing province and hosts a range of unconventional gas play types, including the extensive basin-centred and tight gas accumulations in the Permian Gidgealpa Group, deep dry coal seam gas associated with the Patchawarra and Toolachee formations, as well as the shale gas plays in the Murteree and Roseneath shales. This study uses petroleum systems modelling as a tool to investigate the prospectivity of each unconventional gas play type across the basin. Existing published structure surfaces were updated to incorporate new seismic and well data interpretations and combined into a regional 3D basin model, ensuring seamless data integration across the state border. All publicly-available total organic carbon (TOC) and RockEval data were compiled and used to review source rock distribution and quality, demonstrating the abundance of viable source rock intervals across the basin. Cooper Basin-specific kinetic relationships allowed the estimation of oil and gas windows. All datasets were integrated into a multi-1D petroleum systems model, which was calibrated using vitrinite reflectance and corrected temperature for 90 wells. Petroleum system model outputs, including thermal maturity and hydrocarbon generation, expulsion and retention maps by source interval, were then

used to characterise possible play fairway extents for each play type. The hydrocarbon generation maps and play fairway areas for the basin centred gas and deep dry coal seam gas plays of the Toolachee and Patchawarra formations highlight that these play types are both more extensive and more prospective than the Roseneath and Murteree shale gas plays. However, the overlapping nature of all three play types makes it more convenient to consider them collectively as a composite Gidgealpa Group unconventional gas play. The composite Gidgealpa Group gas play fairway map shows that the Nappamerri and Allunga troughs are highly prospective, along with the deepest areas of the Patchawarra and Arrabury troughs. Results also indicate prospectivity potential for unconventional gas further to the northeast, including areas of the Windorah Tough and Ullenbury Depression, consistent with recent drilling results. Further potential may exist in shallower coal plays outside the composite resource play area.

References Cited

Mahlstedt, N., R. di Primio, B. Horsfield, and C.J. Boreham, 2015, Multi-component Kinetics and Late Gas Potential of Selected Cooper Basin Source Rocks: Geoscience Australia, Canberra, Record 2015/19, 193 p. dx.doi.org/10.11636/Record.2015.019

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Australian Government
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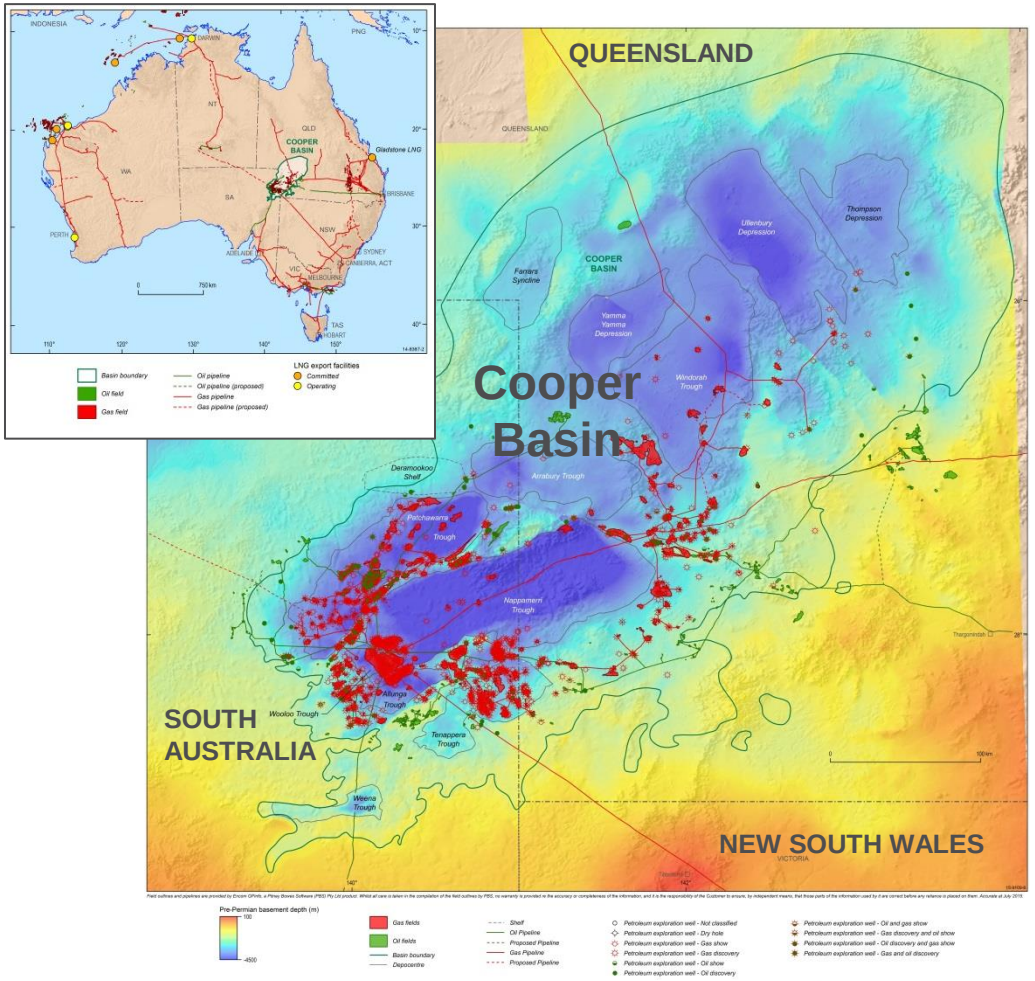
Cooper Basin

