Australian Government

BIOREGIONAL ASSESSMENTS

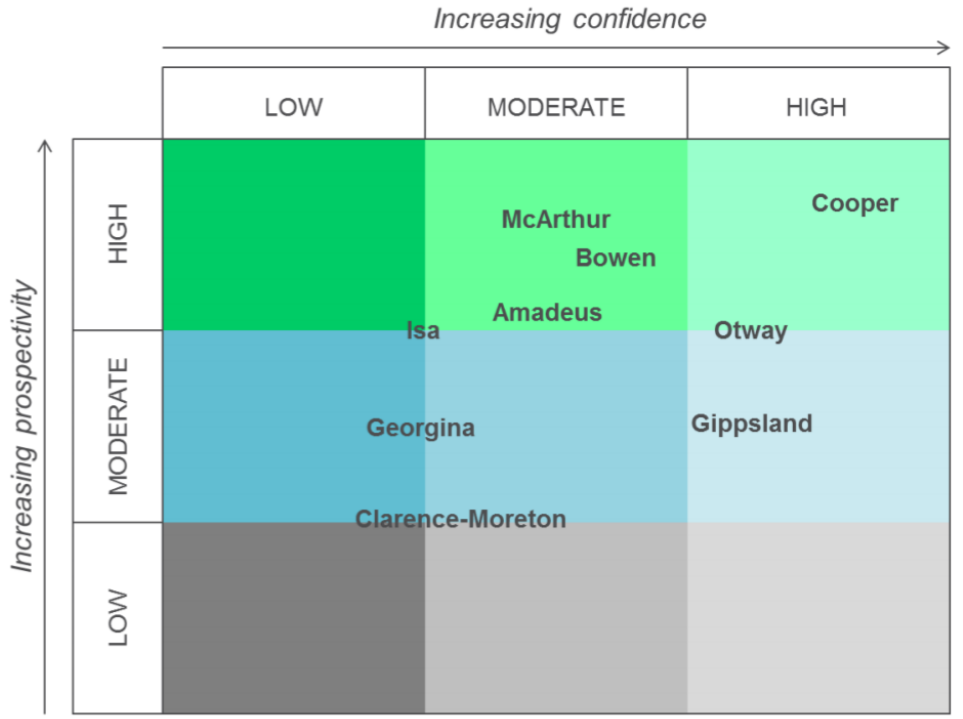
CSIRO

Geological and Bioregional Assessments: assessing the prospectivity for tight, shale and deep-coal resources in the Cooper Basin, Beetaloo Sub-basin and Isa Superbasin

Lisa S. Hall, Meredith L. Orr, Megan E. Lech, Steven Lewis, **Adam H.E. Bailey**, Ryan Owens, Barry E. Bradshaw and George Bernardel

GBA Prospectivity assessments: Stage 1

- Basins selected based on an initial stage of rapid regional prioritisation conducted by Geoscience Australia.
- 27 onshore basins with the potential to deliver shale and/or tight gas to the East Coast Gas Market were assessed.
- Reduced to a shortlist of nine basins where exploration is currently underway.



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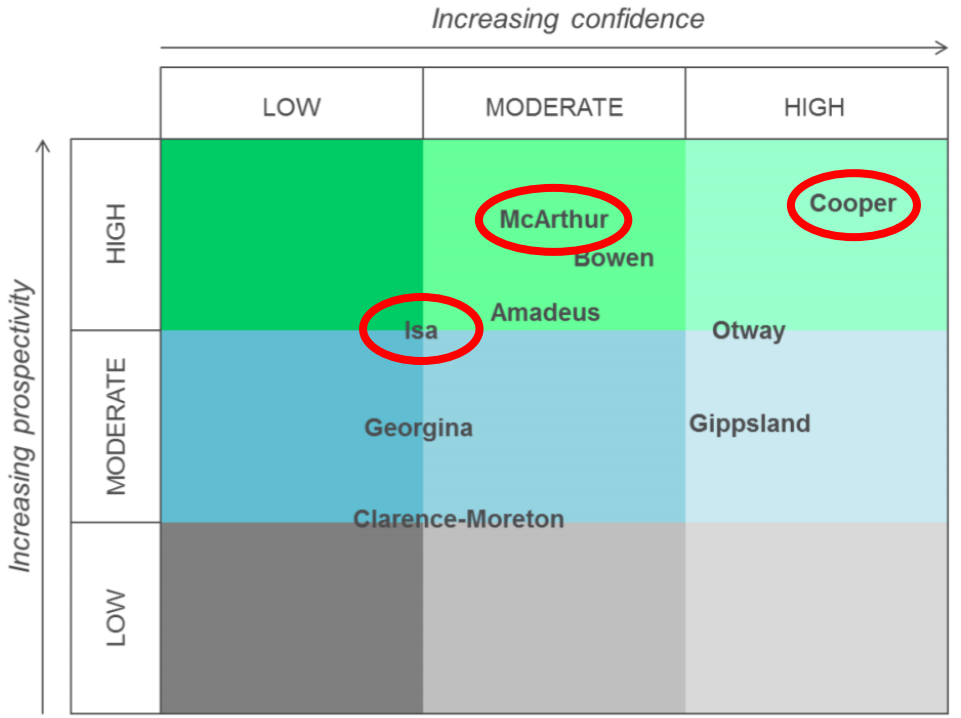
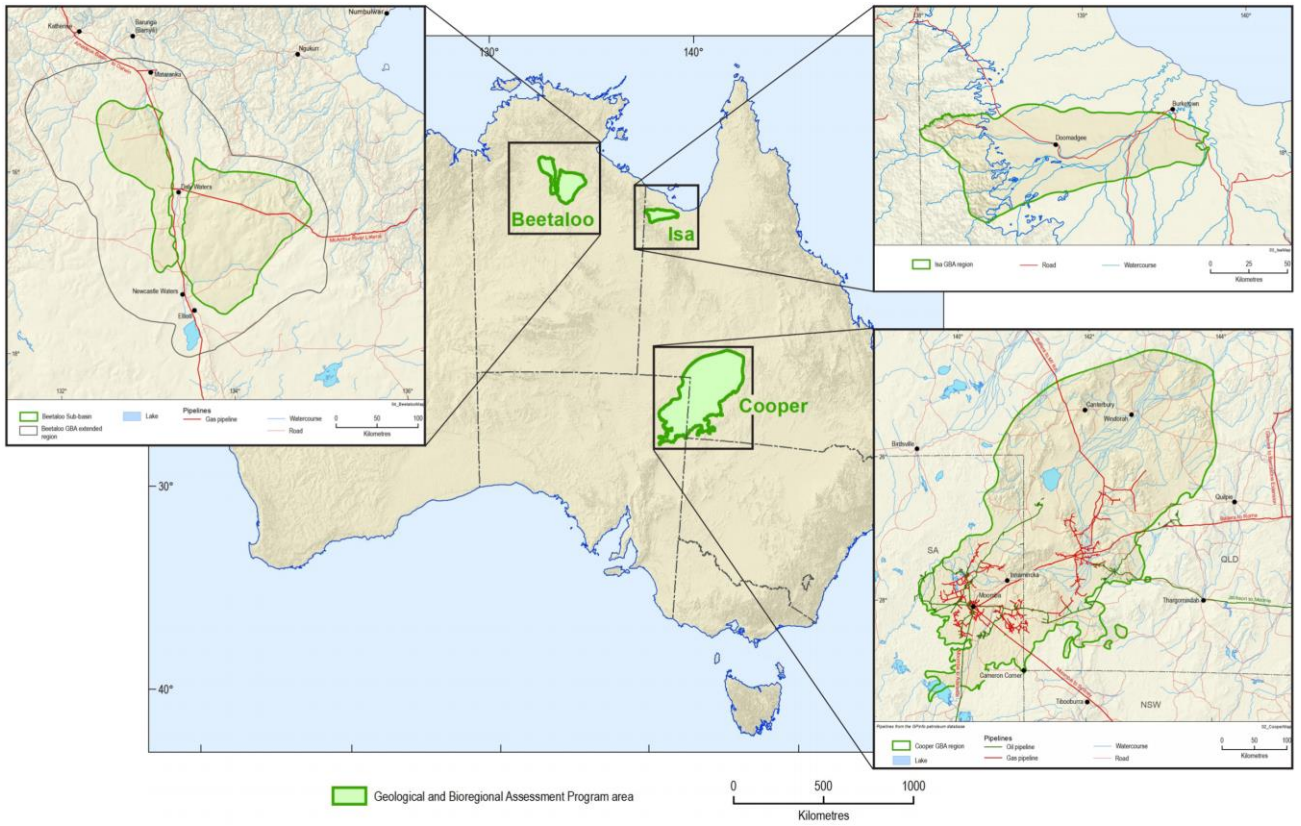


