Australian Government

BIOREGIONAL ASSESSMENTS

PROVIDING SCIENTIFIC WATER RESOURCE INFORMATION ASSOCIATED WITH COAL SEAM GAS AND LARGE COAL MINES

Coal and coal seam gas resource assessment for the Cooper subregion

Product 1.2 for the Cooper subregion from the Lake Eyre Basin Bioregional Assessment

2 June 2015

A scientific collaboration between the Department of the Environment, Bureau of Meteorology, CSIRO and Geoscience Australia

The Bioregional Assessment Programme

The Bioregional Assessment Programme is a transparent and accessible programme of baseline assessments that increase the available science for decision making associated with coal seam gas and large coal mines. A bioregional assessment is a scientific analysis of the ecology, hydrology, geology and hydrogeology of a bioregion with explicit assessment of the potential direct, indirect and cumulative impacts of coal seam gas and large coal mining development on water resources. This Programme draws on the best available scientific information and knowledge from many sources, including government, industry and regional communities, to produce bioregional assessments that are independent, scientifically robust, and relevant and meaningful at a regional scale.

The Programme is funded by the Australian Government Department of the Environment. The Department of the Environment, Bureau of Meteorology, CSIRO and Geoscience Australia are collaborating to undertake bioregional assessments. For more information, visit http://www.bioregionalassessments.gov.au.

Department of the Environment

The Office of Water Science, within the Australian Government Department of the Environment, is strengthening the regulation of coal seam gas and large coal mining development by ensuring that future decisions are informed by substantially improved science and independent expert advice about the potential water related impacts of those developments. For more information, visit http://www.environment.gov.au/coal-seam-gas-mining/.

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Cover photograph

Cooper Creek near Innamincka, SA, 23 May 2013

Credit: Dr Anthony Budd, Geoscience Australia

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Introduction

The Independent Expert Scientific Committee on Coal Seam Gas and Large Coal Mining Development (IESC) was established to provide advice to the federal Minister for the Environment on potential water-related impacts of coal seam gas (CSG) and large coal mining developments.

Bioregional assessments (BAs) are one of the key mechanisms to assist the IESC in developing this advice so that it is based on best available science and independent expert knowledge. Importantly, technical products from BAs are also expected to be made available to the public, providing the opportunity for all other interested parties, including government regulators, industry, community and the general public, to draw from a single set of accessible information. A BA is a scientific analysis, providing a baseline level of information on the ecology, hydrology, geology and hydrogeology of a bioregion with explicit assessment of the potential direct, indirect and cumulative impacts of CSG and coal mining development on water resources.

The IESC has been involved in the development of *Methodology for bioregional assessments of the impacts of coal seam gas and coal mining development on water resources* (the BA methodology; Barrett et al., 2013) and has endorsed it. The BA methodology specifies how BAs should be undertaken. Broadly, a BA comprises five components of activity, as illustrated in Figure 1. Each BA will be different, due in part to regional differences, but also in response to the availability of data, information and fit-for-purpose models. Where differences occur, these are recorded, judgments exercised on what can be achieved, and an explicit record is made of the confidence in the scientific advice produced from the BA.

The Bioregional Assessment Programme

The Bioregional Assessment Programme is a collaboration between the Department of the Environment, the Bureau of Meteorology, CSIRO and Geoscience Australia. Other technical expertise, such as from state governments or universities, is also drawn on as required. For example, natural resource management groups and catchment management authorities identify assets that the community values by providing the list of water-dependent assets, a key input.

The Technical Programme, part of the Bioregional Assessment Programme, will undertake BAs for the following bioregions and subregions:

- the Galilee, Cooper, Pedirka and Arckaringa subregions, within the Lake Eyre Basin bioregion
- the Maranoa-Balonne-Condamine, Gwydir, Namoi and Central West subregions, within the Northern Inland Catchments bioregion
- the Clarence-Moreton bioregion
- the Hunter and Gloucester subregions, within the Northern Sydney Basin bioregion
- the Sydney Basin bioregion
- the Gippsland Basin bioregion.

Technical products (described in a later section) will progressively be delivered throughout the Programme.

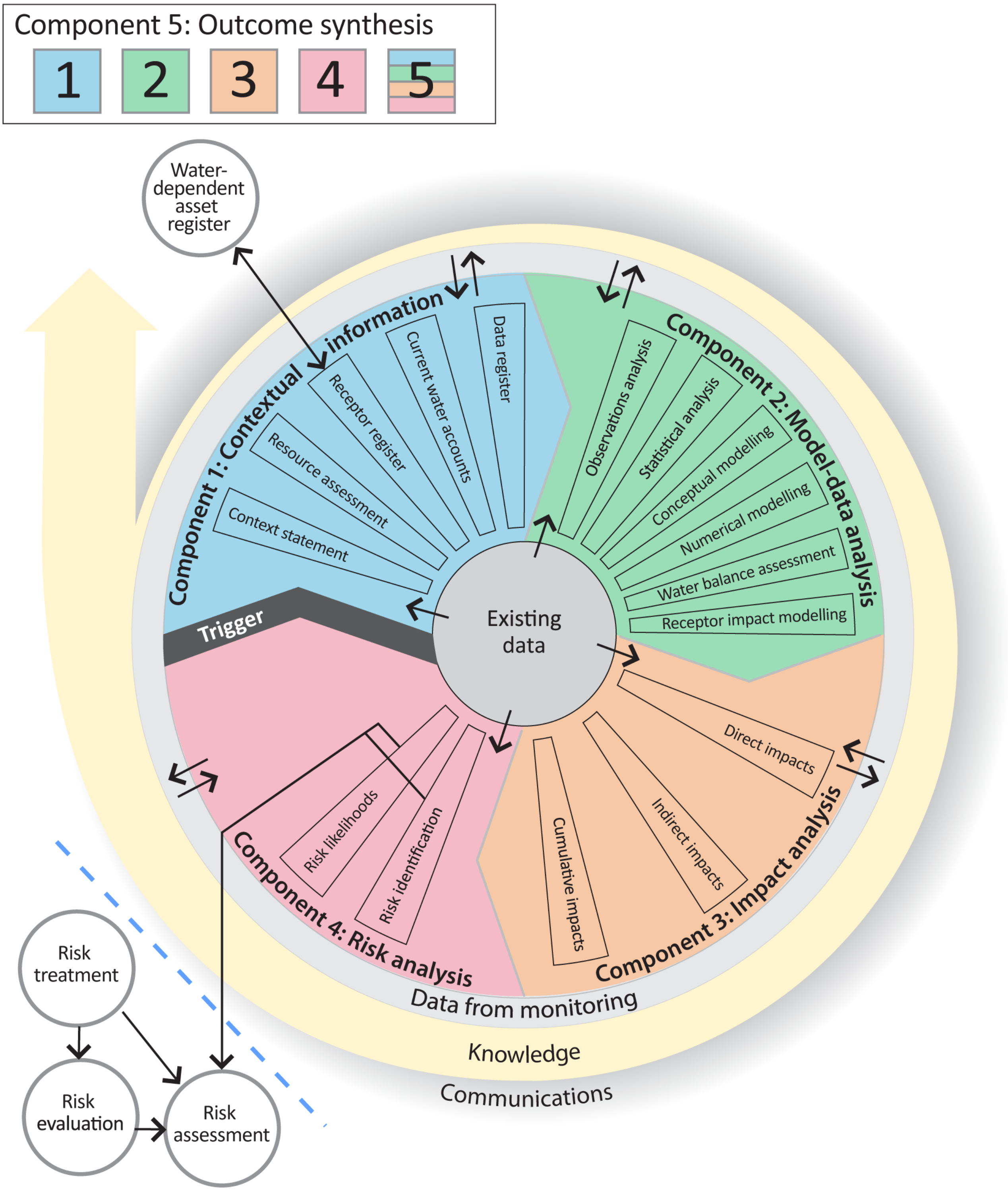


Figure 1 Schematic diagram of the bioregional assessment methodology

The methodology comprises five components, each delivering information into the bioregional assessment and building on prior components, thereby contributing to the accumulation of scientific knowledge. The small grey circles indicate activities external to the bioregional assessment. Risk identification and risk likelihoods are conducted within a bioregional assessment (as part of Component 4) and may contribute activities undertaken externally, such as risk evaluation, risk assessment and risk treatment. Source: Figure 1 in Barrett et al. (2013), © Commonwealth of Australia

Methodologies

For transparency and to ensure consistency across all BAs, submethodologies have been developed to supplement the key approaches outlined in the *Methodology for bioregional assessments of the impact of coal seam gas and coal mining development on water resources* (Barrett et al., 2013). This series of submethodologies aligns with technical products as presented in Table 1. The submethodologies are not intended to be 'recipe books' nor to provide step-by-step instructions; rather they provide an overview of the approach to be taken. In some instances, methods applied for a particular BA may need to differ from what is proposed in the submethodologies – in this case an explanation will be supplied. Overall, the submethodologies are intended to provide a rigorously defined foundation describing how BAs are undertaken.

