

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

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Abstract. The Geological and Bioregional Assessment Program is a series of independent scientific studies undertaken by Geoscience Australia and the CSIRO, supported by the Bureau of Meteorology, and managed by the Department of Agriculture, Water and the Environment. The program consists of three stages across three regions with potential to deliver gas to the East Coast Gas Market. Stage 1 was a rapid regional prioritisation conducted by Geoscience Australia, to identify those sedimentary basins with the greatest potential to deliver shale and/or tight gas to the East Coast Gas Market within the next 5–10 years. This prioritisation process assessed 27 onshore eastern and northern Australian basins with shale and/or tight gas potential. Further screening reduced this to a shortlist of nine basins where exploration was underway. The shortlisted basins were ranked on a number of criteria. The Cooper Basin, the Beetaloo Subbasin and the Isa Superbasin were selected for more detailed assessment. Stage 2 of the program involved establishing a baseline understanding of the identified regions. Geoscience Australia produced regional geological evaluations and conceptualisations that informed the assessment of shale and/or tight gas prospectivity, ground- and surface-water impacts and hydraulic fracturing models. Geoscience Australia's relative prospectivity assessments provide an indication of where viable petroleum plays are most likely to be present. These data indicate areal and stratigraphic constraints that support the program's further work in Stage 3, on understanding likely development scenarios, impact assessments and causal pathways.

Keywords: GBA region, regulatory efficiency, user panel, approval processes, sustainable development, Cooper Basin, Isa Superbasin, Beetaloo Subbasin, shale gas, tight gas, deep coal gas, baseline, unconventional gas development, geology, hydrogeology, prospectivity, chemical screening, protected matters, hydraulic fracturing, well integrity, matters of national environmental significance, matters of state environmental significance, causal network, causal pathway, hazard analysis, impact analysis, potential impact, gas resources, water resources.

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Introduction

In 2017, the Australian Government announced a program of assessments to be conducted in three underexplored onshore areas that are considered to be prospective for shale and tight gas, known as the Geological and Bioregional Assessment (GBA) Program.

The GBA program assessed the potential impacts of shale, tight and deep coal gas development on water and the environment, providing independent scientific advice to governments, industry and the community. Work was undertaken by Geoscience Australia and the CSIRO, supported by the Bureau of Meteorology and managed by the Department of Agriculture,

Water and the Environment. Through an initial stage of rapid regional prioritisation conducted by Geoscience Australia, 27 onshore eastern and northern basins with the greatest potential to deliver shale and/or tight gas to the East Coast Gas Market within the next 5–10 years were assessed. This was reduced to a shortlist of nine basins where exploration is currently underway. Shortlisted basins were ranked on criteria including prospectivity, interpretation confidence, access to markets and access to infrastructure. As a result, the Cooper Basin, the Beetaloo Subbasin and the Isa Superbasin were selected for assessment under Stage 2 of the GBA program (Hall *et al.* 2018).

In the second stage of the GBA program, Geoscience Australia undertook regional geological evaluations and

Table 1. Summary of input parameters by play type and classification criteria used to develop relative prospectivity maps for each GBA region (Bailey *et al.* 2020; Hall *et al.* 2020; Lech *et al.* 2020)