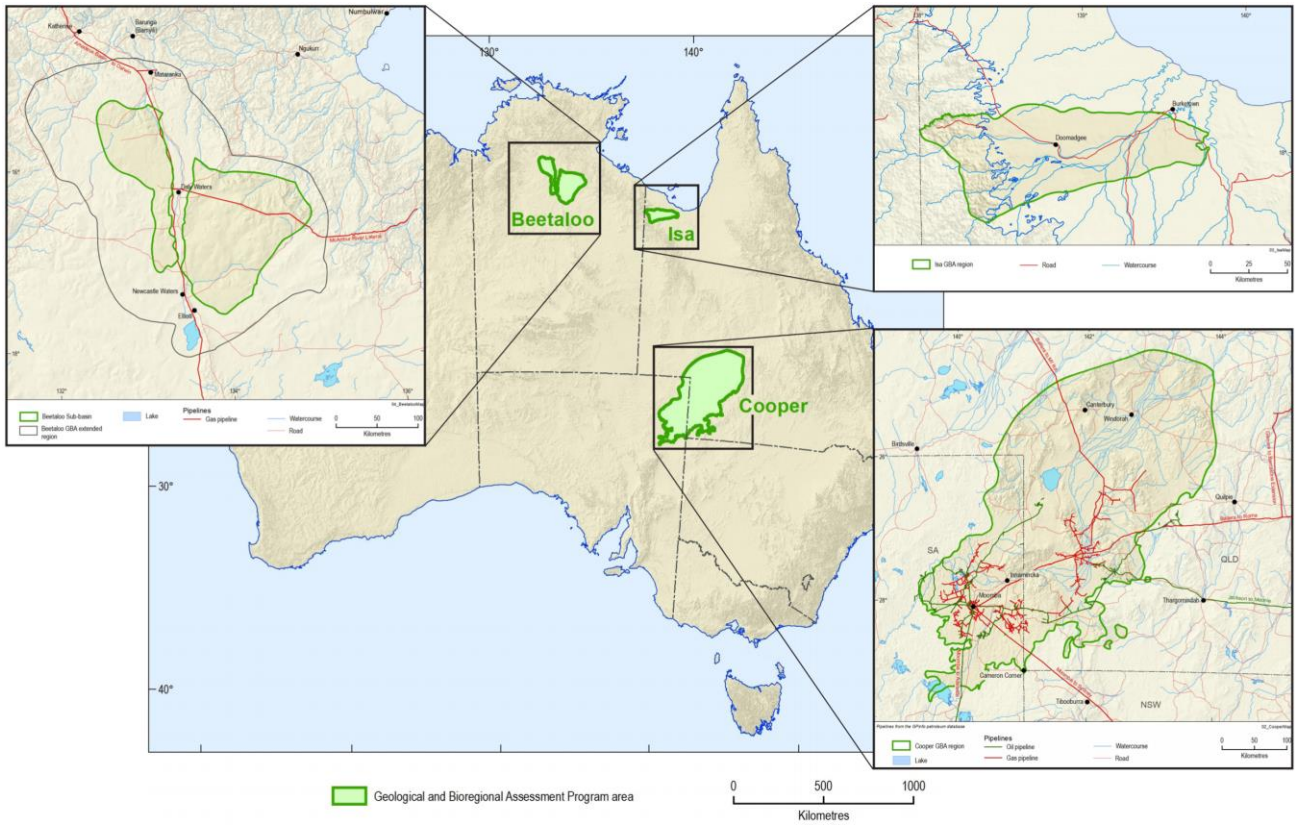
GBA Prospectivity assessments: Stage 2

- Regional geological evaluations and conceptualisations to establish a baseline understanding of the assessment regions.
- These data informed the assessment of relative shale and/or tight gas prospectivity.



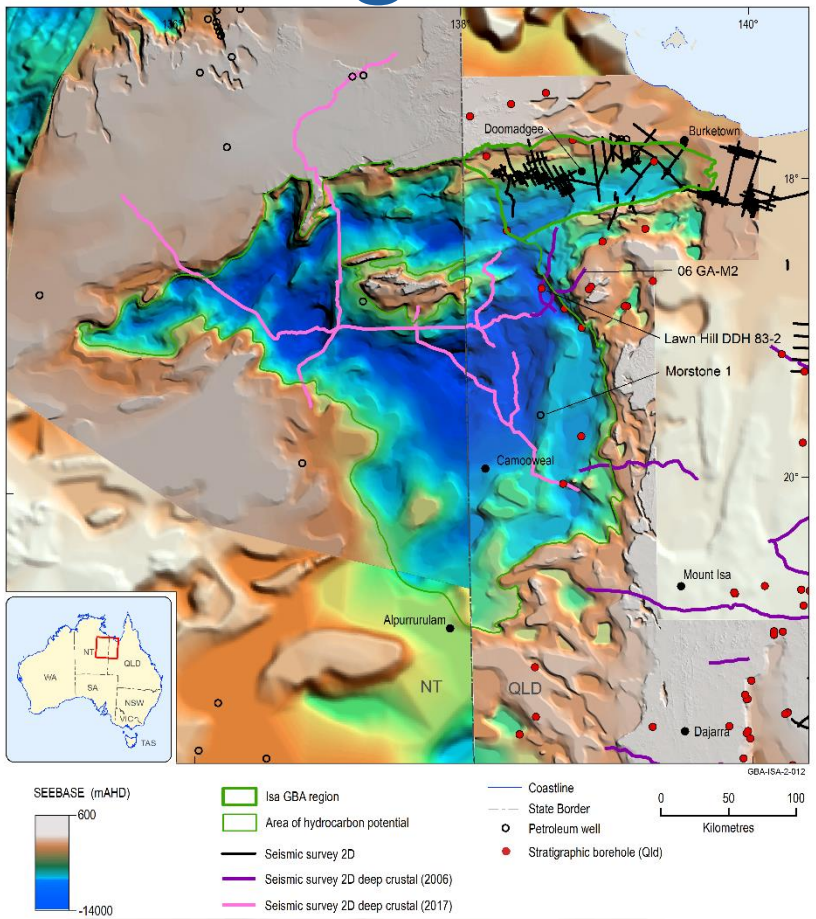
GBA Prospectivity assessments: Stage 2

- Relative prospectivity assessments:
  - provide an indication of where viable petroleum plays are most likely to be present within assessed regions
  - Highlight areal and stratigraphic constraints on play extent
- These assessments helped construct likely development scenarios and refined the scope of Stage 3 impact assessments.