Table 1 Methodologies and associated technical products listed in Table 2

Code	Proposed title	Summary of content	Associated technical product
M01	*Methodology for bioregional assessments of the impacts of coal seam gas and coal mining development on water resources*	A high-level description of the scientific and intellectual basis for a consistent approach to all bioregional assessments	All
M02	*Compiling water-dependent assets*	Describes the approach for determining water-dependent assets	1.3 Description of the water-dependent asset register
M03	*Assigning receptors and impact variables to water-dependent assets*	Describes the approach for determining receptors associated with water-dependent assets	1.4 Description of the receptor register
M04	*Developing a coal resource development pathway*	Specifies the information that needs to be collected and reported in product 1.2 (i.e. known coal and coal seam gas resources as well as current and potential resource developments). Describes the process for determining the coal resource development pathway (reported in product 2.3)	1.2 Coal and coal seam gas resource assessment 2.3 Conceptual modelling
M05	*Developing the conceptual model for causal pathways*	Describes the development of the conceptual model for causal pathways, which summarises how the 'system' operates and articulates the links between coal resource developments and impacts on receptors	2.3 Conceptual modelling
M06	*Surface water modelling*	Describes the approach taken for surface water modelling across all of the bioregions and subregions. It covers the model(s) used, as well as whether modelling will be quantitative or qualitative.	2.6.1 Surface water numerical modelling
M07	*Groundwater modelling*	Describes the approach taken for groundwater modelling across all of the bioregions and subregions. It covers the model(s) used, as well as whether modelling will be quantitative or qualitative. It also considers surface water – groundwater interactions, as well as how the groundwater modelling is constrained by geology.	2.6.2 Groundwater numerical modelling

Code	Proposed title	Summary of content	Associated technical product
M08	*Receptor impact modelling*	Describes how to develop the receptor impact models that are required to assess the potential impacts from coal seam gas and large coal mining on receptors. Conceptual, semi-quantitative and quantitative numerical models are described.	2.7 Receptor impact modelling
M09	*Propagating uncertainty through models*	Describes the approach to sensitivity analysis and quantifying uncertainty in the modelled hydrological response to coal and coal seam gas development	2.3 Conceptual modelling 2.6.1 Surface water numerical modelling 2.6.2 Groundwater numerical modelling 2.7 Receptor impact modelling
M10	*Risk and cumulative impacts on receptors*	Describes the process to identify and analyse risk	3 Impact analysis 4 Risk analysis
M11	*Hazard identification*	Describes the process to identify potential water-related hazards from coal and coal seam gas development	2 Model-data analysis 3 Impact analysis 4 Risk analysis
M12	*Fracture propagation and chemical concentrations*	Describes the likely extent of both vertical and horizontal fractures due to hydraulic stimulation and the likely concentration of chemicals after production of coal seam gas	2 Model-data analysis 3 Impact analysis 4 Risk analysis

Each submethodology is available online at http://www.bioregionalassessments.gov.au. Submethodologies might be added in the future.

Technical products

The outputs of the BAs include a suite of technical products variously presenting information about the ecology, hydrology, hydrogeology and geology of a bioregion and the potential direct, indirect and cumulative impacts of CSG and coal mining developments on water resources, both above and below ground. Importantly, these technical products are available to the public, providing the opportunity for all interested parties, including community, industry and government regulators, to draw from a single set of accessible information when considering CSG and large coal mining developments in a particular area.

The information included in the technical products is specified in the BA methodology. Figure 2 shows the information flow within a BA. Table 2 lists the content provided in the technical products, with cross-references to the part of the BA methodology that specifies it. The red rectangles in both Figure 2 and Table 2 indicate the information included in this technical product.

This technical product is delivered as a report (PDF). Additional material is also provided, as specified by the BA methodology:

- all unencumbered data syntheses and databases
- unencumbered tools, model code, procedures, routines and algorithms
- unencumbered forcing, boundary condition, parameter and initial condition datasets
- the workflow, comprising a record of all decision points along the pathway towards completion of the BA, gaps in data and modelling capability, and provenance of data.

The PDF of this technical product, and the additional material, are available online at http://www.bioregionalassessments.gov.au.

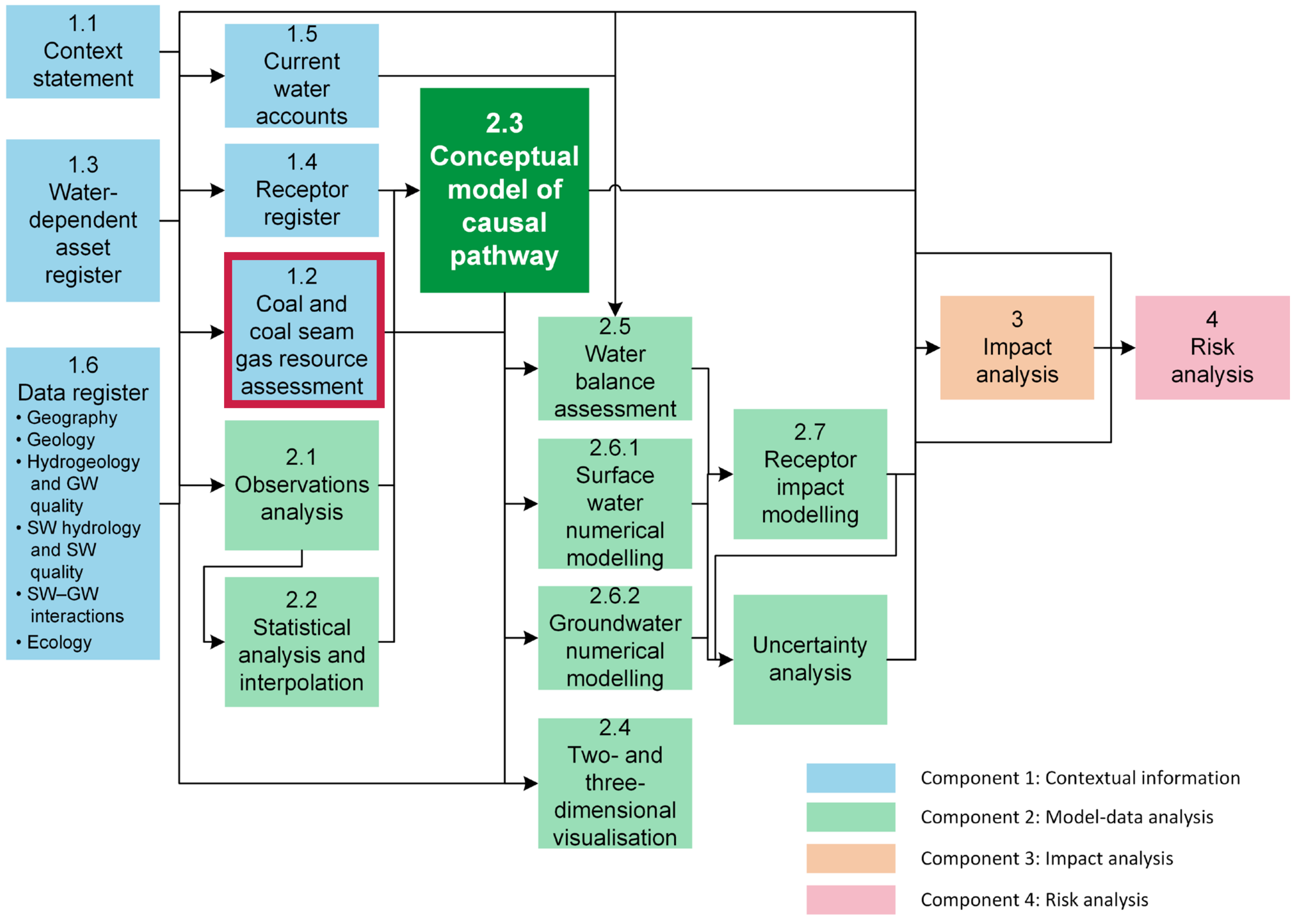


Figure 2 The simple decision tree indicates the flow of information through a bioregional assessment

The red rectangle indicates the information included in this technical product.

Table 2 Technical products delivered by the Lake Eyre Basin Bioregional Assessment

For each subregion in the Lake Eyre Basin Bioregional Assessment, technical products are delivered online at http://www.bioregionalassessments.gov.au, as indicated in the 'Type' column[b]. Other products – such as datasets, metadata, data visualisation and factsheets – are provided online.

Component	Product code	Title	Section in the BA methodology[a]	Type[b]
Component 1: Contextual information for the Cooper subregion	1.1	Context statement	2.5.1.1, 3.2	PDF, HTML
	1.2	Coal and coal seam gas resource assessment	2.5.1.2, 3.3	PDF, HTML
	1.3	Description of the water-dependent asset register	2.5.1.3, 3.4	PDF, HTML, register
	1.4	Description of the receptor register	2.5.1.4, 3.5	PDF, HTML, register
	1.5	Current water accounts and water quality	2.5.1.5	PDF, HTML
	1.6	Data register	2.5.1.6	Register
Component 2: Model-data analysis for the Cooper subregion	2.1-2.2	Observations analysis, statistical analysis and interpolation	2.5.2.1, 2.5.2.2	Not produced
	2.3	Conceptual modelling	2.5.2.3, 4.3	PDF, HTML
	2.5	Water balance assessment	2.5.2.4	Not produced
	2.6.1	Surface water numerical modelling	4.4	Not produced
	2.6.2	Groundwater numerical modelling	4.4	Not produced
	2.7	Receptor impact modelling	2.5.2.6, 4.5	Not produced
Component 3: Impact analysis for the Cooper subregion	3-4	Impact analysis	5.2.1	PDF, HTML
Component 4: Risk analysis for the Cooper subregion		Risk analysis	2.5.4, 5.3	
Component 5: Outcome synthesis for the Lake Eyre Basin bioregion	5	Outcome synthesis	2.5.5	PDF, HTML

[a]*Methodology for bioregional assessments of the impacts of coal seam gas and coal mining development on water resources* (Barrett et al., 2013)

[b]The types of products are as follows:

- 'PDF' indicates a PDF document that is developed by the Lake Eyre Basin Bioregional Assessment using the structure, standards, and look and feel specified by the programme.
- 'HTML' indicates the same content as in the PDF document, but delivered as webpages.
- 'Register' indicates controlled lists that are delivered using a variety of formats as appropriate.
- 'Not produced' indicates that the product was not developed. A webpage explains why and points to relevant submethodologies (Table 1).