- 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



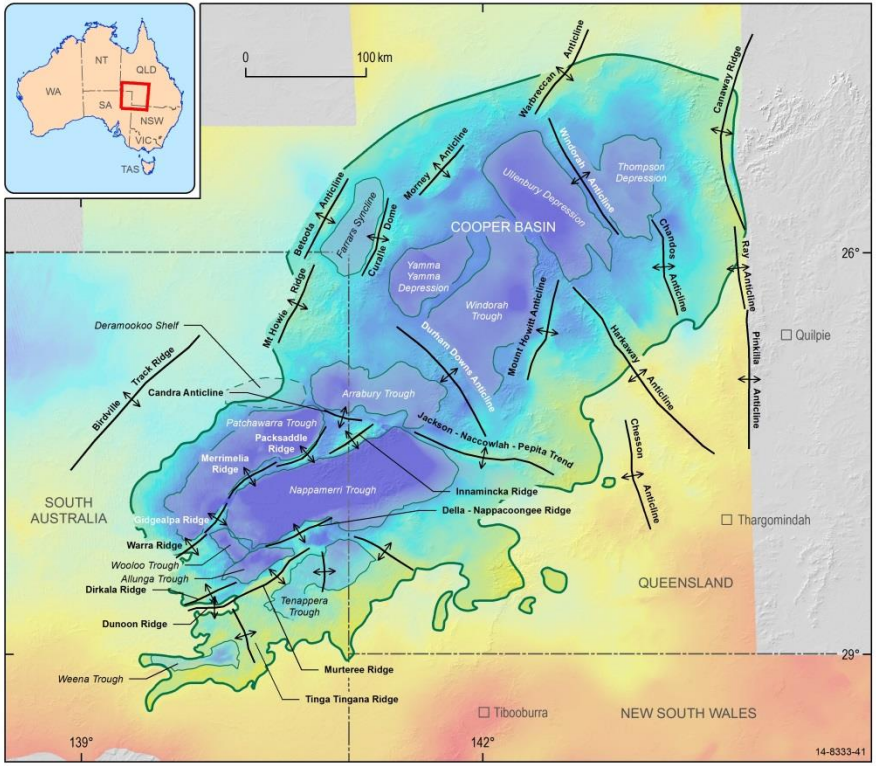
Project Aims

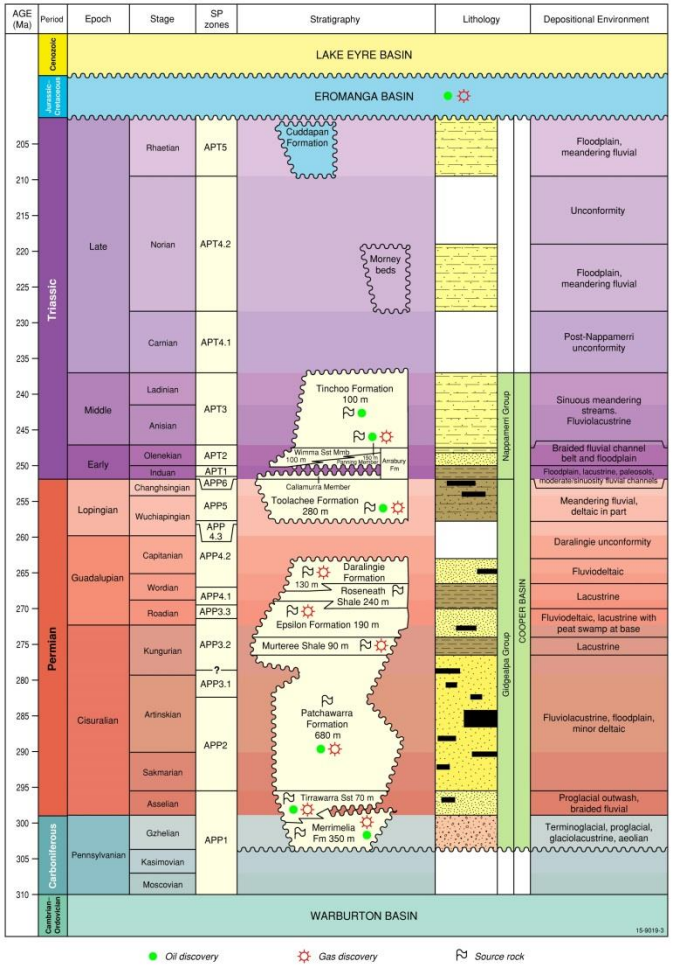
- To use basin and petroleum systems modelling as a tool to investigate the petroleum prospectively of Permian source rocks in the Cooper Basin.
- Workflow:
  - Basin architecture and evolution:
    - 3D regional basin model (structure surfaces, isopachs, lithofacies)
  - Source rock geochemistry:
    - 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 hydrocabon prospectivity**

➢ **Underpin future resource assessment studies**

Structural Elements & Tectono-stratigraphy

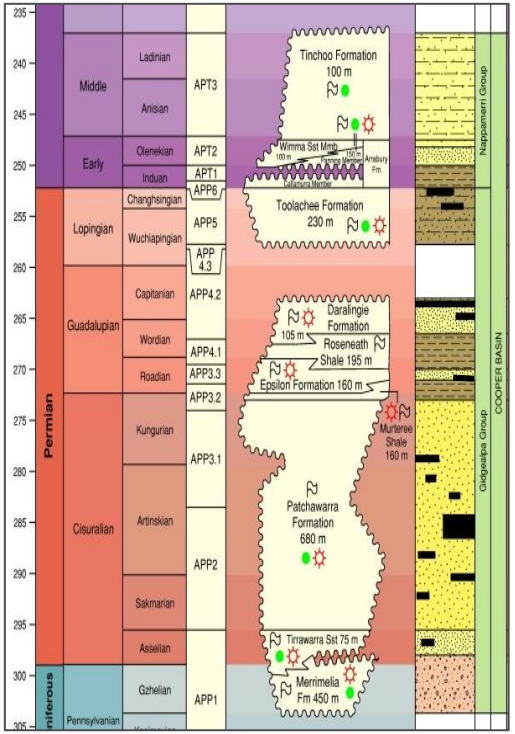


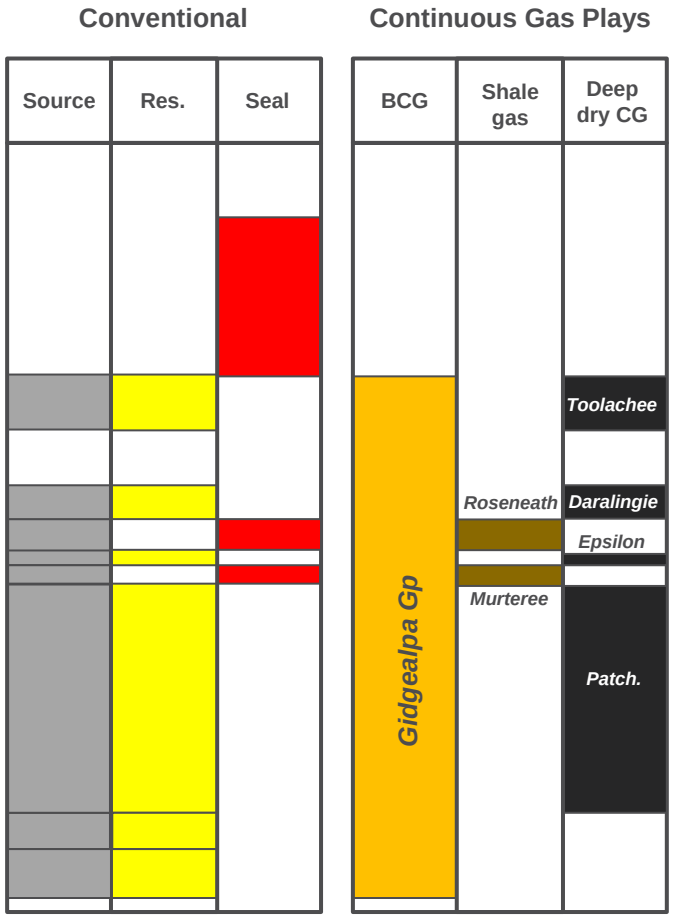


Cooper Basin Source Rocks

10 key Permian source rocks:

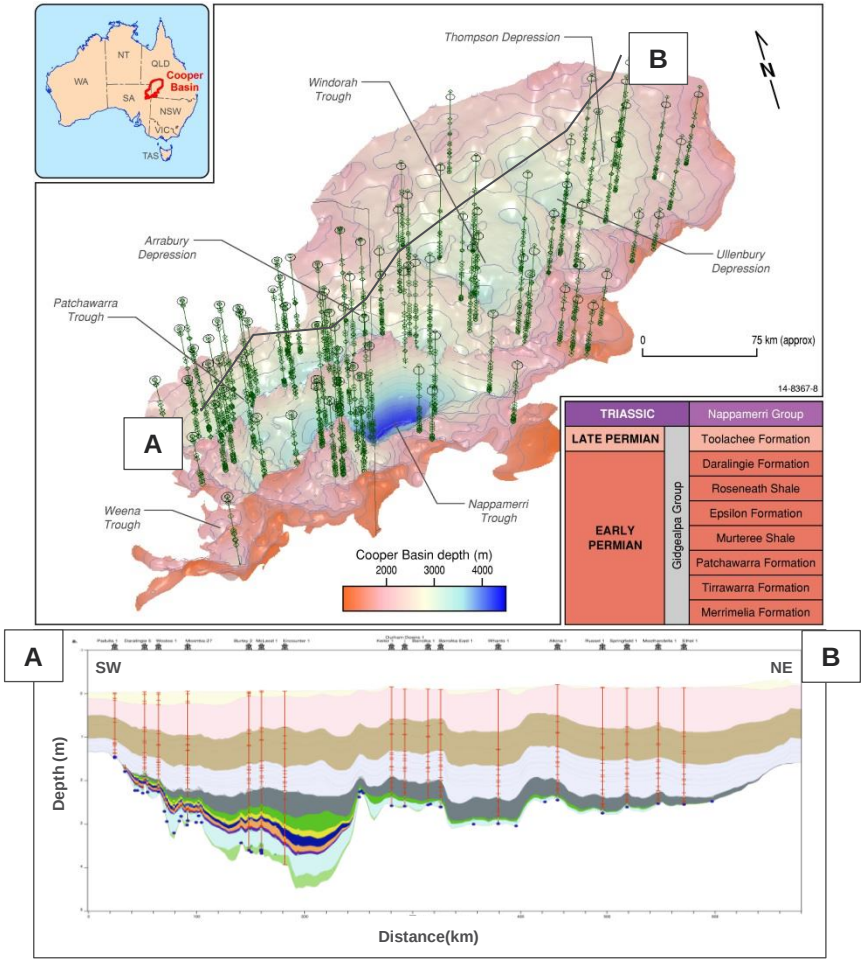
- Toolachee Fm coal
- Toolachee Fm coaly shale
- Daralingie Fm coal
- Daralingie Fm coaly shale
- Roseneath Shale
- Epsilon Fm coal
- Epsilon Fm coaly shale
- Murteree Shale
- Patchawarra Fm coal
- Patchawarra Fm coaly shale