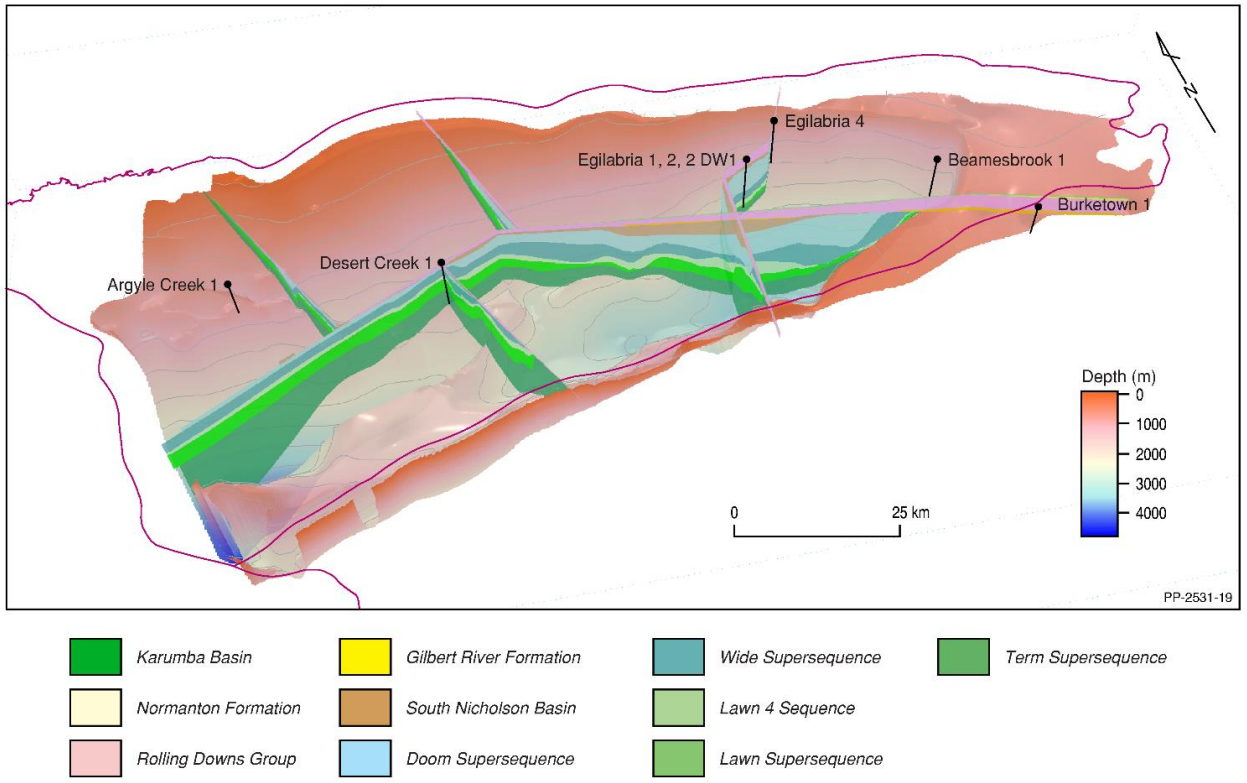


GBA Prospectivity Assessments: GBA regions

- Assessments occur within regions defined specifically for the GBA program – known as ‘GBA regions’.
- GBA regions identified not only on the known extent of each assessed geological basin, but including factors such as:
  - data availability and quality;
  - presence of a known petroleum system, and;
  - likelihood of development being able to deliver gas to market .



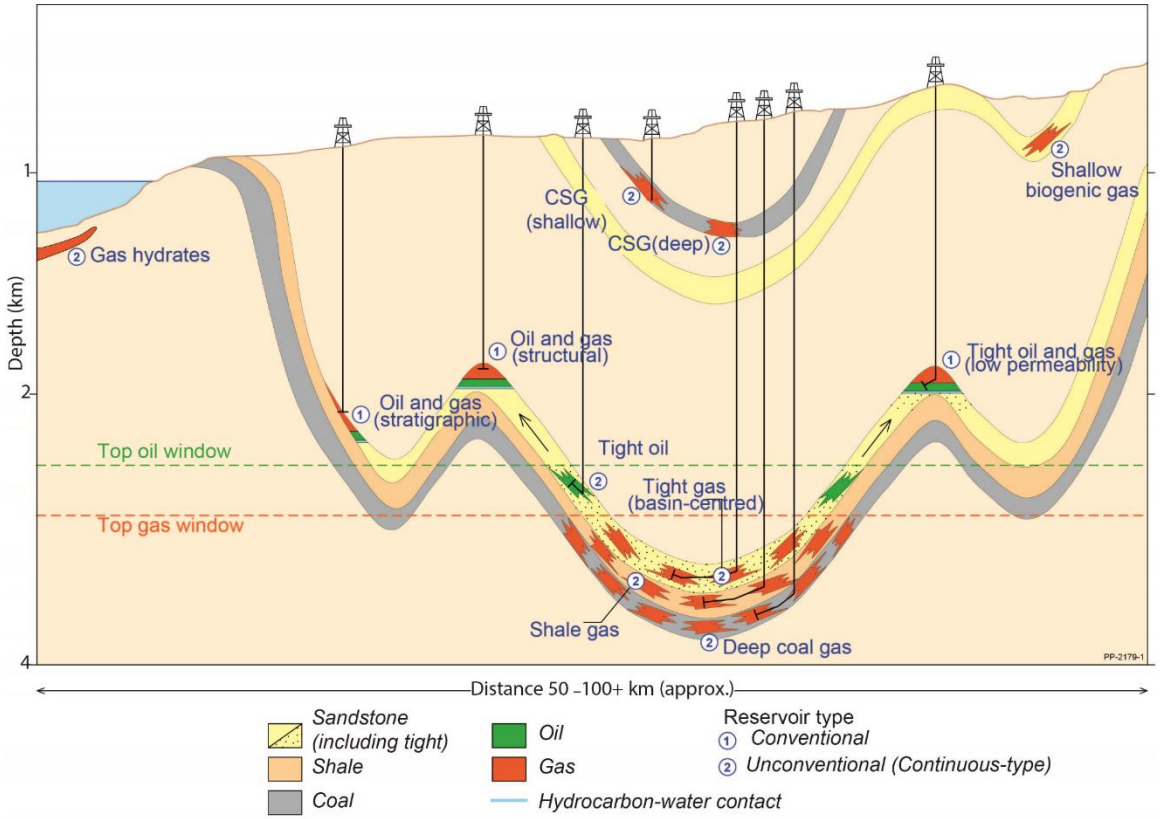
Prospectivity Assessments



- Undertaken following detailed evaluations of the structure and stratigraphic architecture in each GBA region.
- These provided the geological framework and properties of stratigraphic sequences hosting potential petroleum resources.

Prospectivity Assessments

- Criteria to assess the relative prospectivity for shale, deep coal and tight gas plays were selected from evaluated geological properties, e.g:
  - Formation thickness and extent
  - Source rock properties
  - Reservoir characteristics
  - Pressure regimes
- Separate criteria were developed for different play types.

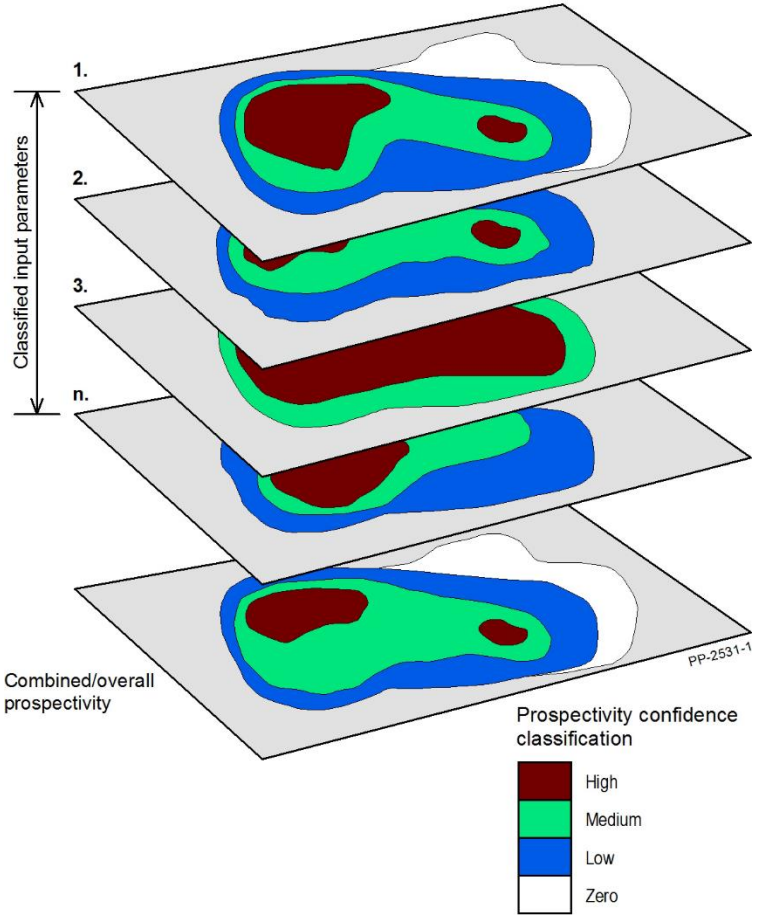


Source: Schenk and Pollastro (2002); Cook et al. (2013b); Schmoker et al. (1995)