Parameter	Absent (0)	Low (0.25)	Medium (0.5)	High (1)
Cooper GBA region				
Shale gas play				
Net shale thickness (m)	<15	N/A	≥15–<30	≥30
Pressure regime (Patchawarra) (m) ^A	N/A	N/A	<2800	≥2800
Pressure regime (Roseneath, Murteree) (psi/ft)	N/A	<0.433	≥0.433–<0.55	≥0.55
Total organic carbon (wt%)	<1	N/A	≥1–<2	≥2
Thermal maturity (%Ro)	<0.75; >3.5	N/A	≥0.75–<1.2	≥1.2–≤3.5
Original hydrogen index (mg HC/g TOC)	<50	≥50–<150	≥150–<250	≥250
Tight gas play				
Gidgealpa Group cumulative net sand thickness in major overpressure zone (m)	<10	10–<50	≥50–<100	≥100
Deep coal gas play				
Net coal thickness (m)	<10	N/A	≥10–<25	≥25
Thermal maturity (%Ro) – wet gas	<0.75 or ≥1.4	N/A	≥0.75–0.9	≥0.9–1.4
Thermal maturity (%Ro) – dry gas	<1.4 or ≥2.5	≥2.5–3.5	≥2–2.5	≥1.4–2
Beetaloo GBA region				
Mid formation depth (m)	<700	N/A	700–1000	>1000
Net source rock thickness (m)	<15	N/A	15–30	>30
Thermal maturity (%EqVR) – wet gas	<1.1 or >1.4	N/A	N/A	1.1–1.4
Thermal maturity (%EqVR) – dry gas	<1.4	N/A	N/A	>1.4
Isa GBA region				
Net source rock thickness (m)	<15	N/A	15–30	>30
Thermal maturity – depth proxy ^B	Formation not present	N/A	≤500 m	≥500 m

^AA pressure gradient map was not available for the Patchawarra formation. Instead, a depth of 2800 m was used as a proxy for the zone of major overpressure based on the observed pressure–depth relationship in the basin (Lech *et al.* 2020).

^BA depth proxy was developed for maturity using one-dimensional burial modelling (Bailey *et al.* 2020).

conceptualisations, establishing a baseline understanding of the regions identified for assessment. These baseline data informed the assessment of relative shale and/or tight gas prospectivity and informed further work on ground- and surface-water impacts and hydraulic fracturing models. Relative prospectivity assessments provide an indication of where viable petroleum plays are most likely to be present within the assessed regions, highlighting areal and stratigraphic constraints on play extent. These assessments helped to construct likely development scenarios and refined the scope of impact assessment and causal pathways in Stage 3 of the GBA program. Outlined herein is the work undertaken by Geoscience Australia in assessing the relative prospectivity for tight, shale and deep-coal hydrocarbon resources in the Cooper Basin, tight and shale hydrocarbon resources in the Beetaloo Subbasin and shale resources in the Isa Superbasin. These assessments occur within regions defined specifically for the GBA program, identified not only on the known extent of each assessed geological basin, but also including factors such as data availability and quality, the presence of a known petroleum system and the likelihood of

development in that area being able to deliver gas to market (Owens *et al.* 2020; Orr *et al.* 2020a, 2020b).

Prospectivity assessments

Prospectivity assessments were undertaken following detailed evaluations of the structure and stratigraphic architecture in each GBA region, which provided the geological framework required to better understand the distribution and properties of stratigraphic sequences hosting potential petroleum resources.

Cooper GBA region

The Cooper GBA region is defined by the outline of the Cooper Basin, an Upper Carboniferous–Middle Triassic sedimentary basin that is up to 2500 m thick. The Cooper Basin does not outcrop at the surface, and 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 is currently of interest, with a focus on shale, tight and deep coal gas hosted within the Permian

succession. The Cooper Basin currently produces hydrocarbons and is host to extensive processing and pipeline infrastructure, making these plays well placed to be rapidly commercialised pending further exploration success. Three play types were assessed in the Cooper GBA region:

- 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).

Due to the high level of data availability in the Cooper GBA region, relative prospectivity mapping was used to determine likely prospective play areas (Salter *et al.* 2014; Royal Dutch Shell 2017). The key geological properties required to assess prospectivity for each play type were identified in collaboration with state agencies (Department of the Premier and Cabinet, SA and Geological Survey of Queensland) and industry (Table 1). Quantitative data representing each geological property were classified according to the thresholds indicated in Table 1 and plotted to produce input parameter maps (Fig. 1). The classified data were then multiplied together to construct a composite map, highlighting the relative prospectivity over the assessment area for each play type by formation (Fig. 1). In addition, a combined relative prospectivity map for each play type was created by taking the maximum prospectivity value of the formation-based maps to capture overall shale, tight and deep coal gas prospectivity (Fig. 2). Further detail is available in the Stage 2 reports for the Cooper GBA region (Geological and Bioregional Assessment Program 2021b).