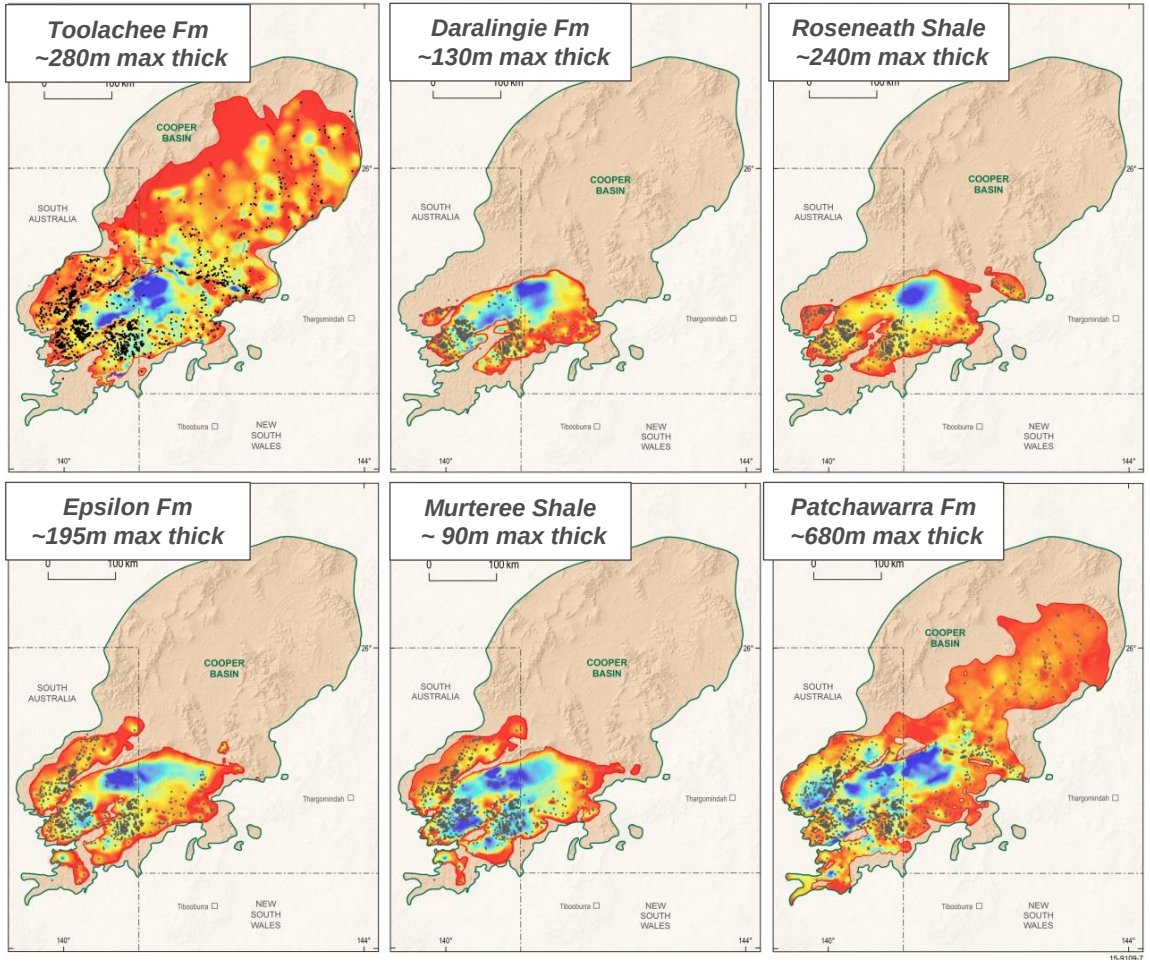
Regional 3D Basin Model

- 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



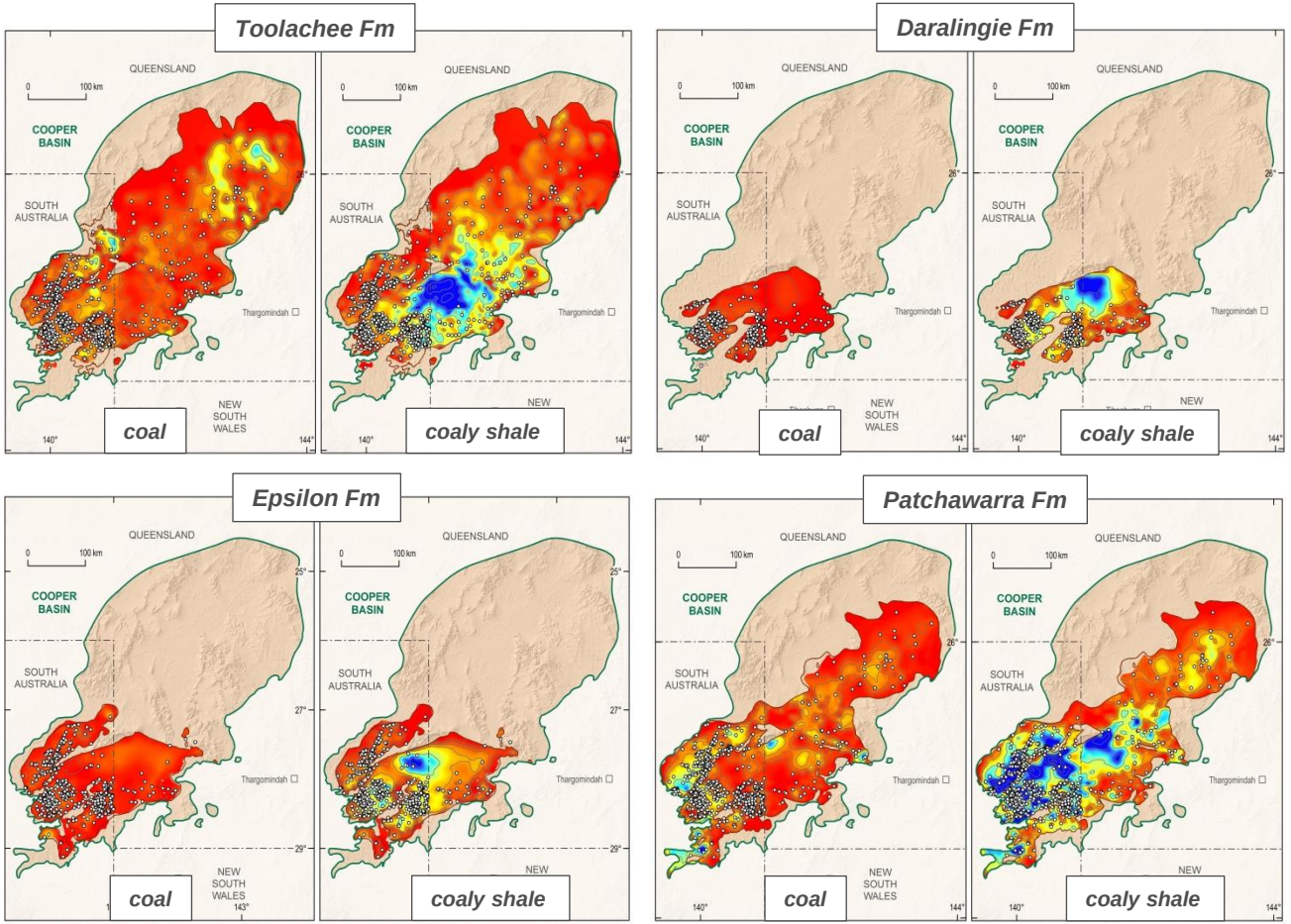
Source Rock Distribution

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



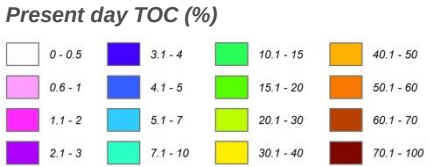
Source Rock Net Thickness

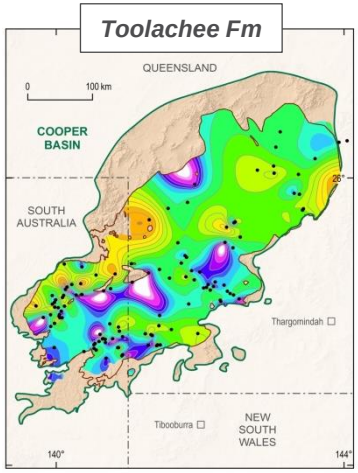
- Toolachee, Daralingie, Epsilon and Patchawarra Formations mixed lithology
- SA: Sun and Camac (2004) electrofacies mapping, with updated coal thicknesses
- QLD: new electrofacies maps consistent SA methodology

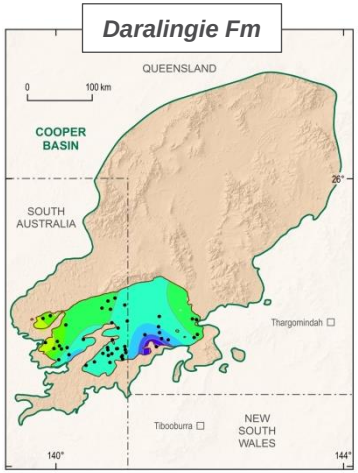


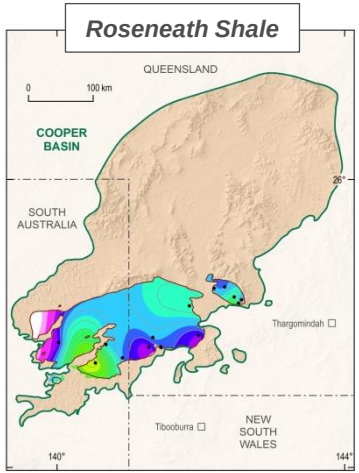
Source Richness

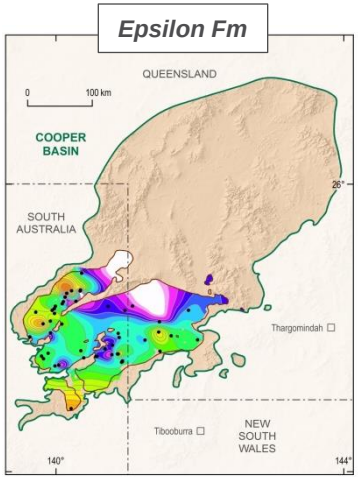
- Present day TOC maps by lithology:
  - Coal: average TOC ~ 70%
  - Shales and coaly shales: TOC maps formation.
- Good – excellent source potential across all formations (TOC> 2%)
- Highest TOCs associated with the Toolachee and Patchawarra coaly shales
- Original HI and TOC maps also generated for input into the petroleum systems modelling