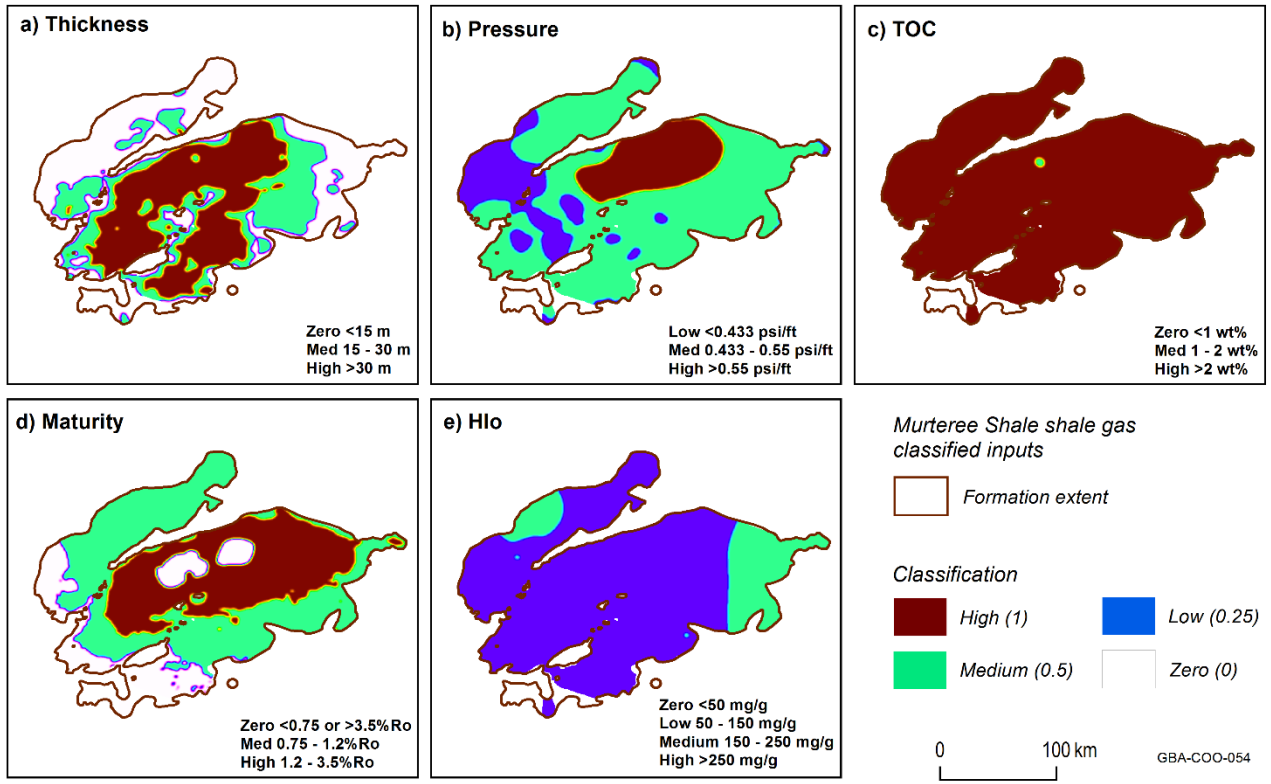
See Stage 2 reports for reference details: https://www.bioregionalassessments.gov.au/gba

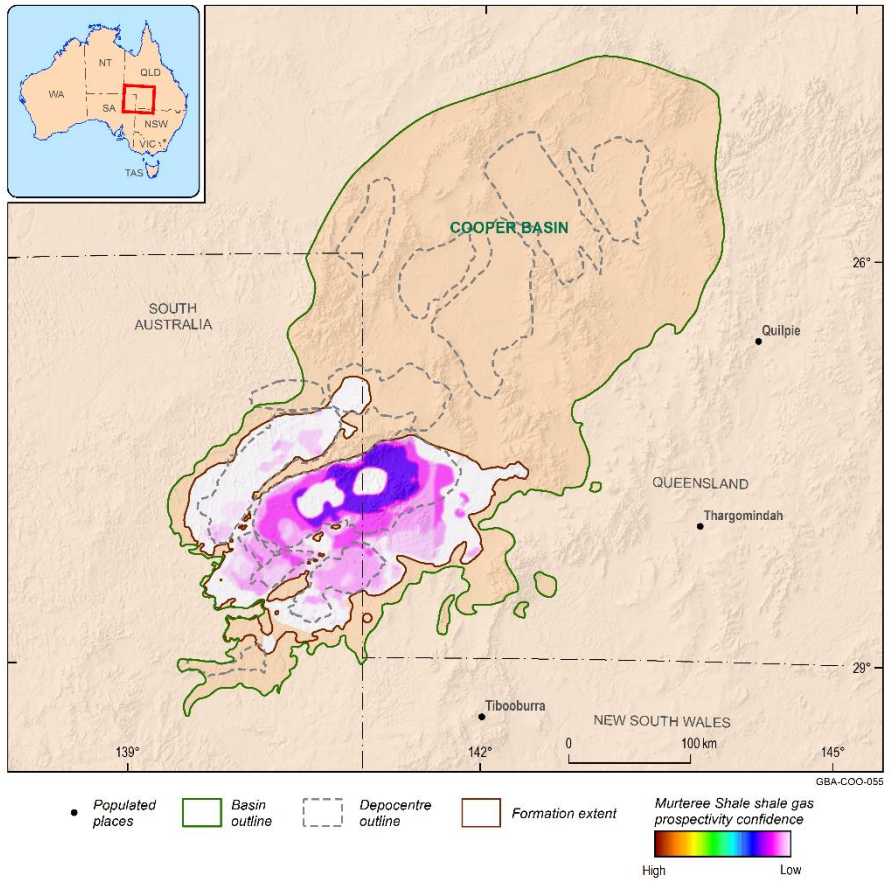
Prospectivity Assessments

- Input maps were developed from classified parameters representing each criteria.
- Input parameters were assigned a ranking between zero and one (absent = zero).
- Classified input parameter maps were multiplied together to highlight relative prospectivity for each play type by formation.
- Combined relative prospectivity maps for each play type were created by taking the maximum prospectivity value of the formation-specific maps for that play type.



Prospectivity Assessments: Example classified data

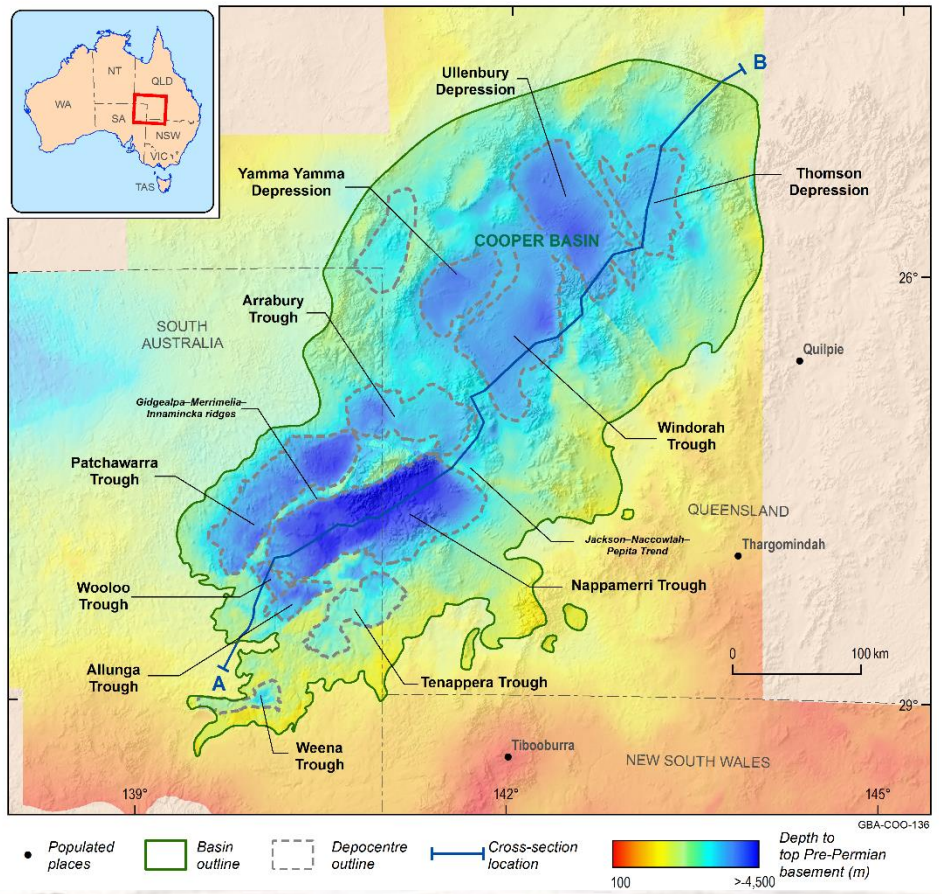




Cooper Basin – Murteree Shale

Prospectivity Assessments: Cooper GBA region

- Defined by the outline of the Cooper Basin
  - Upper Carboniferous–Middle Triassic basin,
  - Does not outcrop at the surface,
  - With the overlying Jurassic–Cretaceous Eromanga Basin forms Australia's most developed onshore oil and gas province.
- A range of unconventional gas plays in the Cooper Basin are currently of interest, with a focus on **shale**, **tight** and **deep coal gas** hosted within the Permian succession.