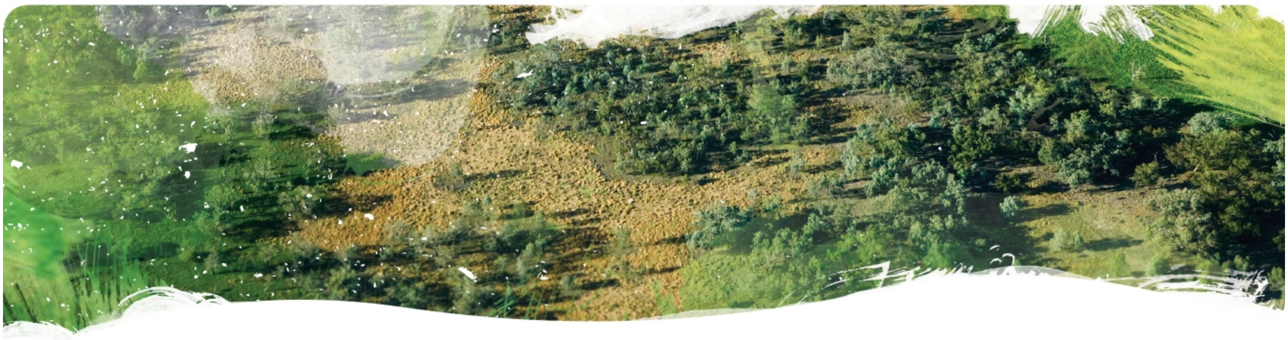
About this technical product

The following notes are relevant only for this technical product.

- All reasonable efforts were made to provide all material under a Creative Commons Attribution 3.0 Australia Licence. The copyright owners of the following figures, however, did not grant permission to do so: Figure 12.
- All maps created as part of this BA for inclusion in this product used the Albers equal area projection with a central meridian of 140.0° East for the Lake Eyre Basin bioregion and two standard parallels of –18.0° and –36.0°.
- Contact bioregionalassessments@bom.gov.au to access metadata (including copyright, attribution and licensing information) for all datasets cited or used to make figures in this product. At a later date, this information, as well as all unencumbered datasets, will be published online.
- The citation details of datasets are correct to the best of the knowledge of the Bioregional Assessment Programme at the publication date of this product. Readers should use the hyperlinks provided to access the most up-to-date information about these data; where there are discrepancies, the information provided online should be considered correct. The dates used to identify Bioregional Assessment Source Datasets are the dataset's published date. Where the published date is not available, the last updated date or created date is used. For Bioregional Assessment Derived datasets, the created date is used.

References

Barrett DJ, Couch CA, Metcalfe DJ, Lytton L, Adhikary DP and Schmidt RK (2013) Methodology for bioregional assessments of the impacts of coal seam gas and coal mining development on water resources. A report prepared for the Independent Expert Scientific Committee on Coal Seam Gas and Large Coal Mining Development through the Department of the Environment. Department of the Environment, Australia. Viewed 7 September 2015, http://www.iesc.environment.gov.au/publications/methodology-bioregional-assessments-impacts-coal-seam-gas-and-coal-mining-development-water.



1.2 Coal and coal seam gas resource assessment for the Cooper subregion

The coal and coal seam gas resource assessment summarises the known coal and coal seam gas resources, and developments both now and potentially in the future. The following data and information are presented:

- the geology and spatial distribution of known coal resources
- the baseline of current coal and coal seam gas extraction
- exploration and mining tenements
- proposed future developments (both new developments and expansion or closure of existing developments), including details of location, timing, methods and extraction volumes as determined from proposed development plans.

This information will be used to develop the coal resource development pathway (as reported in product 2.3), which articulates the most likely combination of developments at a subregion or bioregion scale, including all individual coal and coal seam gas resource projects that are expected.

1.2.1 Available coal and coal seam gas resources

Summary

Coal occurs within the Permian rocks of the Tirrawarra Sandstone, Patchawarra, Epsilon, Daralingie and Toolachee formations of the geological Cooper Basin. Coal is also recorded in the Jurassic Birkhead Formation and Cretaceous Winton Formation of the geological Eromanga Basin, stratigraphically overlying the Cooper Basin. Lignite is found in the Cenozoic Eyre Formation, of the geological Lake Eyre Basin, overlying the Eromanga Basin. Mining development is precluded because the depth to major coal seams is greater than 1000 m.

Gas is associated with coal-bearing units throughout the Cooper subregion. Coal seam gas (CSG) production does not currently occur as a stand-alone operation in the Cooper subregion, although since 2010 the southern margin has been the focus of detailed CSG exploration and appraisal. The Weena Trough, in particular, has the most advanced CSG-only development occurring in it.

As the Bioregional Assessment Programme is focused on coal and CSG resource developments, this report does not consider other unconventional gas systems (such as shale or tight gas), composite unconventional gas systems[1], or conventional gas resources because it is not possible to separate the source within a composite system.

The Cooper subregion lies across the SA–Queensland border (including a small area of NSW at Cameron Corner), occupying approximately 130,000 km^2 (Figure 3). The geological setting, stratigraphy, basin architecture and structural and tectonic history of the Cooper subregion are summarised in companion product 1.1 for the Cooper subregion (Smith et al., 2015). This report provides further detail on the subregion's coal-bearing units from the Cooper and Eromanga geological basins, and their resource potential. The coal and coal seam gas resource assessment for the Cooper subregion has been carried out according to companion submethodology M04 for developing a coal resource development pathway (Lewis, 2014).

[1] A composite unconventional gas system is a hydrocarbon resource characterised by multiple potential reservoir types within the gas saturated zone. For example, it may be a stacked shale gas and coal seam gas resource.

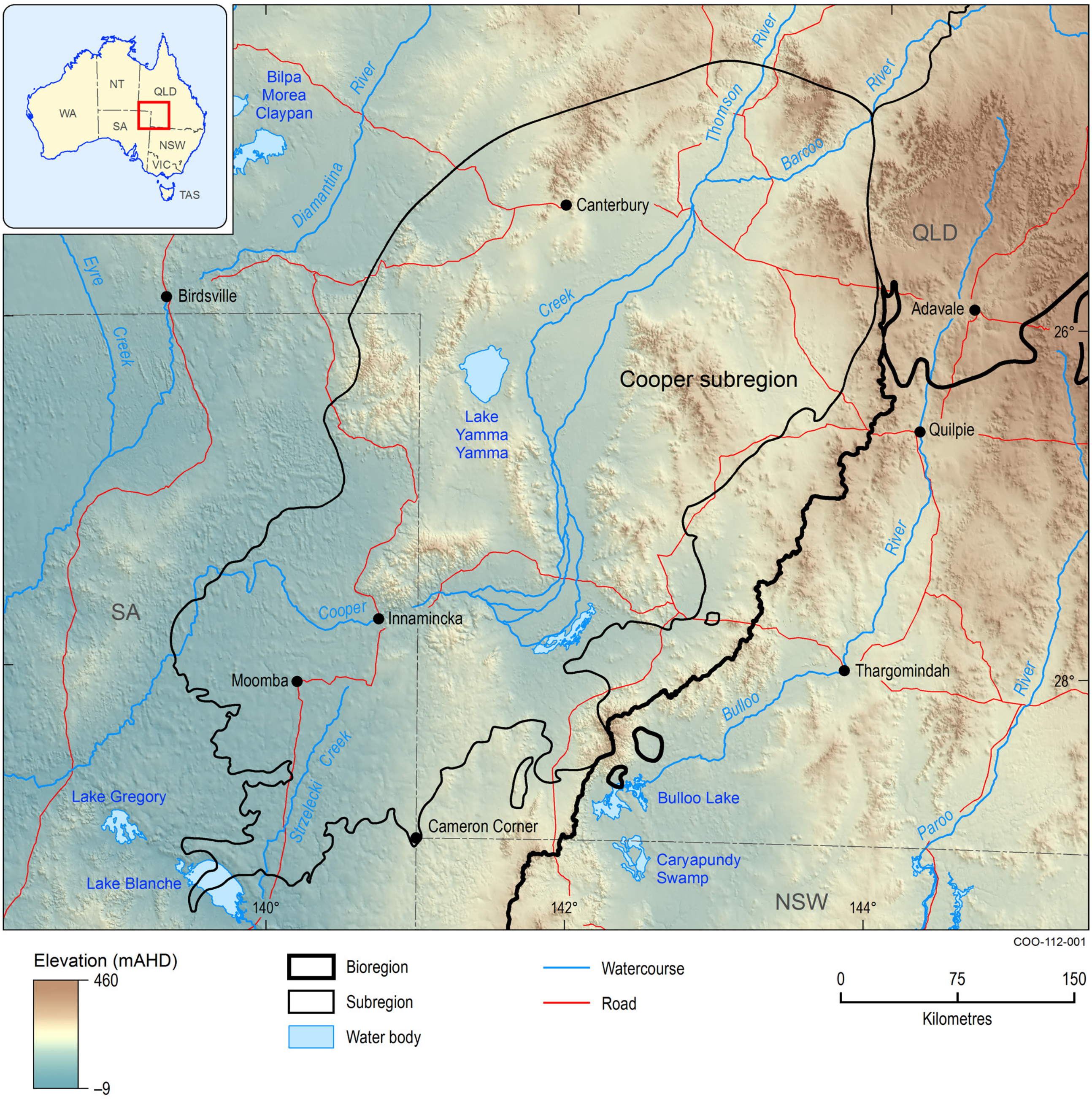


Figure 3 Location and topography of the Cooper subregion

Data: Geoscience Australia (Dataset 1)

The Cooper-Eromanga Basin system is the largest hydrocarbon-producing onshore basin in Australia. Conventional oil and gas have been produced from fields in the Cooper Basin since the 1960s. Gas processing facilities are located at Moomba in SA and Ballera in Queensland, and oil processing facilities at Moomba in SA and Eromanga and Jackson in Queensland. There are approximately 190 producing gas fields, with approximately 820 gas wells, and approximately 115 producing oil fields and 400 producing oil wells in the Cooper Basin (Santos, 2014). Geoscience Australia and BREE (2014) report total production of 6926 petajoules (PJ) and remaining resources of 1693 PJ for conventional gas resources from the Cooper-Eromanga Basin system. The Eromanga Basin is predominantly oil-producing with minor gas. In contrast, the Cooper Basin is gas-dominant with a considerable light liquid component. Oil and gas production in the Cooper Basin has been from eight formations in a thick sequence containing several coal-bearing units and carbonaceous siltstones, predominantly from the Gidgealpa Group (Radke, 2009).