Areas of higher prospectivity were identified within most depocentres, including the Nappamerri, Patchawarra, Windorah, Allunga and Wooloo troughs, consistent with recent exploration activity (Fig. 2). The relative prospectivity maps inform where the plays are most likely to be present within the basin (Fig. 2).

Beetaloo GBA region

The Beetaloo GBA region boundary is located at the extent of the Mesoproterozoic Beetaloo Subbasin, as formally defined by the Department of Primary Industry and Resources (NT) (2017). Outside this boundary, the subbasin's sedimentary fill shallows towards the surface, and in many areas, becomes extensively faulted and deformed, with limited data available for assessing petroleum prospectivity. The Beetaloo Subbasin is divided into eastern and western elements by the Daly Waters High and is overlain by the Neoproterozoic to Paleozoic Georgina, Wiso and Daly Basins and the Mesozoic Carpentaria Basin. The Beetaloo Subbasin is prospective for unconventional petroleum and is estimated to contain significant resources, particularly within the shales of the Kyalla and Velkerri formations. Three play types were assessed in the Beetaloo GBA region:

- Velkerri formation (Amungee member) dry gas play.
- Velkerri formation (Amungee member) liquids-rich gas play.
- Kyalla formation liquids-rich gas play.

The extent of a fourth play type, the Hayfield sandstone member liquids-rich gas play, was derived from Côté *et al.*

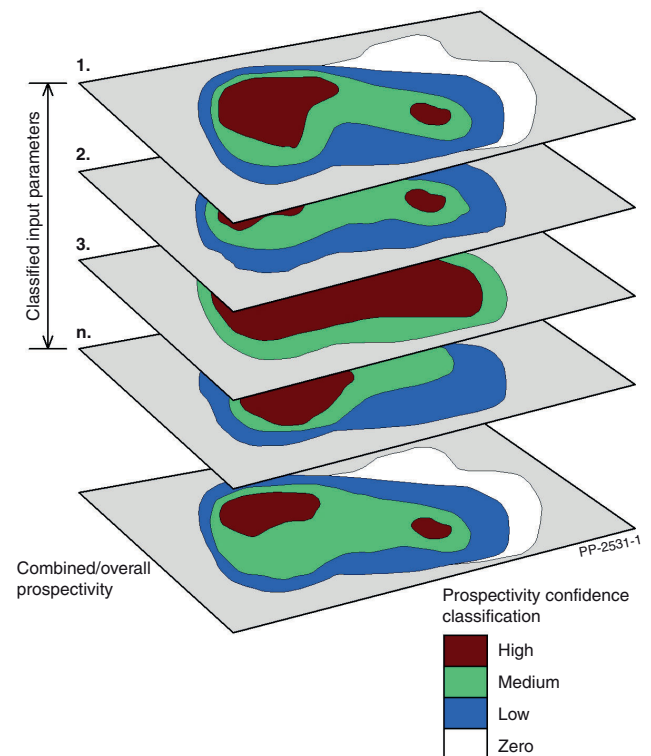


Fig. 1. Schematic workflow for combining classified input parameter maps to obtain the relative prospectivity of a formation or play (Lech *et al.* 2020).

(2018) as there were insufficient public domain data to assess this play distribution.

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 (Hall *et al.* 2020). Play fairway analysis was used to identify areas where specific petroleum plays are likely to be present, based on key selected geological parameters (Table 1). The resulting classified maps were multiplied together to produce an overall relative prospectivity map for each play type, which highlights regions with the most favourable geological conditions for play presence (Figs. 1 and 3).