Prospectivity Assessments: Cooper GBA region

- Three Cooper GBA region play types were assessed:
  - Shale gas plays (Patchawarra Formation, Roseneath and Murteree shales).
  - Wet and dry deep coal gas plays (Toolachee, Epsilon and Patchawarra).
  - Basin-centred tight gas plays (Gidgealpa Group).

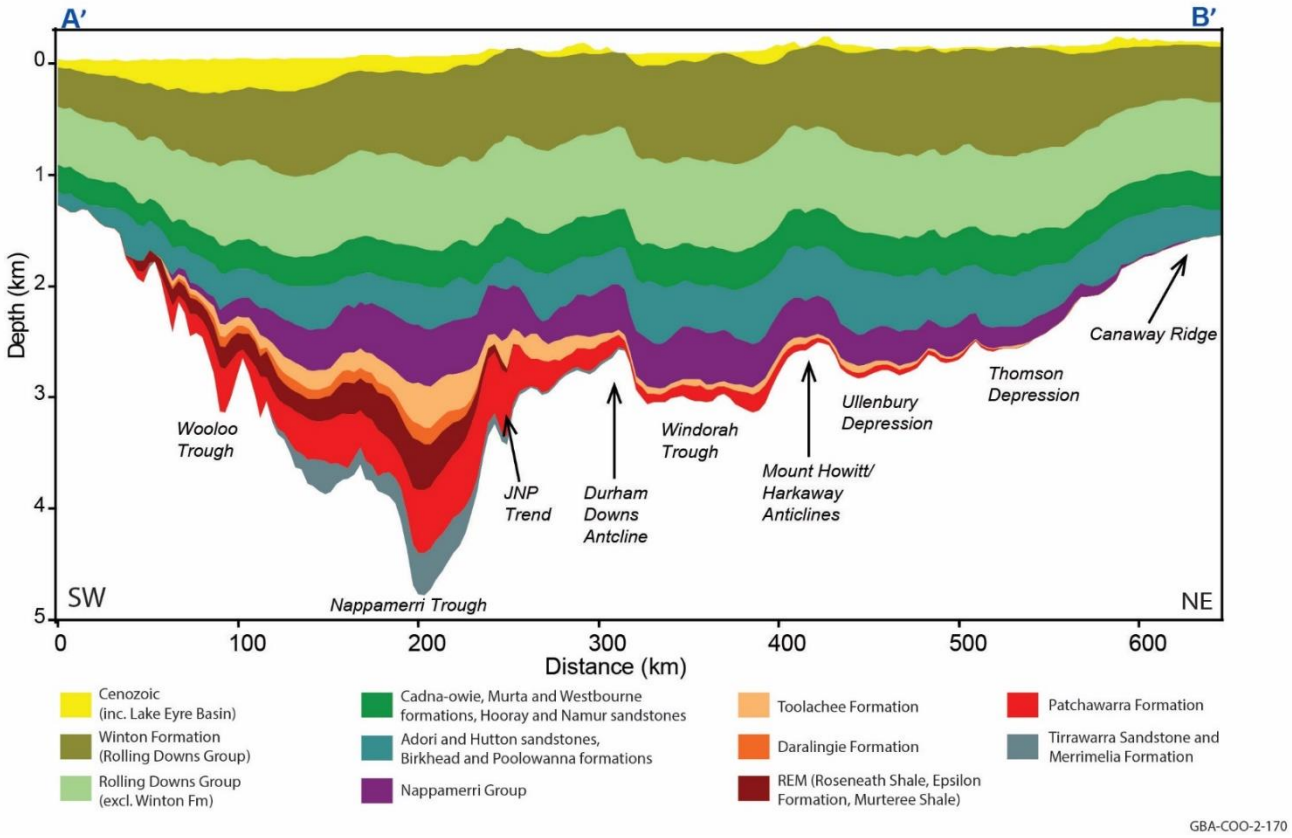


Table 62 Summary of shale gas play specific input parameters and classifying criteria used to develop combined relative prospectivity confidence maps. Associated data sources, assumptions, limitations and references are also provided

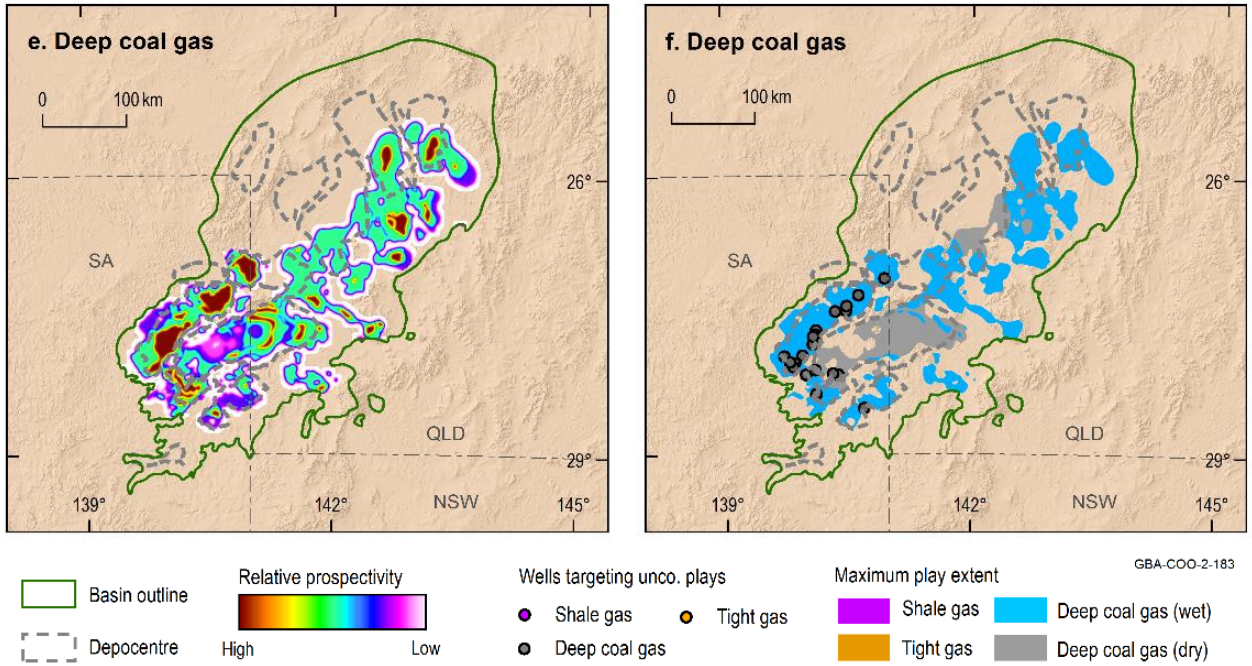
Parameter (P)	Classified input parameter thresholds				Comments	Data source	Description/Assumptions	Limitations	Reference for threshold criteria
	Zero (0)	Low (0.25)	Medium (0.5)	High (1)					
Net thickness of organically rich shale (TOC > 2 wt%)	<15 m	na	≥15–<30 m	≥30 m	Minimum requirement by Charpentier and Cook (2011)	Shale thickness from Hall et al. (2015a)	Used 3D model from Hall et al. (2015a). Derived from gross shale thickness multiplied by net organic rich ratio. True vertical thickness used	Variable density and irregular distribution of well tops and velocity data may affect the quality of structural modelling results	Charpentier and Cook (2011); Boyer (2018)
Pressure regime (Roseneath and Murteree shales)		<0.433 psi/ft (<9.79 MPa/km)	≥0.433–<0.55 psi/ft (≥9.79–<12.44 MPa/km)	≥0.55 psi/ft (≥12.44 MPa/km)	Desirable requirement by Charpentier and Cook (2011)	Pressures in well completion reports	Pressure-depth thresholds used to identify top of overpressured zone basin-wide. See Section 4.2.2 on overpressure for further information	Pressure map for REM[II] available only. Well coverage is concentrated in producing fields; all formations are not sampled equally or consistently	EIA (2013); Hall et al. (2015b); Boyer (2018)
Pressure regime (Patchawarra Formation)		na	<2800 m	≥2800 m	Single threshold used to estimate pressure regime therefore less confidence than Roseneath and Murteree shales. Desirable requirement by Charpentier and Cook (2011)	Depth surface maps from Hall et al. (2015a); Measured formation pressures in well completion reports from Kulikowski et al. (2016a)	Basin specific pressure-depth thresholds for middle of formations determined from data. See Section 4.2.2 on overpressure for further information	Gridded pressure maps not available. Non-REM formations use a depth-based proxy for likelihood of overpressure occurring. Dataset highlights pressure depletion and poorly reported tests. After Kulikowski et al. (2016a)	Defined by Geoscience Australia analyst based on well data from Kulikowski et al. (2016a)
Total organic carbon (TOC)	<1 wt%	na	≥1–<2 wt%	≥2 wt%	Minimum requirement by Charpentier and Cook (2011)	Hall et al. (2019)	Present day average TOC	Errors of up to 10% can occur between 'LECO' and 'Rock-Eval' methods (coals are the most difficult to measure accurately using the Rock-Eval method) (Hall et al., 2015a)	Hall et al. (2015b)
Thermal maturity	<0.75%Ro (oil) or >3.5%Ro (gas)	na	≥0.75–<1.2%Ro (oil)	≥1.2–≤3.5%Ro (wet/dry gas)	Modified from minimum requirement by Charpentier and Cook (2011)	Hall et al. (2019)	Vitrinite reflectance map for middle of formation	Variation of maturity throughout formation thickness not considered. Additional variability present in kinetic parameters and uncertainties in temperature history, palaeo-temperature data etc. See Hall et al. (2016b)	Hall et al. (2015b); Hall et al. (2019)
HI_o (original Hydrogen Index)	<50 mg HC/g TOC	≥50–<150 mg HC/g TOC	≥150 –<250 mg HC/g TOC	≥250 mg HC/g TOC	Minimum requirement by Charpentier and Cook (2011)	Hall et al. (2016b)	Derived from present day HI. For rocks with TOC <3 wt% the HI can be suppressed, resulting in underestimation of true hydrocarbon potential. HI_o also represents kerogen type	Data density varies depending on formation and location in the basin. Therefore, the maps may not be representative of the entire basin. HI_o is a highly variable parameter, and as it is derived from HI, confidence in these maps is reduced	Modified from Charpentier and Cook (2011); Hill (2019)