Recent exploration, appraisal, and production activity has also focused on basin-centred gas, shale gas, deep coal seam gas, and composite hydrocarbon resources. Coal seam gas (CSG) was recognised as a potentially economic resource target in the Cooper Basin in 2000 (Simon, 2000), and exploration wells dedicated to CSG were drilled from 2007. More information on these unconventional oil and gas resources can be found in Goldstein et al. (2012), Geological Survey of Queensland (2012) and the Australian Gas Resource Assessment (Geoscience Australia and BREE, 2012, 2014).

1.2.1.1 Coal

Coal occurs within the Permian rocks of the Tirrawarra Sandstone, Patchawarra, Epsilon, Daralingie and Toolachee formations of the geological Cooper Basin (Figure 4). Coal thickness and distribution maps for the Patchawarra and Toolachee formations are provided in companion product 1.1 for the Cooper subregion (Smith et al., 2015). In addition, coal seams have also been recorded in the overlying geological Eromanga Basin, particularly the Jurassic Birkhead Formation and Cretaceous Winton Formation. Lignite occurs in the Cenozoic Eyre Formation (Smith et al., 2015). Further information on coal classifications can be found in Appendix A.

There are no identified coal resources currently reported in the Cooper subregion (as per Australia's national classification for mineral resources, see Appendix A). There are no coal mining tenements and only one exploration tenement in the Cooper subregion as the depth to major coal seams is greater than 1000 m, which is too deep for economic extraction.

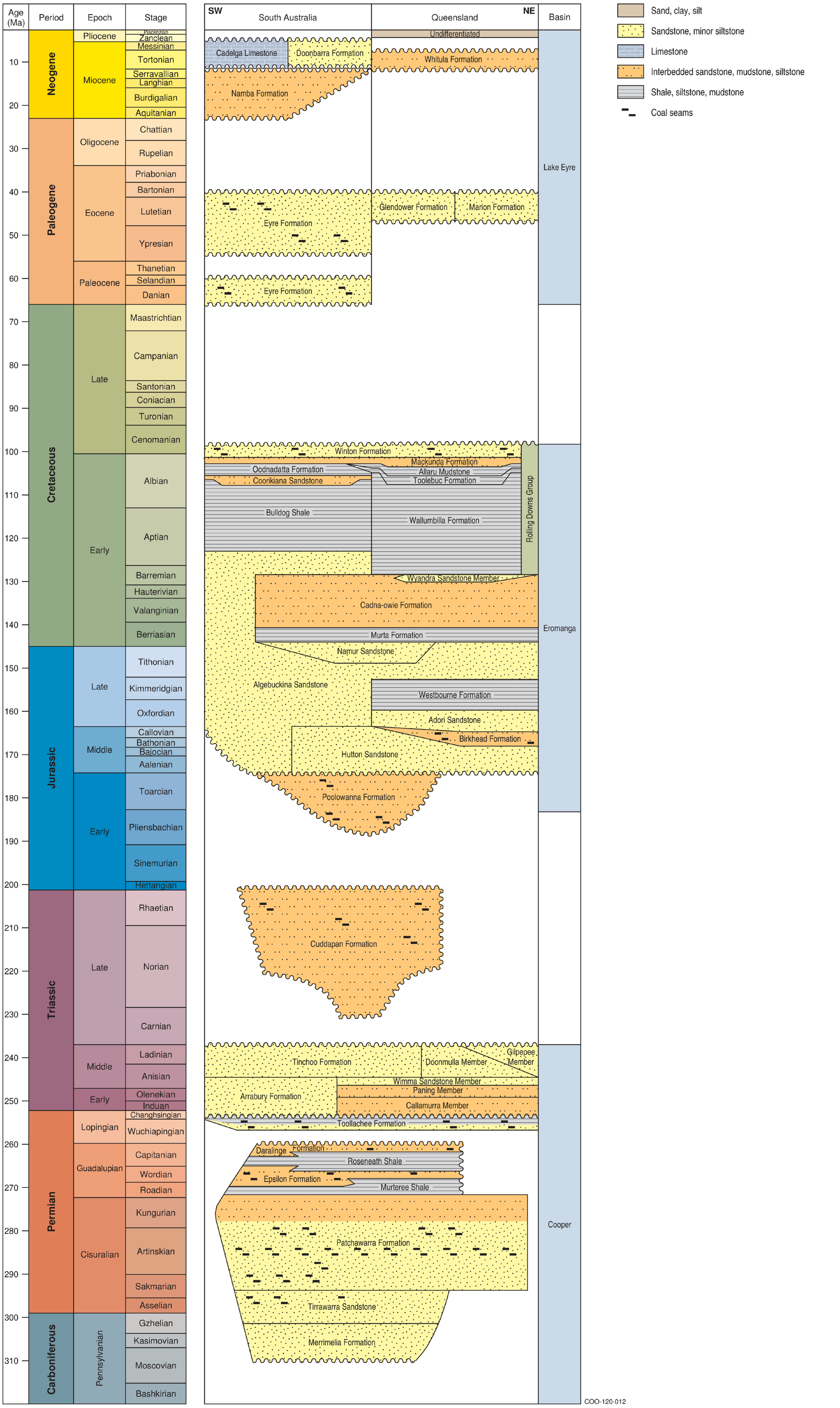


Figure 4 Stratigraphy of the Cooper subregion, showing geological ages, units, rock types and basin associations

Data: Alexander et al. (1998), Alexander et al. (2006), Alley (1998), Draper (2002), Golder Associates (2011), Gray and McKellar (2002), Gray et al. (2002), Moussavi-Harami (1996), Radke (2009), Ransley (2012a, 2012b), Santos (2003)

The stratigraphy of the Cooper Basin is being refined by Geoscience Australia, SA and Queensland agencies. Where possible, this will be reflected in subsequent products for the Cooper subregion.

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

1.2.1.1.1 Patchawarra Formation coal

Patchawarra Formation coal seams average 2.1 m thick but can be 22 to 30 m, with 30% of seams exceeding 2 m thick (Alexander et al., 1998). The thickest laterally extensive coal seam in the Patchawarra Formation is known as the VC50 coal. It ranges in thickness from 13 to 23 m, and is thickest in the Nappamerri and Patchawarra troughs (in the western part of the basin, see Figure 5). Recently reported coal intersections in the Weena Trough includes a 45 m thick seam in the Patchawarra Formation, part of an 89 m net coal interval (Strike Energy Limited, 2014b). The Patchawarra Formation is sufficiently mature to generate gas from coal seams over much of the basin, and elevated gas readings are recorded when mature Patchawarra Formation coals are intersected in wells. Given that depths (from surface) to the coal-bearing Patchawarra Formation exceed 1000 m across the subregion, there is no potential for coal to be mined (Menpes et al., 2012).

Davenport-1/ST1, an unconventional gas exploration well, was drilled into the Milpera Trough, with the aim of testing the thickest, most thermally mature coals (Beach Energy, 2012a). This well encountered thick Permian coal seams, notably a 10 m thick seam from the Toolachee Formation, a 29 m thick seam in the Epsilon Formation, and 19.5 m thick Vm3 seam and 40 m thick Vu seam from the Patchawarra Formation. The thickest Toolachee Formation coal (1611 to 1621 m depth) is described as black, subvitreous to vitreous, silty, grading to carbonaceous siltstone, firm to moderately hard. The thickest Epsilon Formation coal (1697 to 1726 m depth) is described as black, subvitreous to vitreous, brittle to hard, with silty sections. The Patchawarra Vm3 seam (1905 to 1926 m depth) is described as black to brownish black, dull, with vitreous laminations, brittle to hard, and grading to silty in places. The Vu coal (1975 to 2012 m depth) is described as black, dull to subvitreous, soft to firm. The Vm3 and Vu coal seams were sampled, and analyses undertaken to determine gas characteristics. Proximate analyses of the Patchawarra coal seams had an average ash content of 3.66%, average moisture content of 3.33%, average volatile matter content of 29.23% and average fixed carbon content of 63.78% (Beach Energy, 2012a).

Coal seam gas (CSG) exploration well Forge-1 in the Weena Trough encountered 24 m total thickness of coal from the Permian section (Figure 6). This included a 16.5 m interval (intersected at 1313 to 1329.5 m depth) cored from the Patchawarra Formation, described as a black, dull, earthy coal. Proximate analyses of the Patchawarra Formation coal indicated average ash content of 4.86%, average moisture content of 12.03%, average volatile matter content of 35.78% and average fixed carbon content of 47.34% (Strike Energy Limited, 2010).

CSG appraisal wells in the Weena Trough at Le Chiffre-1, Klebb-1, Klebb-2 and Klebb-3 have intersected up to 147 m of total coal thickness (Strike Energy Limited, 2015), with up to 89 m of coal in the Patchawarra Formation. The main coal seams intersected in these wells are the Vm3 and Vu seams. The Vu seam is up to 45 m thick (Strike Energy Limited, 2014b). These are the thickest cumulative and individual coal thicknesses recorded in the Patchawarra Formation, as well as the wider Cooper Basin.