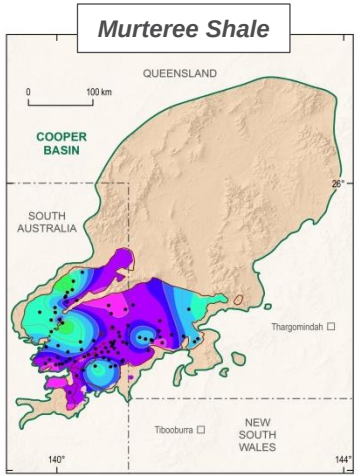


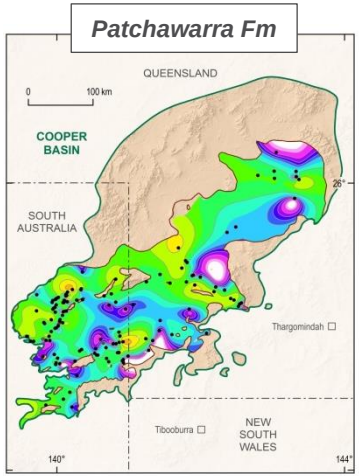






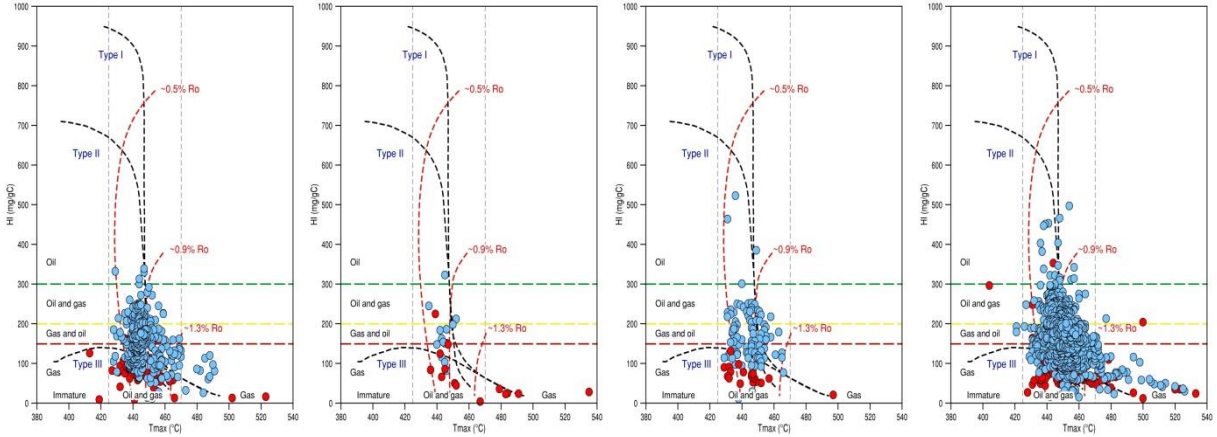




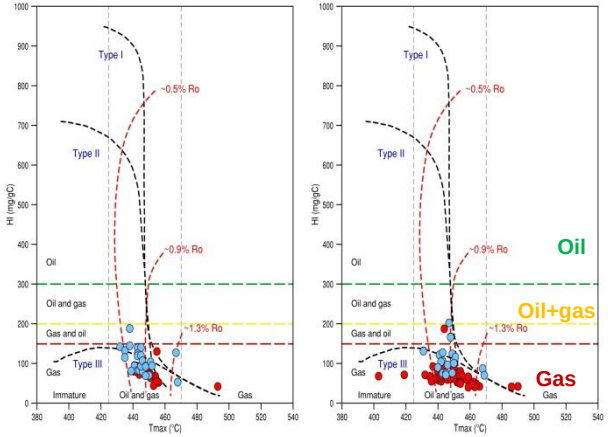


Source Characterisation

Toolachee Fm | Daralingie Fm | Epsilon Fm | Patchawarra Fm



Roseneath Shale | Murteree Shale



- 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**

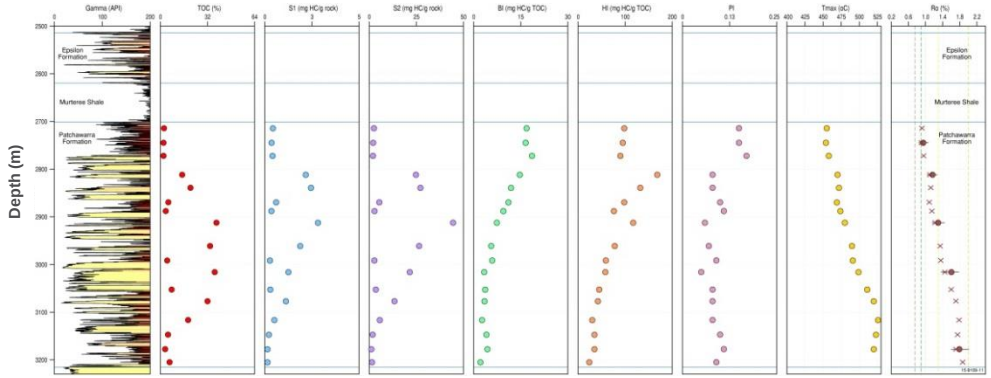
- "Shales". TOC: 2 - 12 %;
- HI's < 200 mg/gC
- Kerogen type III/IV (non-marine) - Gas prone
- **No "sweet" lacustrine shales observed**

Source Rock Kinetics

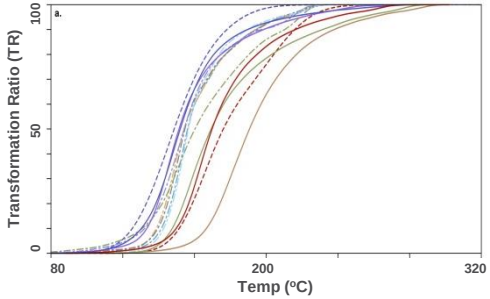
- Cooper basin kinetics (Malhstedt et al., 2015).
  - Consistent with Pepper and Corvi DE – F (Type II/III – IV; non-marine)
  - Potential for late primary gas generation
- Calibration with natural maturity sequence from new sampling

Malhstedt et al. (2015) GA Record
Download from www.ga.gov.au

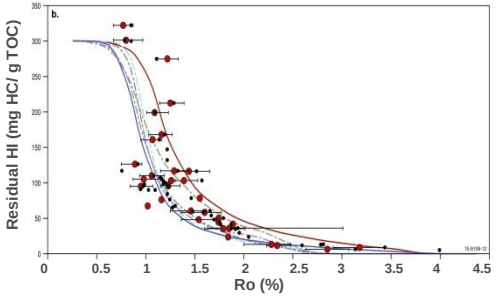
Down well geochemical and maturity profile: new sampling in Allunga Trough -1, SA



Bulk kinetics



Natural maturity sequence (HI vs Ro)



Malhstedt et al. (2015)
- *Toolachee Formation (Vintage Crop 1)*
- *Roseneath Shale (Battunga 1)*
- *Murteree Shale (Wancoocha 1)*
- *Patchawarra Formation (Forge 1)*
- *Patchawarra Formation (Gidgealpa 6)*

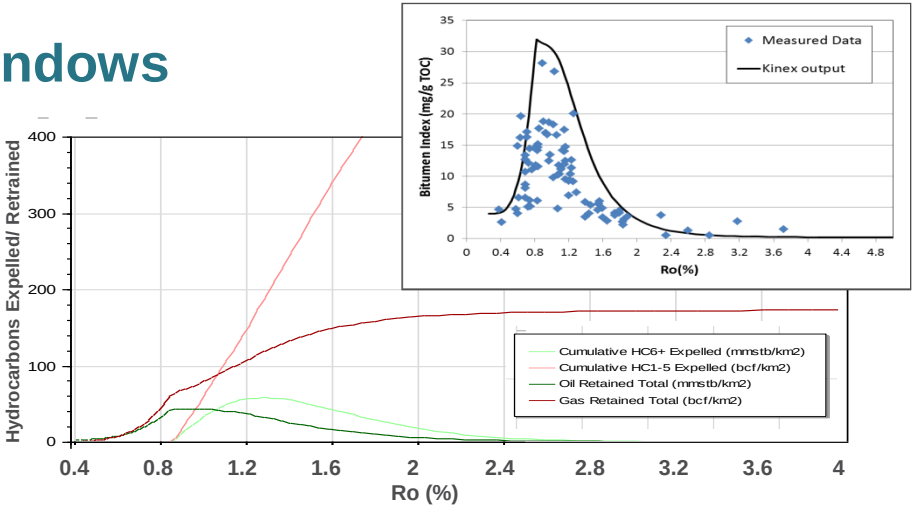
Deighton et al. (2003)
- *Toolachee Formation (Jackson 1C)*
- *Murteree Shale (Murteree 1C)*
- *Patchawarra Formation coal (Gidgealpa 6)*
- *Patchawarra Formation shale (Gidgealpa 6)*
- *Patchawarra Formation coal (Tinga Tingana 1)*
- *Patchawarra Formation shale (Tinga Tingana 1)*