HIo = original hydrogen index; MPa/km = Megapascals per kilometre; na = not applicable; Roseneath Shale, Epsilon Formation and Murteree Shale; %Ro = thermal maturity; psi/ft = pounds per square inch per foot; TOC = total oraganic carbon; wt% = weight (as a percentage)

This table has been optimised for printing on A3 paper (297 mm x 420 mm).

Prospectivity Assessments: Cooper GBA region

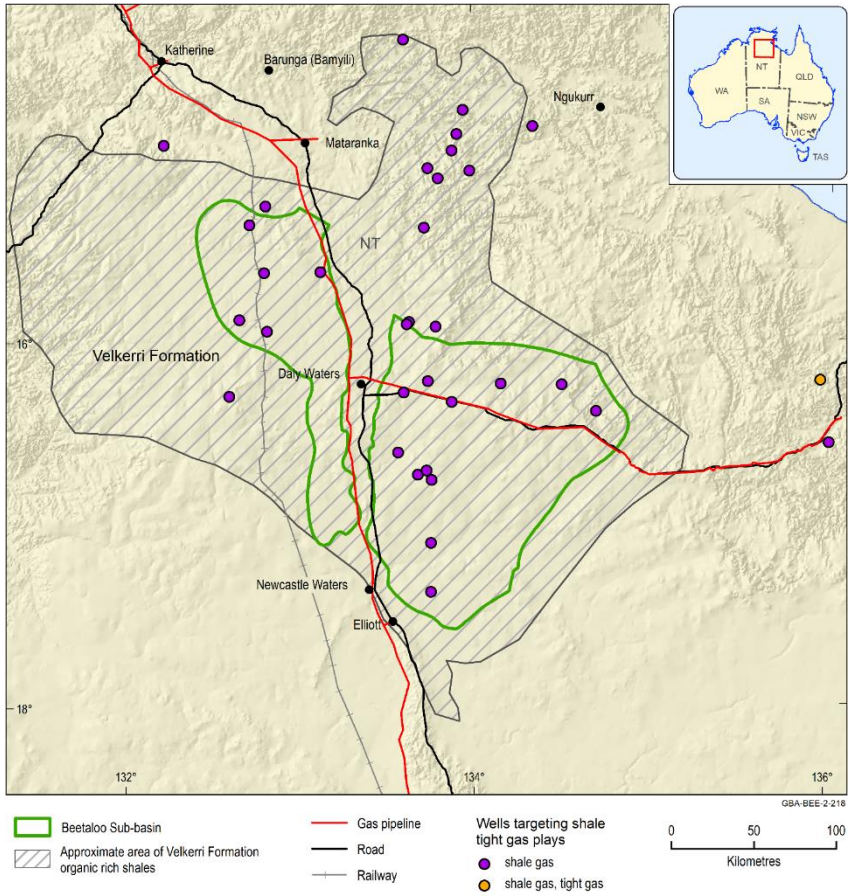
- Areas of higher prospectivity were identified within most depocentres:
  - The Nappamerri Trough;
  - Patchawarra Trough;
  - Windorah Trough;
  - Allunga Trough, and;
  - Wooloo Trough.



- This is consistent with recent exploration activity.
- Relative prospectivity maps inform where the plays are most likely to be present within the basin.

Prospectivity Assessments: Beetaloo GBA region

- Defined by the extent of the Beetaloo Sub-basin:
  - Mesoproterozoic basin,
  - Overlain by younger basins,
  - Particularly prospective for unconventional resources.
- Several **shale gas** plays in the Beetaloo Basin are currently of interest, with a focus on the Velkerri and Kyalla formations.



Prospectivity Assessments: Beetaloo GBA region

- Three Beetaloo GBA region play types were assessed:
  - Velkerri Formation (Amungee Member) dry gas play.
  - Velkerri Formation (Amungee Member) liquids-rich gas play.
  - Kyalla Formation liquids-rich gas play.
- The extent of the Hayfield sandstone member liquids-rich gas play, was derived from previous work (Côté *et al.,* 2018) .