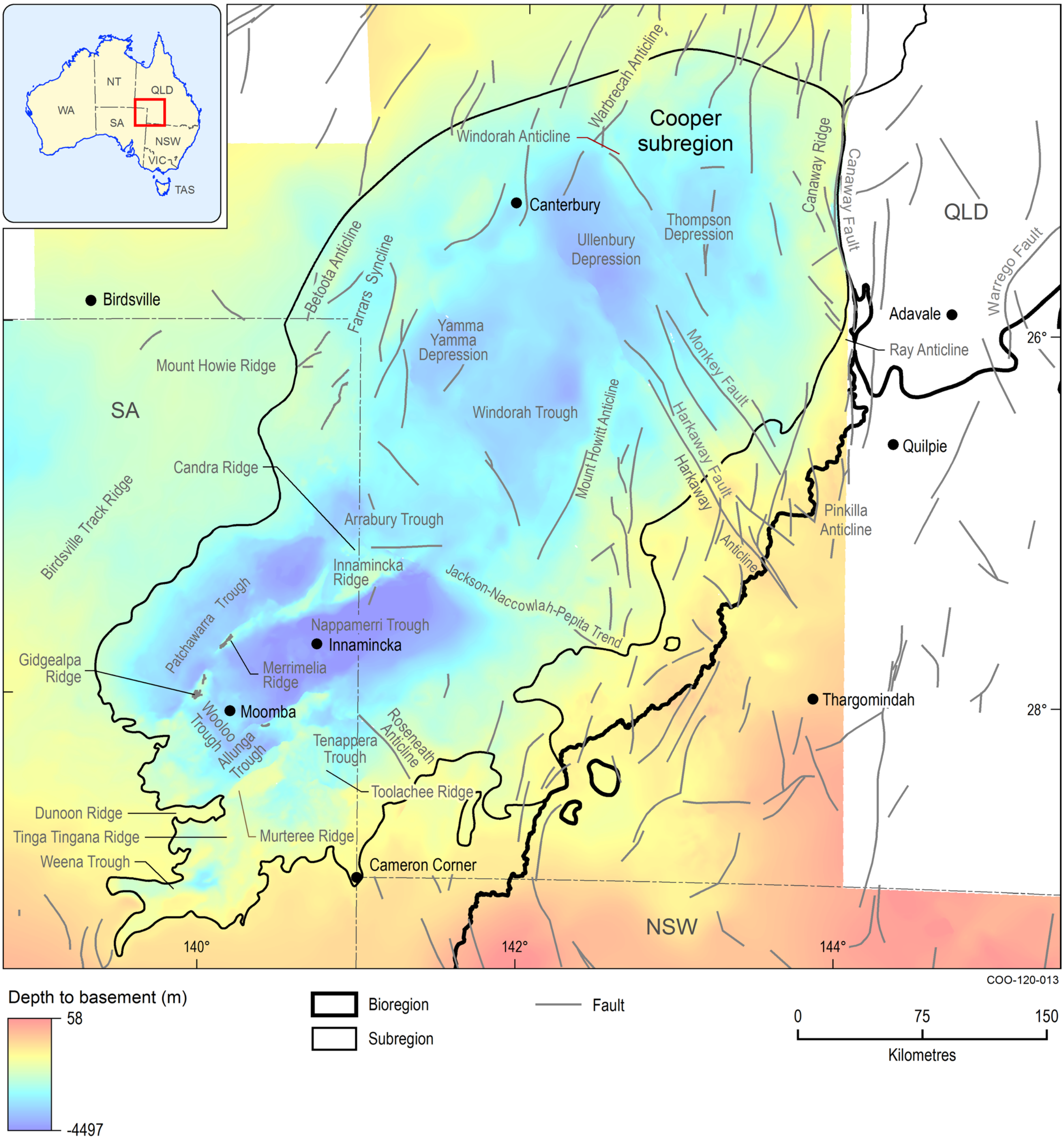


Figure 5 Cooper Basin structural elements shown over depth to basement image

Depth to basement image is the seismic z-horizon. This is the top of the Warburton Basin, interpreted from seismic data and well intersections.

Data: Draper (2002b), Geoscience Australia (Dataset 2), Gravestock and Jensen-Schmidt (1998), Ransley et al. (2012b), Department for Manufacturing, Innovation, Trade, Resources and Energy (DMITRE), South Australia (Dataset 3)

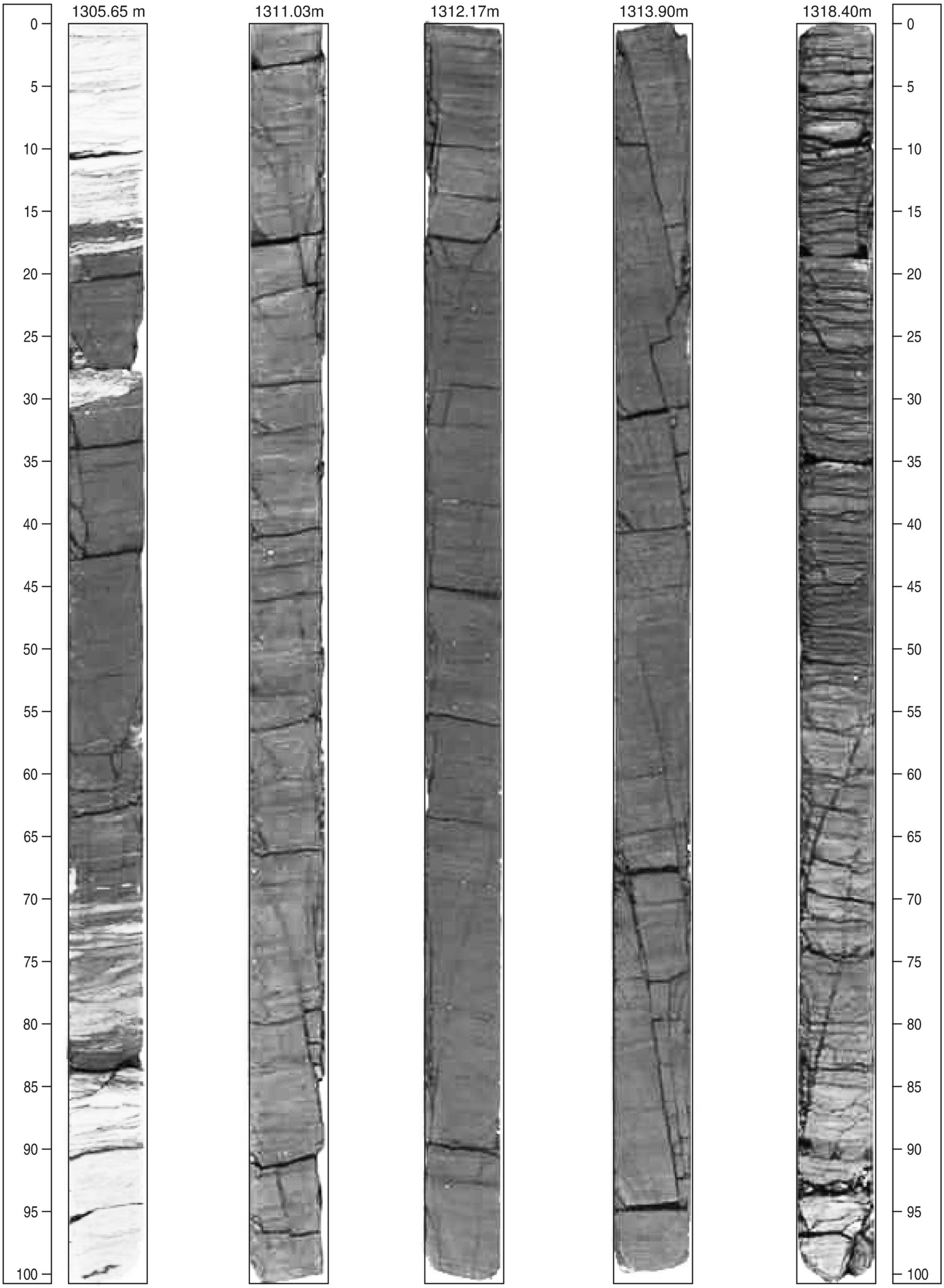


Figure 6 Example of Patchawarra Formation coal from Forge-1 coal seam gas exploration well

This core photograph shows the uniform black, earthy coal with silty interbeds from the Weena Trough.
Source: Strike Energy Limited (2010, p. 248, Appendix 5) © Strike Energy

1.2.1.1.2 Toolachee Formation

Thick, laterally extensive coal seams are characteristic of the Toolachee Formation. The average coal seam thickness in the Toolachee Formation is 4.3 m, but individual seams may be up to 22 m. Forty-two percent of coal seams exceed 2 m thickness (Alexander et al., 1998). The Toolachee Formation coals are sufficiently mature for thermogenic gas generation in the Nappamerri and Arrabury troughs, and parts of the Patchawarra Trough. In addition, high mud gas readings (natural gas readings detected in returned drilling muds) have commonly been recorded during drilling through mature Toolachee Formation coals (Menpes et al., 2012). Coal in the Toolachee Formation intersected in drilling has been described as black to greyish black, dull to subvitreous, moderately hard to firm and variably silty (e.g. Beach Energy, 2012a, 2012b; Santos Limited, 1988, 1997).

1.2.1.1.3 Other coal-bearing units

The Epsilon and Daralingie formations within the Permian sequence of the Cooper Basin also contain coal seams of varying thickness and quality. The Epsilon Formation is generally considered as part of the Roseneath – Epsilon – Murteree shale gas target sequence (Goldstein et al., 2012). Coal in the Epsilon Formation is described as black to greyish black, dull to vitreous, moderately hard to firm and variably silty (Beach Energy, 2012a, 2012b; Beach Petroleum Limited, 2004; Santos Limited, 1988; Strike Energy Limited, 2010).

Coal seams are a minor component of the Permian Daralingie Formation, and have been intersected in some petroleum exploration wells. Such coals are described as black, subvitreous to vitreous, hard to brittle and silty (Beach Energy, 2012b; Santos Limited, 1988, 1990, 1993; Senex Energy Limited, 2011). It generally occurs as minor interbeds within siltstone or shale-dominated sequences, with individual seams up to 1 m thick (Santos Limited, 1988). The Tirrawarra Sandstone is reported to contain trace coal intersections (Alexander et al., 1998).

The principal coal-bearing unit in the Eromanga Basin is the Winton Formation, comprising up to 1200 m of non-marine shale and siltstone with minor coal layers. Individual coal seams are thin (1 to 2 m) and not laterally extensive. The Winton Formation coals may be sufficiently mature to generate thermogenic gas in some parts of the subregion, however, the thin, discontinuous nature of the seams and low gas contents are below current commercial thresholds (Goldstein et al., 2012). Coal also occurs in the Birkhead Formation, with seams generally less than 1 m thick. The Birkhead Formation becomes progressively sandy from the north-east to the south and south-west at the expense of coal.

The Eyre Formation includes beds of lignite and clay, with minor root horizons. Carbonaceous lithologies are commonly leached in outcrop. The lignite beds are thin and of low quality (Callen et al., 1995).

1.2.1.2 Coal seam gas

Coal in the Cooper Basin is widely recognised as a major hydrocarbon-generating source for the Cooper–Eromanga petroleum system (e.g. Radke, 2009). However, coal seam gas is generally not targeted as a stand-alone resource; rather it is part of combined hydrocarbon targets, commonly occurring with tight gas and shale gas at the same locality.