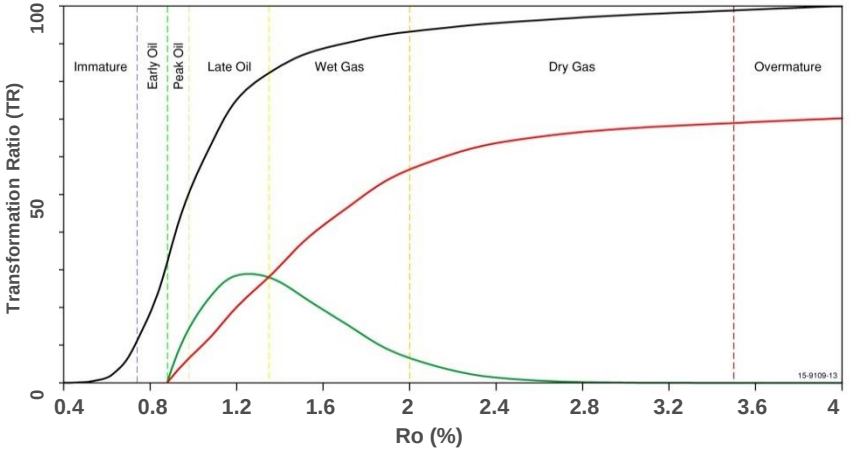
Pepper and Corvi (1995)
- *Organofacies DE*
- *Organofacies F*

- *Natural maturity sequence - measured Ro (%)*
- *Natural maturity sequence - calculated Ro (%) from Tmax*

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

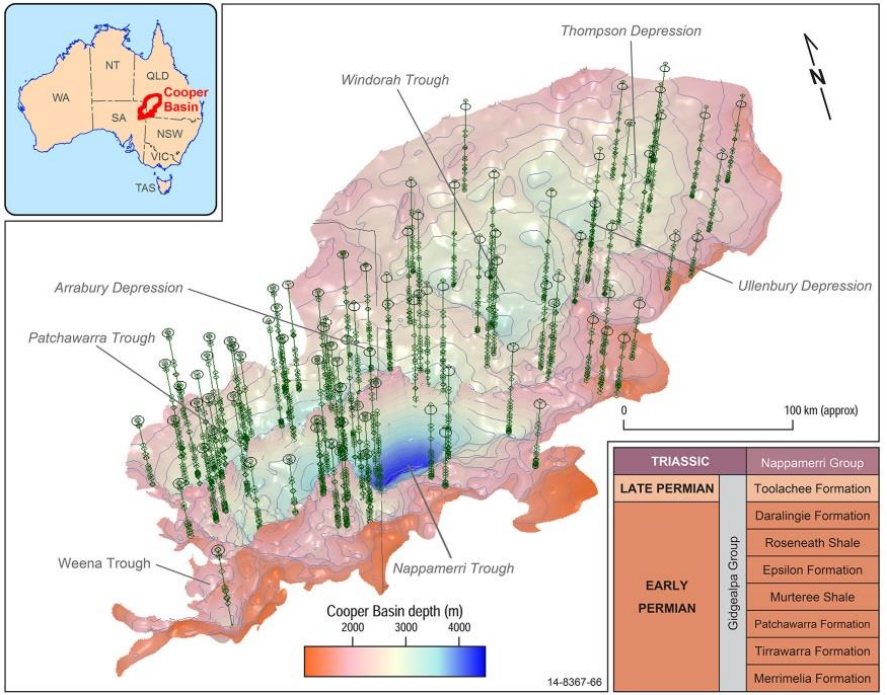




	Cooper Basin	
	Ro (%)	Tmax (°C)
Early oil	0.75 - 0.9	435 - 445
Peak oil	0.9 - 1	445 - 455
Late oil	1 – 1.3	455 - 475
Wet gas	1.3 - 2	475 - 530
Dry gas	2 – 3.5	530 - 650
Over-mature	> 3.5	> 650

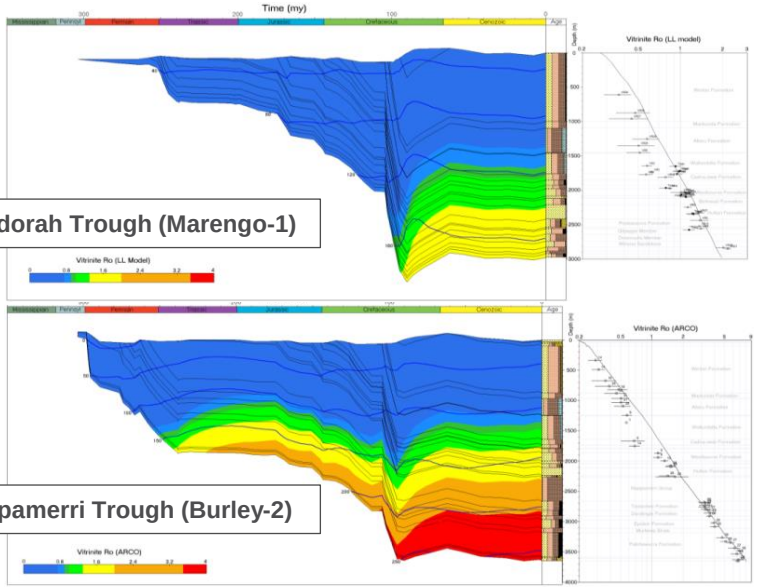
Burial and Thermal History Modelling Set Up