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 Subbasin extent (Fig. 3). 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 subbasin (Fig. 3). Further detail is available in the Stage 2 reports for the Beetaloo GBA region (Geological and Bioregional Assessment Program 2021a).

Isa GBA region

The Isa GBA region was defined as the area of the Paleoproterozoic Isa Superbasin that contains an identified shale gas system from which future development could result in delivery of gas within 5–10 years (Lewis *et al.* 2020). The full extent of the Isa Superbasin is currently unknown, though it is

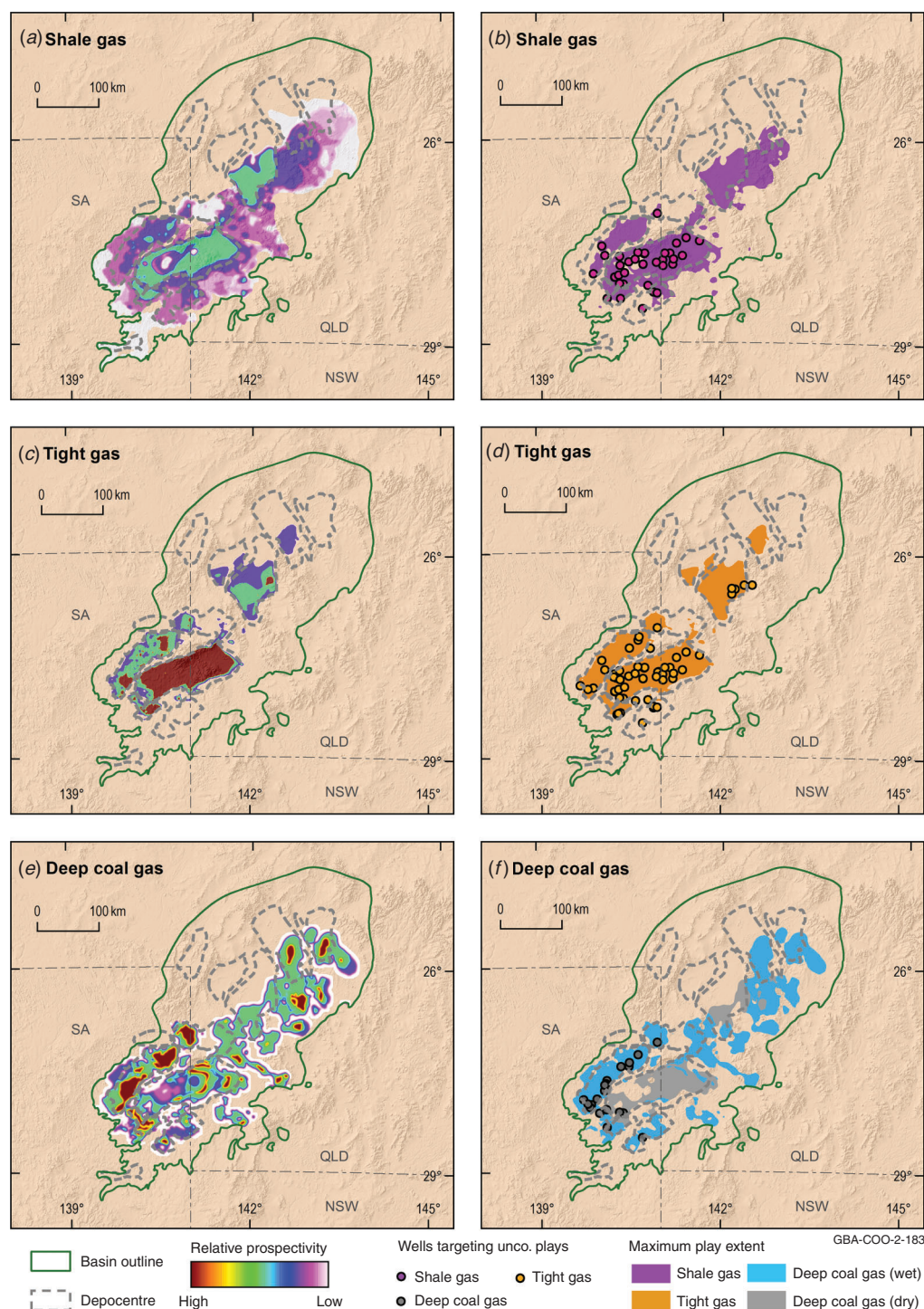


Fig. 2. Combined relative prospectivity maps by play type for the Cooper GBA region: (a) shale gas relative prospectivity map, (b) maximum extent of shale gas plays with location of key wells targeting shale gas, (c) basin-centred tight gas relative prospectivity map, (d) maximum extent of basin-centred tight gas plays with location of key wells targeting tight gas, (e) deep coal gas (dry and wet) relative prospectivity map and (f) maximum extent of deep coal gas play with location of key wells targeting deep coal gas play. The maximum area in which each play type may be present was derived from the relative prospectivity maps using a cut-off value of 0.2. Well coverage is not exhaustive, as there are inconsistencies in how wells have been classified depending on the information source. Only key wells used in shale, tight and deep coal gas characterisation are shown (Holland *et al.* 2020). Basin outline in green represents a surface projection of the extent of the Cooper Basin.