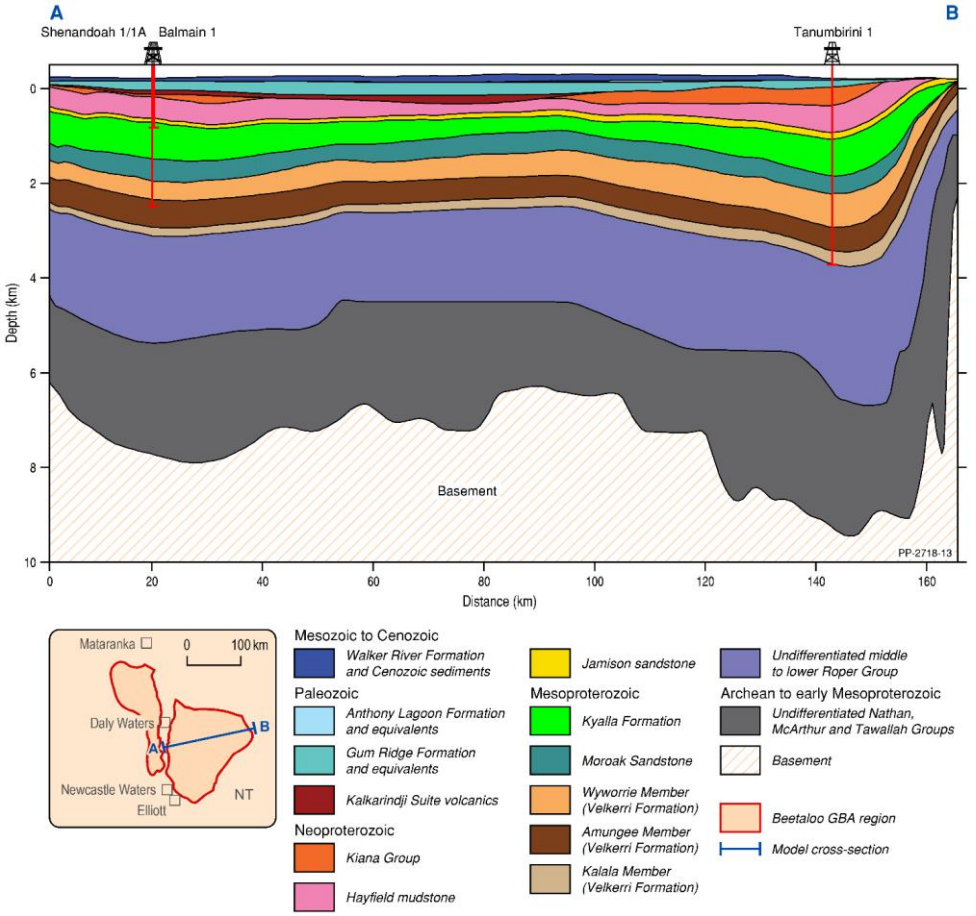
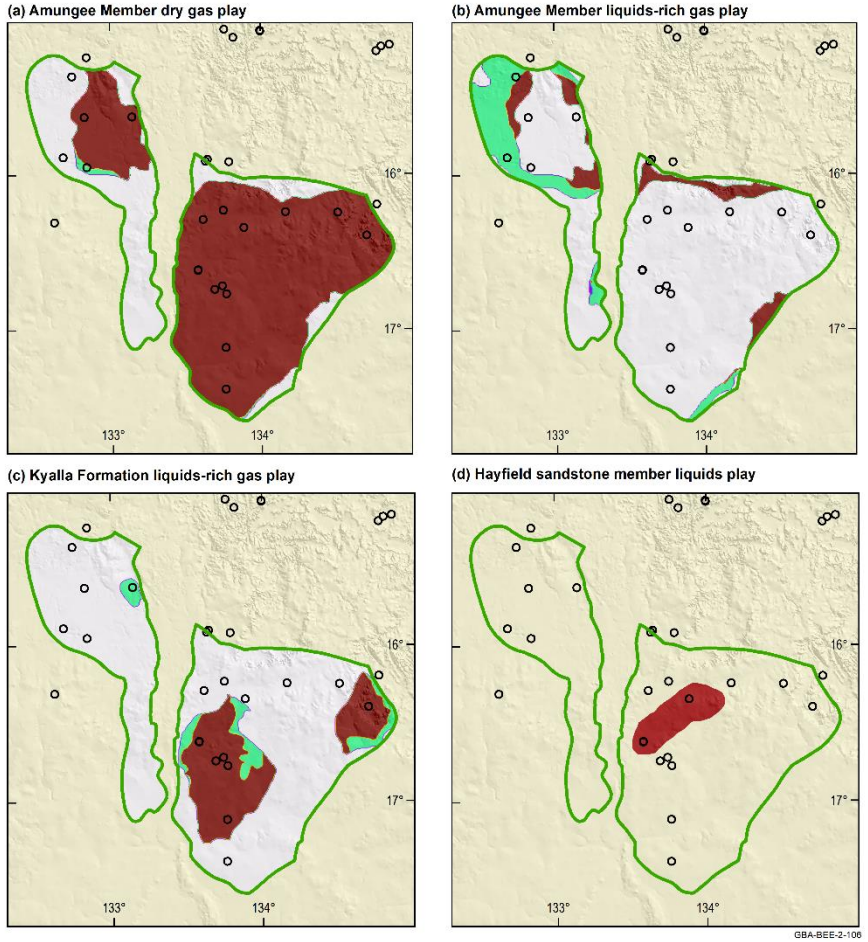


Table 40 Summary of shale gas play specific input parameters and classifying criteria used to develop play fairway maps.

Parameter (P)	Zero (0)	Medium (0.5)	High (1)	Map source
Mid-formation depth (m)	< 700 m	700–1000 m	> 1000 m	Three-dimensional geological model (Orr et al., 2019)
Net shale thickness greater than 2 wt% TOC	< 15 m	15–30 m	> 30 m	Gross stratigraphic thickness from three-dimensional geological model (Orr et al., 2019) * net organically rich ratio (Section 3.2 – this report)
Thermal maturity (liquids-rich gas) **OR**	< 1.1 OR > 1.4 %EqVR	n/a	1.1–1.4 %EqVR	Source rock maturity map (Section 3.4 – this report)
Thermal maturity (dry gas)	1.4 %EqVR	n/a	> 1.4 %EqVR	Source rock maturity map (Section 3.4 – this report)

Due to data limitations, likely prospective play areas in the Beetaloo GBA region were determined through the use of play fairway analysis rather than prospectivity mapping as in the Cooper Basin.

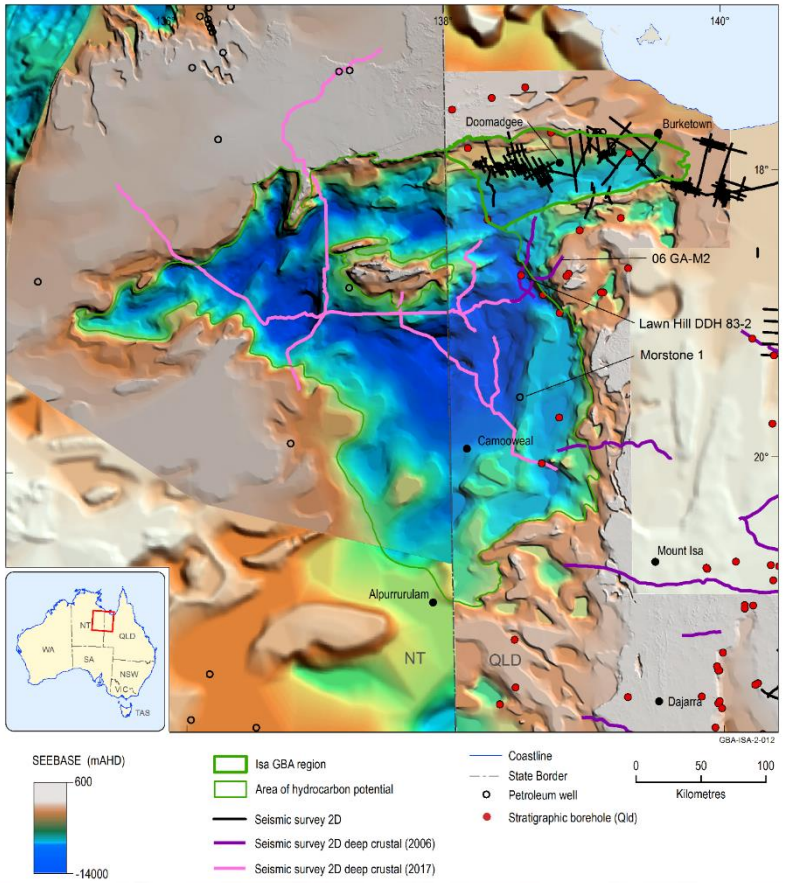
Prospectivity Assessments: Beetaloo GBA region



- Results demonstrate that:
  - The Amungee Member of the Velkerri Formation is potentially prospective for either liquids-rich or dry gas over most of the Beetaloo Sub-basin extent.
  - The Kyalla Formation liquids-rich gas play and the Hayfield sandstone member liquids-rich gas/oil play are primarily restricted to the central part of the eastern sub-basin.

Prospectivity Assessments: Isa GBA region

- Defined as the area of the Isa Superbasin that contains **an identified shale gas system** from which future development could result in **delivery of gas within five to ten years:**
  - Overlain by younger basins,
  - Paleo–Mesoproterozoic.
  - New data recently acquired by Geoscience Australia's Exploring for the Future program will help further define the basin.



Prospectivity Assessments: Isa GBA region

- Two Isa GBA region plays were assessed:
  - Lawn Supersequence shale gas play.
  - River Supersequence shale gas play.