- 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



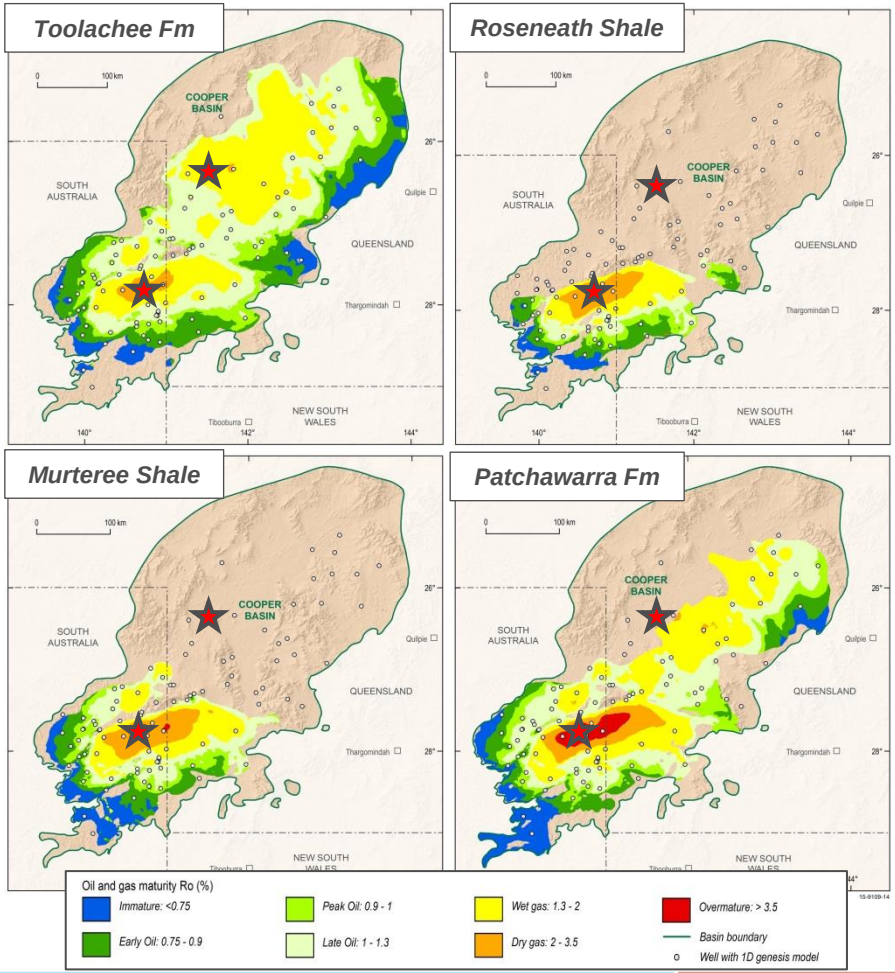
Maturity Modelling Results

- 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.



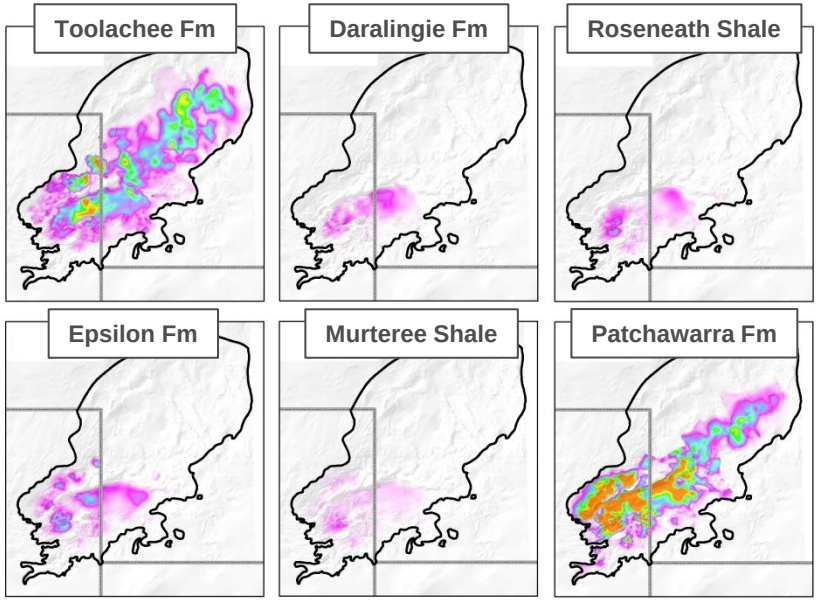
Windorah Trough (Marengo-1)

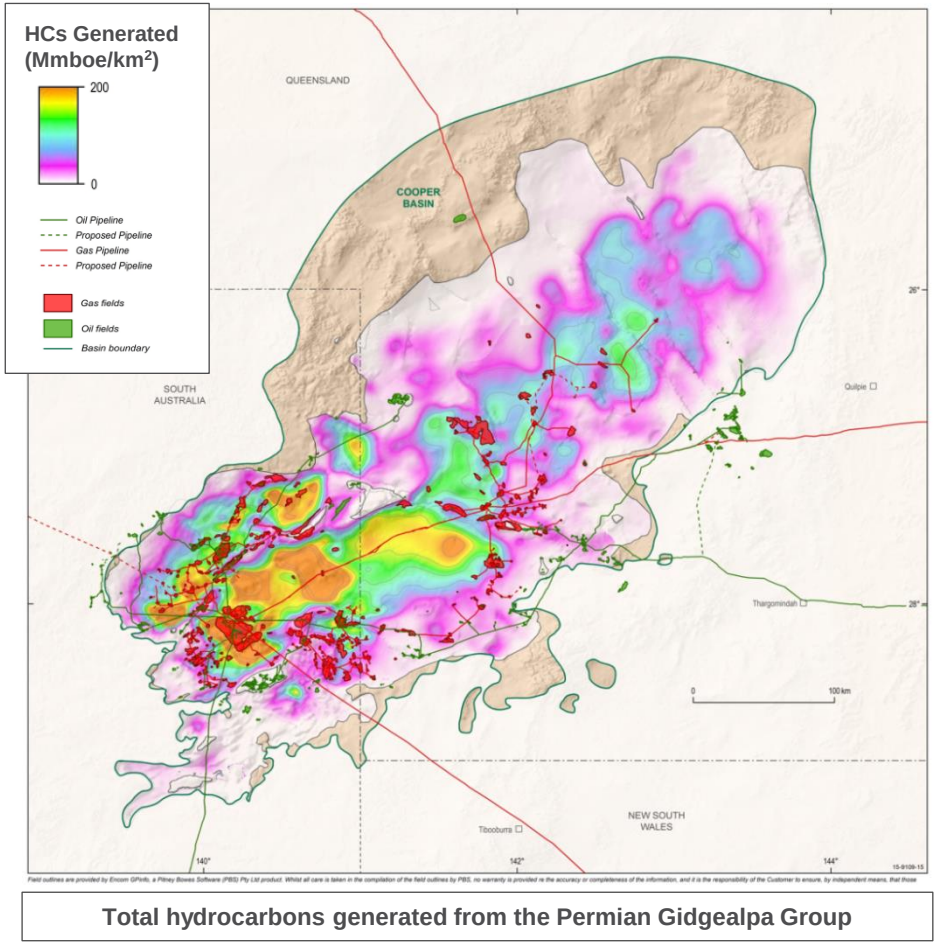
Nappamerri Trough (Burley-2)