Beetaloo GBA region

Isa GBA region

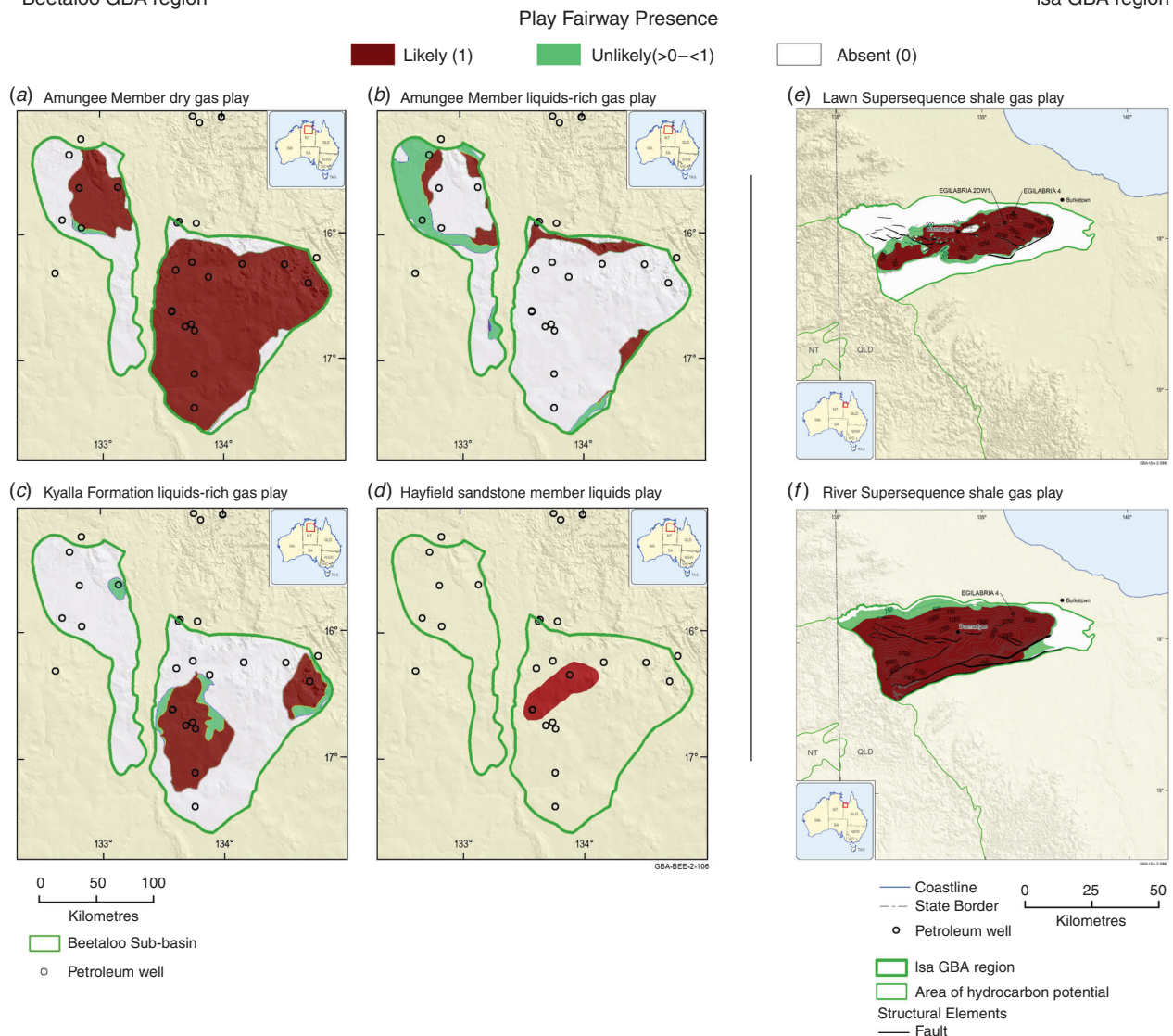


Fig. 3. Play fairway maps showing variation in relative prospectivity (whether or not a play fairway is interpreted as likely, unlikely or absent) for various play types across the Beetaloo and Isa GBA regions: (a) Amungee member dry gas play, (b) Amungee member liquids-rich gas play, (c) Kyalla formation liquids-rich gas play, (d) Hayfield sandstone member liquids-rich gas play, (e) Lawn supersequence shale gas play and (f) River supersequence shale gas play. Note, the Isa GBA region ‘Area of Potential’ is described in Lewis *et al.* (2020). Depth contours on (e) and (f) are relative to ground level, with intervals every 250 m.

likely to extend under the Mesoproterozoic South Nicholson Basin into the northern territory (Carr *et al.* 2020). Resource development companies are currently pursuing shale gas plays hosted within proven Paleoproterozoic petroleum systems. Two plays were assessed in the Isa GBA region:

- Lawn supersequence shale gas play.
- River supersequence shale gas play.

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. Map data were only available for two geological properties: net source rock thickness and

formation depth (used as a proxy for source rock thermal maturity) (Table 1). These key mapped properties were classified based on defined criteria (Bailey *et al.