In the Cooper subregion, there are no current or historic CSG production facilities. This section describes the general characteristics of coal seam gas reported in exploration drilling in the Cooper subregion. A prospective, CSG-only resource, subject to further appraisal, has been reported in the Weena Trough by Strike Energy Limited. This is discussed in more detail in Section 1.2.3.

Gas peaks associated with coal seams of the Patchawarra, Epsilon and Toolachee formations have been recorded during drilling operations throughout the Cooper Basin. Such gas generally has low water content, relatively low carbon dioxide (less than 35%) and is high in methane (greater than 60%).

Gas from the Patchawarra coal seams intersected in exploration well Davenport-1/ST1 is primarily methane (51.2 mol %), carbon dioxide (25.8 mol %), nitrogen (16.8 mol %), ethane (4.8 mol %), and propane and heavier hydrocarbons (1.5 mol %). The Vm3 seam has an average gas content of 24.8 standard cubic centimetres per gram (scc/g) on a dry, ash-free basis, comprising 84% *lost gas*[2], 14% *measurable gas*[3] and 1.7% *residual gas*[4]. The Vu seam has an average gas content of 22.5 scc/g. This comprises 81% *lost gas*, 17% *measurable gas* and 1.7% *residual gas* (Beach Energy, 2012a). The desorbed gas composition from exploration well Davenport-1/ST1 exhibited the characteristics shown in Table 3 and Table 4.

Table 3 Desorbed gas analyses for the Patchawarra Formation Vm3 coal seam from Davenport-1/ST1

	Methane	Ethane	Propane	i-Butane	n-Butane	Carbon dioxide
Early	61.2%	2.7%	0.4%	0.1%	0.1%	35.7%
Mid	58.1%	4.6%	1.1%	0.2%	0.1%	36.0%
Late	60.8%	11.6%	3.0%	0.5%	0.1%	24.1%

Data: Beach Energy (2012a)
Nitrogen and oxygen were set to zero for this analysis
'Early' refers to gas released in the early stages of desorption testing, 'Mid' refers to gas released in the main part of the test, and 'Late' to the later stages of testing
Average analyses for sample taken from 1905.4 to 1923.6 m depth

[2] Lost gas: gas content calculated using time the sample desorbed before being placed into the test canister, and the rate of desorption during the testing period

[3] Measurable gas: gas content measured during the test period

[4] Residual gas: gas content measured following crushing the sample following desorption testing, or calculated using desorption results

Table 4 Desorbed gas analyses for the Patchawarra Formation Vm3 coal seam from Davenport-1/ST1

	Methane	Ethane	Propane	i-Butane	n-Butane	Carbon dioxide
Early	64.2%	2.5%	0.5%	0.0%	0.0%	32.8%
Mid	58.6%	12.3%	2.2%	0.3%	0.1%	26.4%
Late	65.3%	11.8%	3.6%	0.5%	0.1%	18.7%

Data: Beach Energy (2012a)
Nitrogen and oxygen were set to zero for this analysis
’Early‘ refers to gas released in the early stages of desorption testing, ’Mid‘ refers to gas released in the main part of the test, and ’Late‘ to the later stages of testing
Average analyses for sample taken from 1975.75 to 2002.3 m depth

Gas from the 16.5 m thick Patchawarra Formation coal in exploration well Forge-1 had a gas content of 0.94 scc/g on a dry, ash-free basis; comprising 22% *lost gas*, 76% *desorbed gas* and 2% *residual gas* (Strike Energy Limited, 2010). The desorbed gas exhibited the characteristics shown in Table 5. The favourable gas compositions from the Patchawarra coal have resulted in follow-up drilling, appraisal and production testing (for example Strike Energy Limited, 2014a).

Table 5 Desorbed gas analyses for Forge-1 Patchawarra Formation coal

	Methane	Ethane	Propane	i-Butane	n-Butane	Carbon dioxide
Early A	64.3%	1.1%	0.3%	0.0%	0.0%	34.4%
Early B	61.4%	1.3%	0.4%	0.0%	0.0%	36.9%
Mid	57.1%	2.1%	0.8%	0.1%	0.1%	39.8%
Late	74.4%	1.8%	0.4%	0.1%	0.0%	23.3%

Data: Strike Energy Limited (2010)
Nitrogen and oxygen were set to zero for this analysis
‘Early’ refers to gas released in the early stages of desorption testing, ‘Mid’ refers to gas released in the main part of the test, and ‘Late’ to the later stages of testing
Average analyses for sample taken from 1313 to 1329.5 m depth

Coal from the Winton Formation intersected in exploration well Merninie-1 was sampled and analysed for gas composition. The dry, ash free gas content for the intersected coal averaged 0.86 scc/g (AGL Energy Limited, 2010). Average desorption analyses for these samples are presented in Table 6. This prospect was not progressed due in part to the gas composition characteristics (AGL Energy Limited, 2010).

Table 6 Desorbed gas analyses for Winton Formation coal from Merninie-1

	Methane	Ethane	Propane	i-Butane	n-Butane	Nitrogen	Carbon dioxide
Early	38.3%	1.2%	0.0%	0.0%	0.0%	55.7%	4.9%
Mid	37.8%	0.9%	0.0%	0.0%	0.0%	66.0%	1.3%
Late	31.5%	0.9%	0.0%	0.0%	0.0%	66.3%	1.3%

Data: AGL Energy Limited (2010)
Oxygen was set to zero for this analysis
'Early' refers to gas released in the early stages of desorption testing, 'Mid' refers to gas released in the main part of the test, and 'Late' to the later stages of testing
Average analyses for sample taken from 452.2 m to 699.0 m depth

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1.2.2 Current activity and tenements

Summary

There are no current coal mines or coal seam gas production operations in the Cooper subregion.

The Southern Cooper Basin Gas Project on the southern flanks of the geological Cooper Basin is the only coal seam gas project in the subregion.

1.2.2.1 Coal

There are no current coal mining activities occurring in the Cooper subregion. There is one Exploration Permit for Coal (EPC) within the subregion, EPC 2907 (Figure 7). Activity on this tenement is focused on defining an in situ deep coal exploration target of 600 to 1020 million tonnes of coal for underground coal gasification (Syngas Power Pty Ltd, 2015). It is unclear which coal-bearing units are being targeted, although coals have been reported in petroleum wells sited within the EPC, from the Winton and Birkhead formations, for example, in Cook-1 (Delhi Petroleum Limited, 1986), and the Toolachee Formation, for example, in Windula-1 (Santos Limited, 2006). Underground coal gasification is out of scope for consideration in the Bioregional Assessment Programme, and as such, EPC 2907 is not further considered.

1.2.2.2 Coal seam gas

There is currently no operational coal seam gas production in the Cooper subregion. The Cooper subregion is covered by 105,550 km^2 of exploration, retention, and production leases and applications (Figure 7) held by 124 companies. This amounts to 81% of the subregion. These tenements are focused on conventional oil and gas resources, as well as shale gas, basin-centred gas, tight gas, deep coal seam gas and combinations of these resource types. Oil and gas production facilities are located at Moomba in SA, and Ballera, Jackson and Eromanga in Queensland. They process hydrocarbons from over 300 fields which are transferred into pipelines servicing the east coast gas market as well as oil refining facilities in SA. Figure 7 shows the exploration, retention and production licences and applications for the Cooper subregion, as well as the oil and gas fields and pipelines.

The Southern Cooper Basin Gas Project encompasses petroleum exploration licence (PEL) 94, PEL 95, and PEL 96 on the southern flanks of the Cooper Basin (Figure 8). Strike Energy Limited and Beach Energy Limited, in conjunction with joint venture partners, have been conducting exploration and appraisal to evaluate the gas resource in deep coal seams in the Weena Trough and Milpera Trough and Tinga Tingana Ridge of the Cooper Basin since 2010, about 100 km south of Moomba in SA (Strike Energy Limited, 2014). More details of the Southern Cooper Basin Gas Project are in Section 1.2.1.2.1 and Section 1.2.3.2.1.