Hydrocarbon Generation

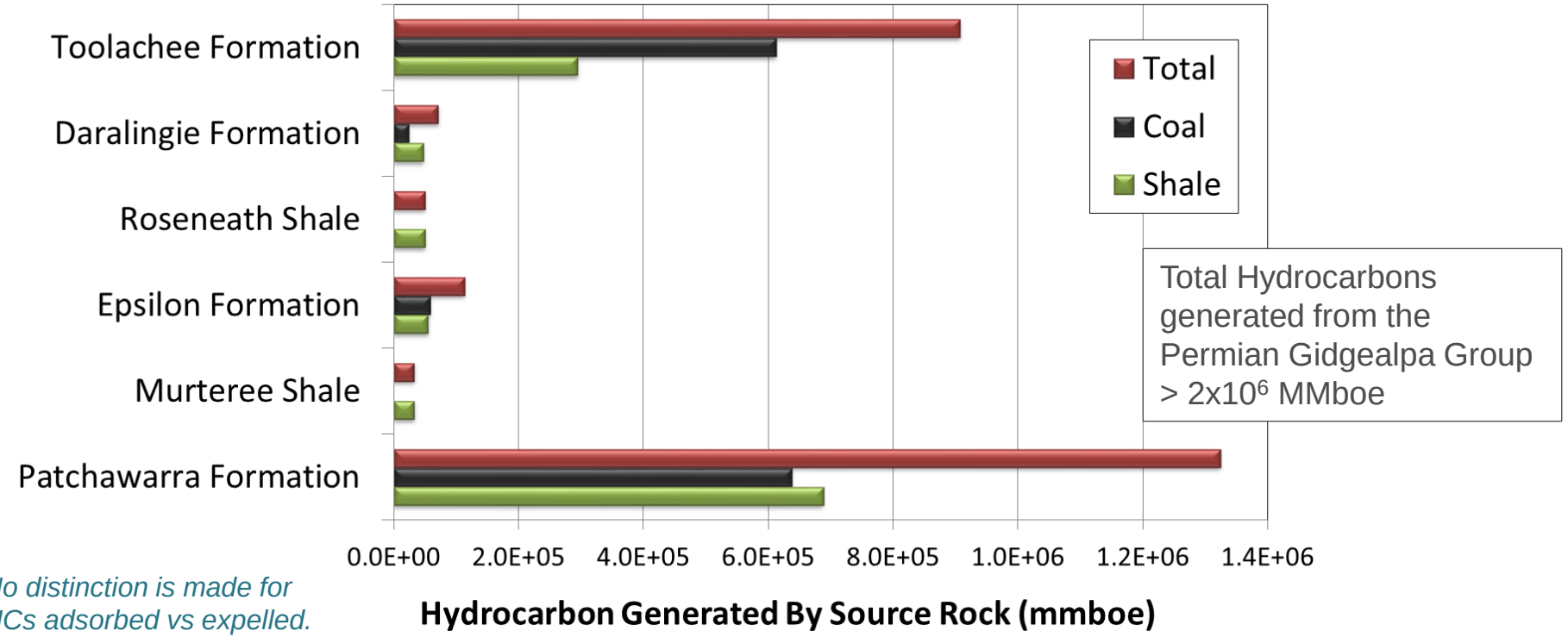
- Integration with source rock properties and 2-component kinetics => hydrocarbons generated





Total hydrocarbons generated from the Permian Gidgealpa Group

Hydrocarbons Generated by Source Rock

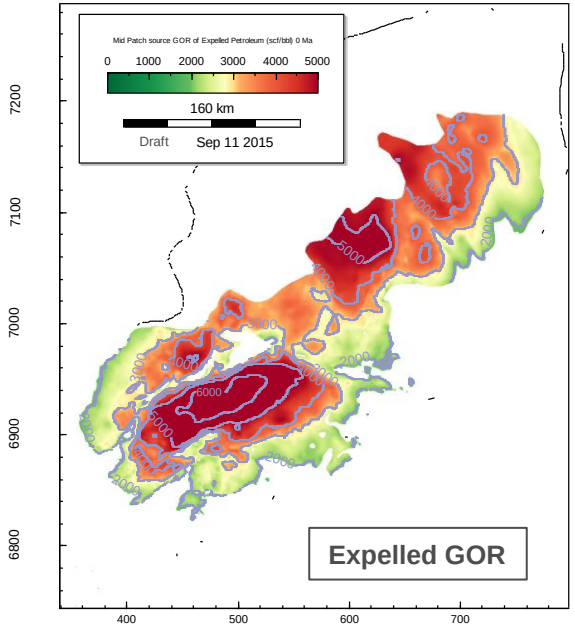


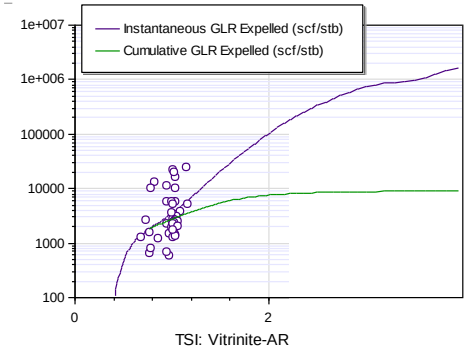
Total Hydrocarbons generated from the Permian Gidgealpa Group > $2x10^6$ MMboe

No distinction is made for HCs adsorbed vs expelled.

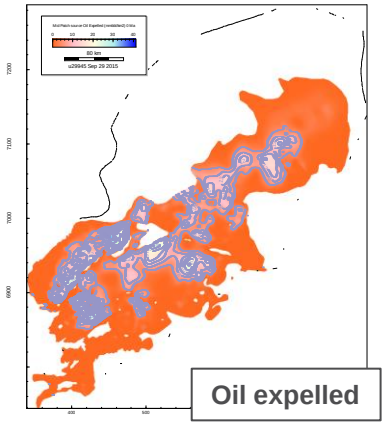
Fluids Expelled/ Retained & GOR

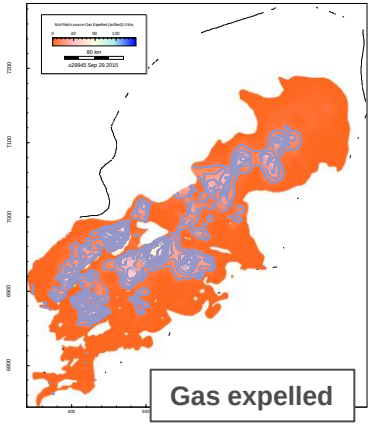
- Test case: Patchawarra Formation coals
- GOR: instantaneous/ in situ fluid vs cumulative expelled
- Need to calibrate with observed data

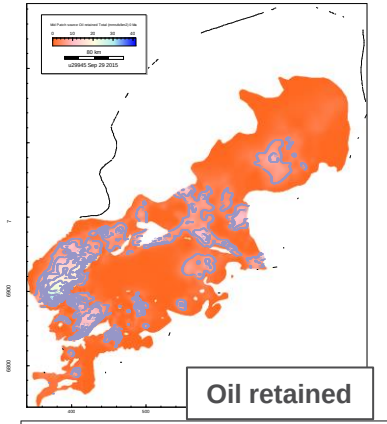


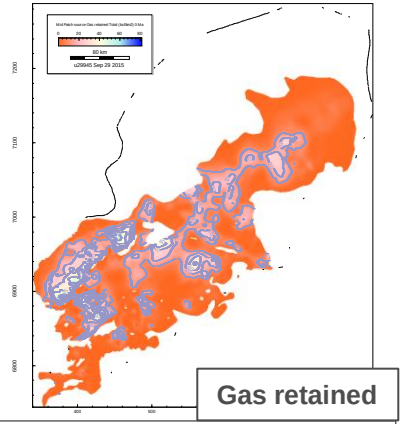


Outputs modified depending on the play type being assessed









Work in progress – Patchawarra 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