* 2020), with the resulting classified maps multiplied together to produce play extent maps (Fig. 3). These maps highlight, based on the available data, regions with the most favourable geological conditions for shale gas plays. They demonstrate that the River supersequence is potentially prospective for shale gas over most of the Isa GBA region, whereas the Lawn supersequence is most likely prospective over the central and eastern parts of the region. Further detail is available in the Stage 2 reports for the Isa GBA region (Geological and Bioregional Assessment Program 2021c).

Summary

As part of the Australian Government's GBA 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.

Conflicts of interest

All authors confirm that there are no conflicts of interest.

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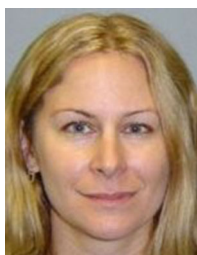
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Dr. Barry E. Bradshaw is a Geoscientist with 29 years of experience undertaking geological and geophysical studies and play-based prospectivity studies for conventional and unconventional hydrocarbon resources, geological storage projects and sediment-hosted mineral deposits. Barry is currently employed as the Energy Resources Advice activity leader at Geoscience Australia, and has previously worked as a Principal Geologist at CGSS consultants, Senior Research Scientist at AGSO/Geoscience Australia and Research Scientist at Texas A&M University (the United States). Barry was graduated from the University of Sydney in 1988, and completed a PhD in Earth Sciences at the University of Waikato (New Zealand) in 1991.



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