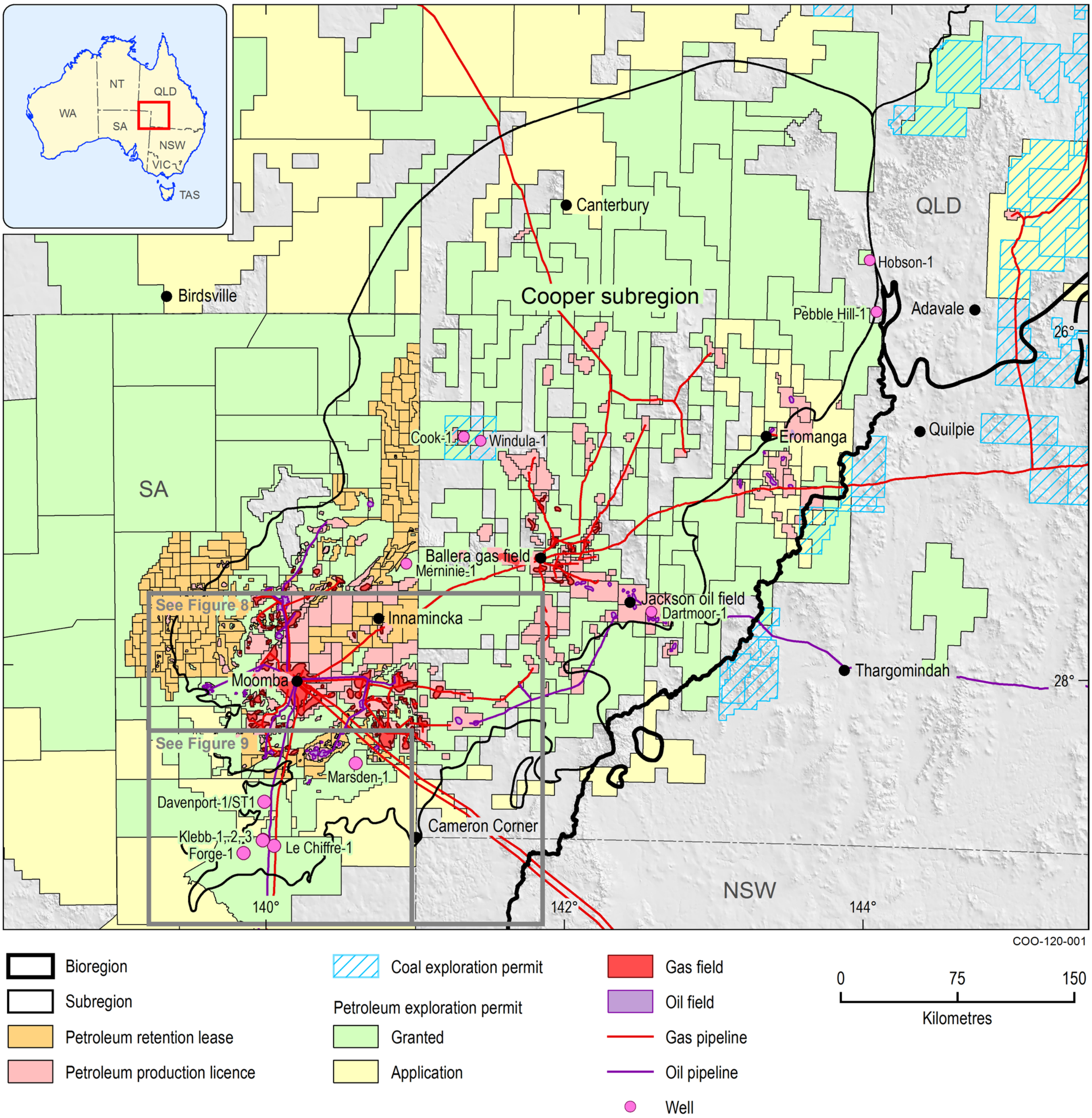

Figure 7 Coal and petroleum tenements in the Cooper subregion

Data: Queensland Department of Natural Resources and Mines (Dataset 1, Dataset 2); SA Department of State Development (Dataset 3, Dataset 4)

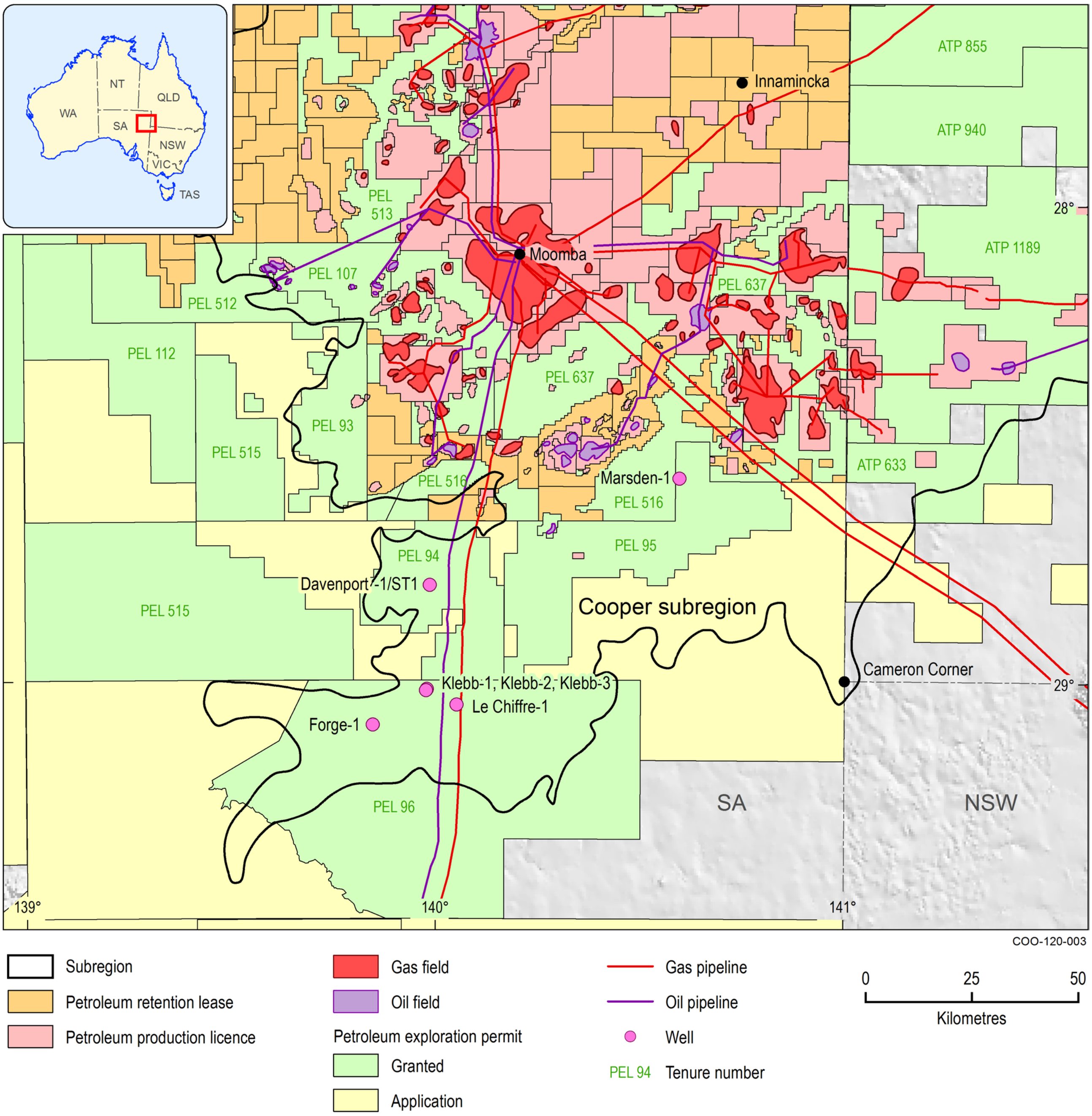

Figure 8 Petroleum tenements covering the southern margin of the Cooper Basin, identified as the most prospective for developments that are only coal seam gas

Data: Queensland Department of Natural Resources and Mines (Dataset 2); SA Department of State Development (Dataset 3, Dataset 4)

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1.2.3 Proposals and exploration

Summary

There is no coal development activity in the Cooper subregion.

There is one coal seam gas (CSG) contingent resource reported in the Cooper subregion. Strike Energy Limited has reported a 2C resource of 168.5 petajoules (PJ) and an 8893 to 23,317 PJ prospective resource for its Southern Cooper Basin Gas Project of which 75% is estimated to be associated with Patchawarra Formation coal. Current testing is underway to prove this resource up, and assess the viability for full-scale production. Strike Energy and Australian Gasfields Ltd are conducting an exploration and appraisal program to evaluate the gas resource in deep coal seams in the Weena Trough and Milpera Trough and Tinga Tingana Ridge of the geological Cooper Basin, about 100 km south of Moomba in SA.

Previous CSG exploration across the subregion has investigated the potential of the Winton Formation and Epsilon Formation coals; however, these have not resulted in the definition of any CSG resources. All other CSG-related gas plays in the Cooper subregion currently under active exploration are part of composite gas plays, including deep coal seam gas targets on the western margin of the Patchawarra Trough. These plays are associated with other continuous unconventional gas plays, including basin-centred, or tight, gas and shale gas, as well as adjacent conventional oil and gas fields.

1.2.3.1 Coal

There is no coal development activity in the Cooper subregion. Given that depth to coal in the Cooper subregion typically exceeds 1000 m (see references in companion product 1.1 for the Cooper subregion (Smith et al., 2015)), there is no prospect of coal mine development in the subregion using current mining methods.

1.2.3.2 Coal seam gas

Core Energy Group (2013) identified total prospective CSG resources for the Cooper-Eromanga region of 38,852 petajoules (PJ), as at 31 December 2012. This estimate does not identify if these resources occur in conjunction with other hydrocarbon resources, or occur as a CSG-only resource, nor are data available at the tenement level. There is one identified CSG resource (as per the Australian National Energy Resources Classification Scheme) reported in the subregion.

Strike Energy has reported an 8893 to 23,317 PJ[1] prospective resource (as per the Society of Petroleum Engineers Petroleum Resource Management System) in its Southern Cooper Basin Gas Project (a joint venture with Australian Gasfields Ltd) in SA, of which 75% is estimated to be

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[1] Strike Energy Limited reported the prospective resource as 8.2 to 21.5 trillion cubic feet (Tcf), which has been converted to PJ using the conversion factor of 1.0845 PJ/Bcf, which is the conversion factor for SA and NSW gas used in Geoscience Australia and BREE (2012).

associated with Patchawarra Formation coal (Strike Energy Limited, 2014b). This resource includes a 2C CSG resource estimate of 168.5 PJ[2] for the Klebb-1 Patchawarra Vu Upper and Le Chiffre-1 Patchawarra Vu Upper and Vu Lower zones within PEL 96 (Strike Energy Limited, 2015a). Current testing is underway to improve resource definition, with the aim of defining CSG reserves, and assessing the viability for full-scale production.

Previous exploration in SA by AGL Energy Limited investigated CSG potential in the Winton Formation with three wells drilled in 2009 (Merninie-1, Merninie-2 and Merninie-3). Due to the lack of reservoir, low gas contents and high levels of gas undersaturation, the 'Innamincka Dome CSG Prospect' was deemed uncommercial (AGL Energy Limited, 2010).

The southern margin of the Cooper Basin in SA has been the main focus of CSG exploration, including in the Weena and Milpera troughs. These are currently covered by Petroleum Exploration Licence (PEL) 94 and PEL 96. Additional exploration for CSG has occurred in the Battunga Trough, in PEL 95. Strike Energy and Beach Energy are involved in pre-development appraisal operations in PEL 94, 95 and 96. Strike Energy is currently undertaking production test operations of CSG-only plays at Klebb-1, Klebb-2 and Klebb-3, and Le Chiffre-1 in PEL 96 (Strike Energy Limited, 2014b). The location of these operations is shown in Figure 9.