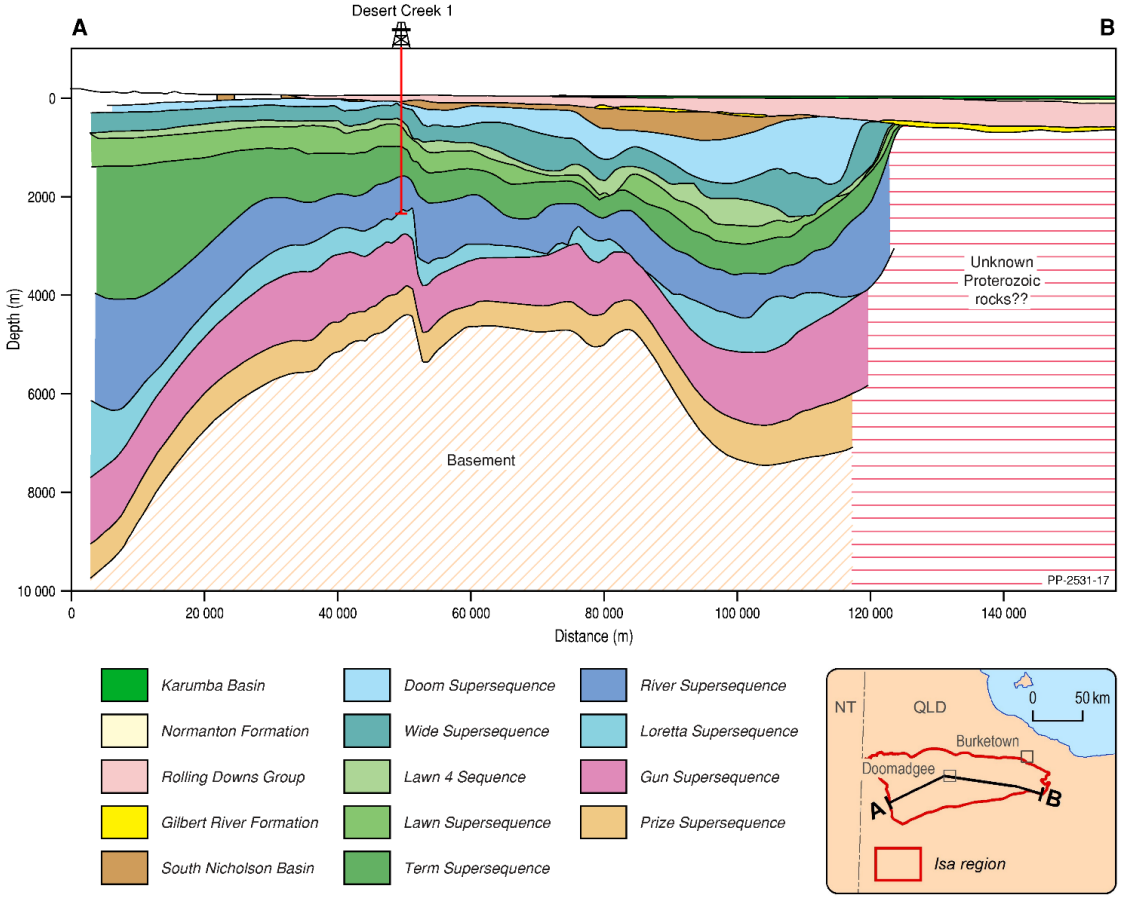


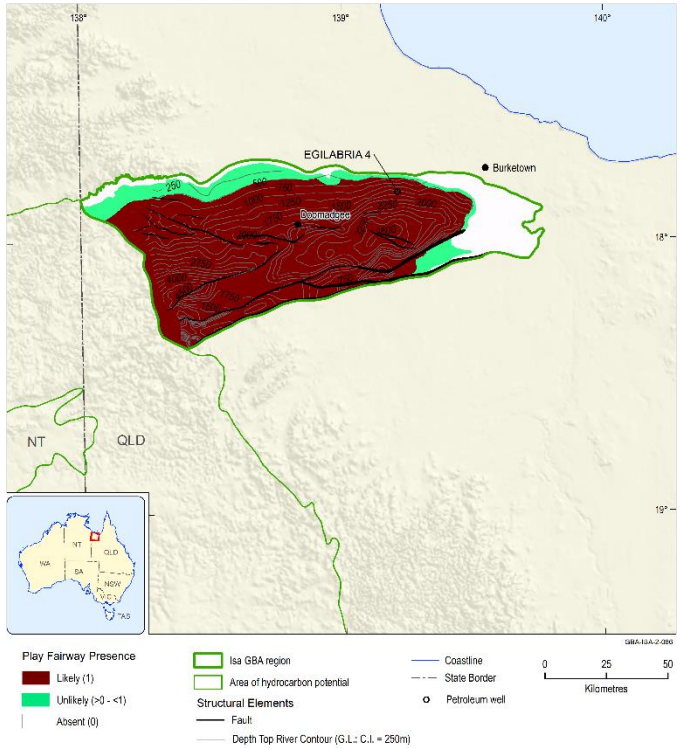
Table 26 Summary of shale gas play input parameters and classification criteria used to develop play fairway maps

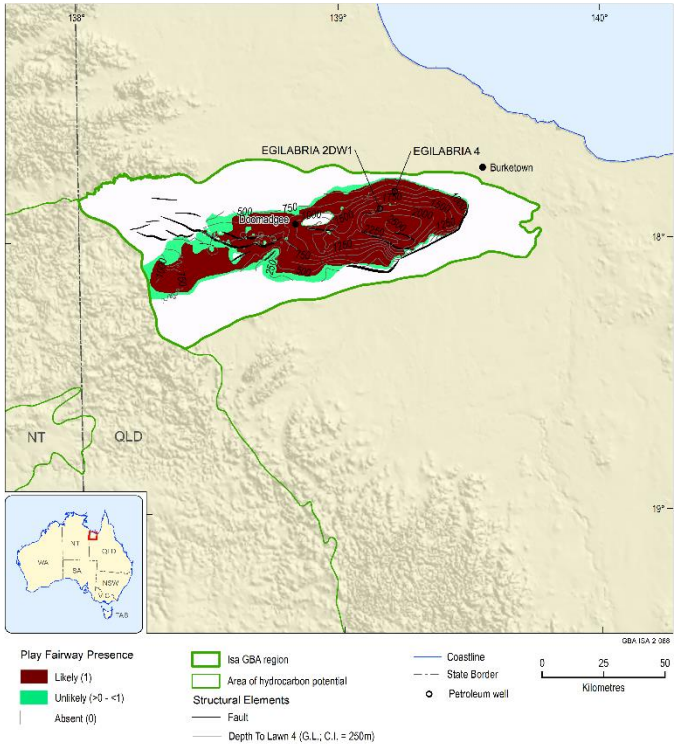
	Classified input parameter thresholds			Comments	Data source	Description/assumptions	Limitations	Reference for threshold criteria
	None (0)	Medium (0.5)	High (1)					
Net shale thickness	< 15 m	≥ 15 to < 30 m	≥ 30 m	Minimum requirements by Charpentier and Cook (2011)	Gross shale thickness sourced from isochore maps by Bradshaw et al. (2018a). See Section 4 for net organic-rich ratios	Derived from sequence/supersequence isochore (true vertical thickness) maps multiplied by net organically rich ratio	Variable coverage and quality of seismic and velocity data for constraining isochore maps; limited well data for determining net organically rich shale ratios	Charpentier and Cook (2011)
Thermal maturity	Formation not present	≤ 500 m (oil)	> 500 m (wet/dry gas)	Modified from minimum requirement by Charpentier and Cook (2011)	Depth-structure maps by Bradshaw et al. (2018a). One-dimensional burial history models by Palu et al. (2018)	Based on depth proxies for thermal maturity in the middle of the sequence/supersequence derived using one-dimensional burial history models. Some manual input is required in areas where originally deeply buried sediments have been inverted to shallow depths	Thermal maturity is very difficult to predict due to the degree of uplift and erosion across the Isa GBA region, and the effect of hydrothermal events on thermal maturity, which often produce inverted maturity profiles. Variable coverage and quality of seismic and velocity data for constraining depth-structure maps; limited well data for constraining burial history models	Palu et al. (2018)

Associated data sources, assumptions, limitations and references are provided.

As with the Beetaloo GBA region, data for assessing play prospectivity is limited in the Isa GBA region. Hence, play fairway analysis was used to map the distribution of known Isa Superbasin shale gas plays.

Prospectivity Assessments: Isa GBA region





- Results demonstrate that:
  - The River Supersequence is potentially prospective for shale gas over most of the Isa GBA region.
  - The Lawn Supersequence is most likely prospective over the central and eastern parts of the region.

Summary

- As part of the Australian Government's Geological and Bioregional Assessments Program, Geoscience Australia has undertaken detailed studies on the stratigraphic and structural architecture of defined regions within three highly prospective onshore petroleum basins.
- A relative prospectivity mapping process has been undertaken in these regions, identifying and mapping the likely extent of shale, tight and deep coal gas plays.
- These maps provide key inputs into Stage 3 of the GBA program, indicating areal and stratigraphic constraints that support further work on likely development scenarios, impact assessments, and causal pathways for each GBA region.

Thank you

Geoscience Australia

Adam Bailey
Geology Discipline Lead, GBA Program

t +61 2 6249 5813
e adam.bailey@ga.gov.au
w www.ga.gov.au

Department of Agriculture, Water and the Environment

Mitchell Bouma
A/g Director - Geological and Bioregional Assessments

t +61 2 6274 2020
e mitchell.bouma awe.gov.au
w www.awe.gov.au

https://www.bioregionalassessments.gov.au/gba