CSG exploration wells (Dartmoor-1 (drilled by Santos Limited in 2002), Pebble Hill-1 (drilled by Bow Energy Ltd in 2009) and Hobson-1 (drilled by Bow Energy in 2009)) have been drilled in the Queensland part of the subregion, however no further CSG activity resulted from these programs. Dartmoor-1 encountered a thick coal seam in the Epsilon Formation, however, subsequent testing was unsuccessful (Santos, 2002). Pebble Hill-1 and Hobson-1 targeted CSG in the Winton Formation; however, results did not warrant further CSG exploration (Bow Energy Ltd, 2010). Exploration in Authority to Prospect (ATP) 940 by Drillsearch since 2007 has focused on deep, basin centred and tight gas, which includes deep CSG as part of a composite gas system. Exploration on the northern and western flanks of the Patchawarra Trough has focused on composite unconventional gas targets, including gas associated with deep coal seams of the Patchawarra Formation (Drillsearch Energy Limited, 2015a, 2015b; Santos, 2015).

All other gas exploration targets in the Cooper subregion are part of composite gas plays, or conventional oil and gas resources. Figure 10 shows the distribution of petroleum wells in the subregion, and indicates oil and gas production wells, and wells with hydrocarbon shows. Although composite targets may contain some (generally unspecified) component of CSG, they are associated with other unconventional gas resource types, including basin-centred, or tight, gas and shale gas. This includes areas excised from and immediately adjacent to PEL 94 and PEL 95 (in SA), where drilling has encountered other unconventional gas accumulations, as well as conventional oil and gas occurrences. For example, the Aldinga-1 oil well, within PPL 210, is in an area excised from PEL 95. Oil shows were recorded in conventional exploration wells Maslins-1 (PEL 94) (Beach Petroleum Limited, 2003) and Seacliff-1 (PEL 95) (Beach Petroleum Limited, 2004).

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[2] Strike Energy Limited reported the 2C resource estimate as 155.4 billion cubic feet (Bcf), which has been converted to PJ using the conversion factor of 1.0845 PJ/Bcf, which is the conversion factor for SA and NSW gas used in Geoscience Australia and BREE (2012)

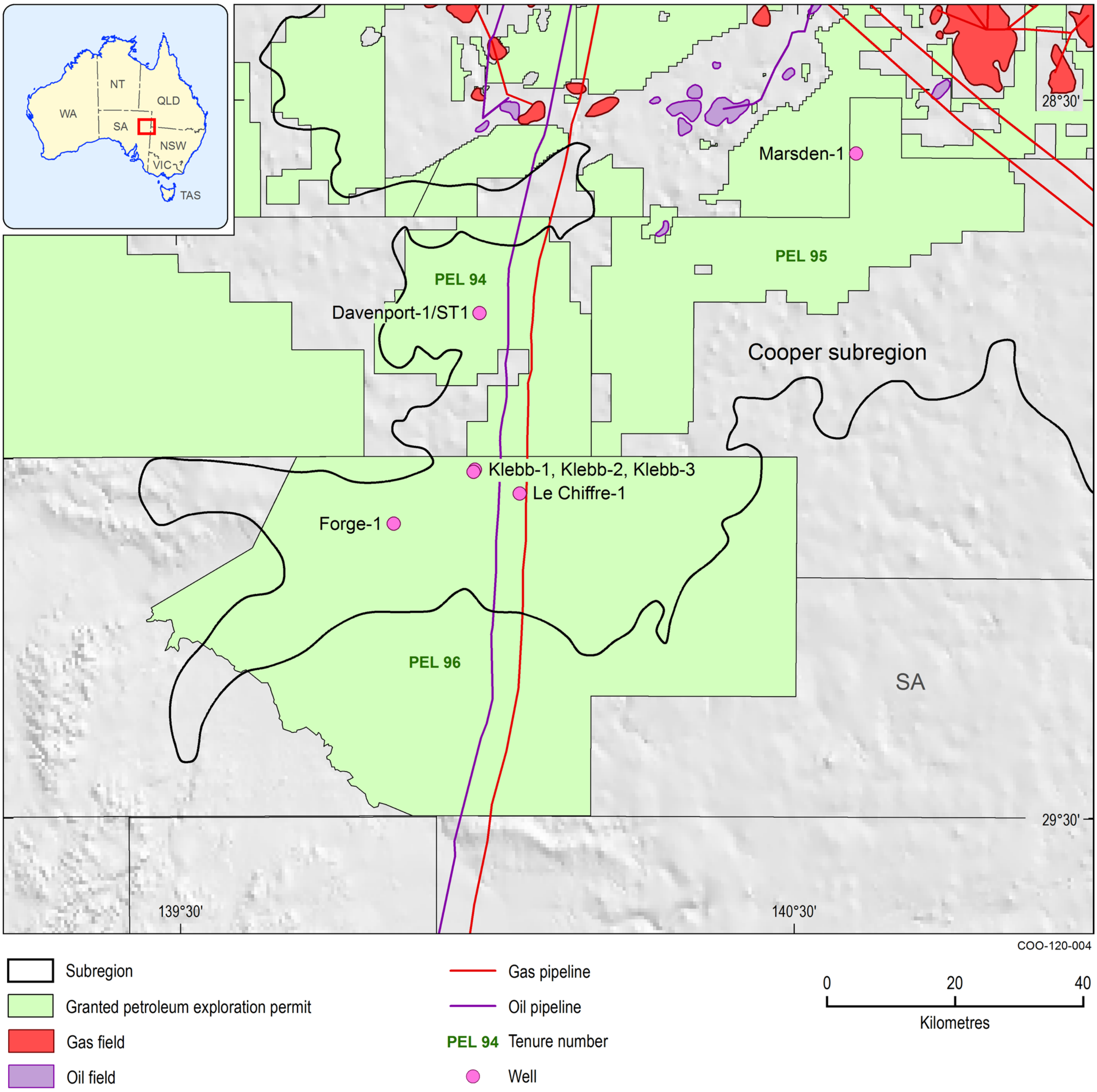

Figure 9 Map showing location of PEL 94, PEL 95 and PEL 96 and location of coal seam gas wells

Data: SA Department of State Development (Dataset 4, Dataset 6)
PEL = petroleum exploration licence

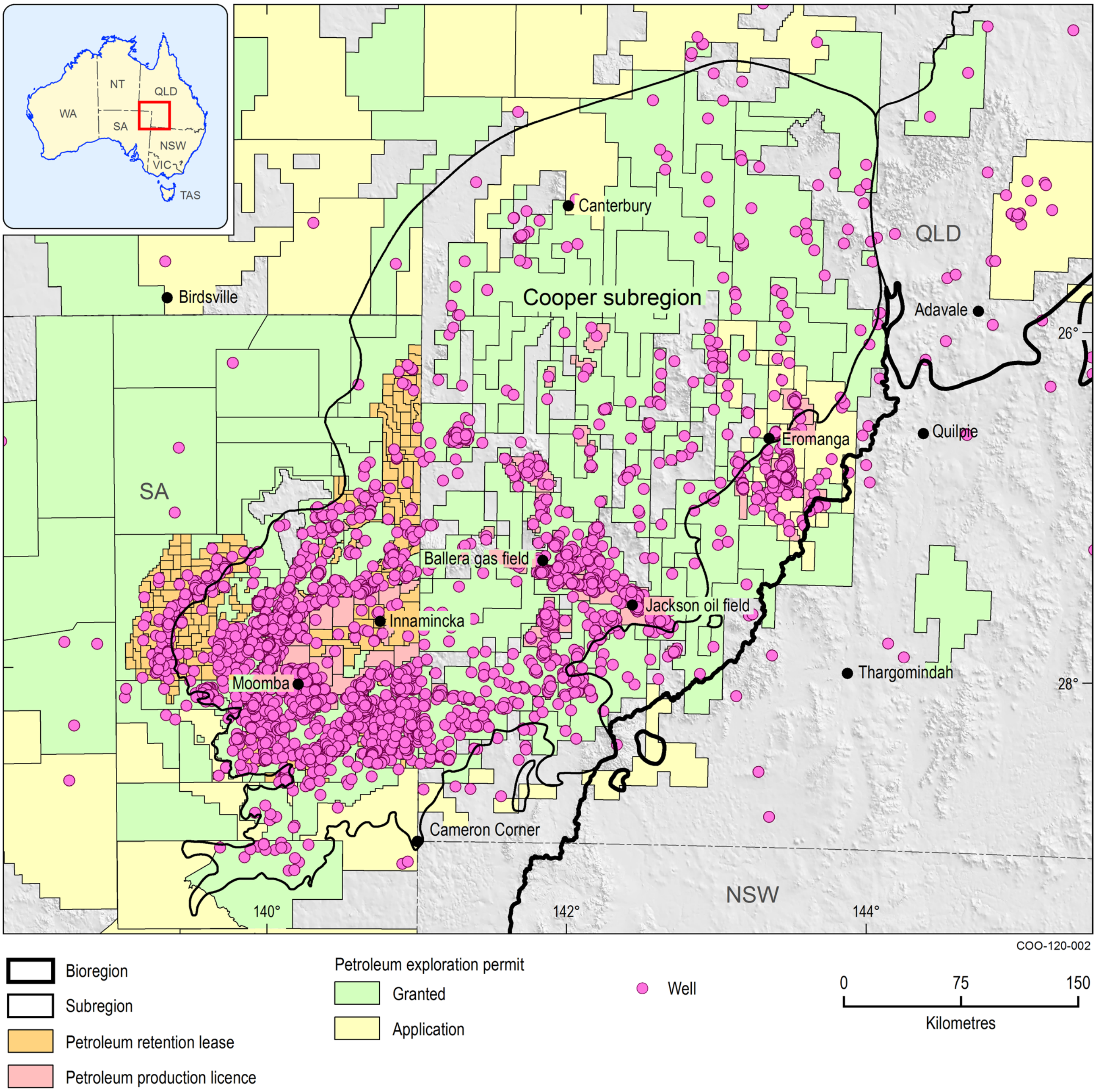

Figure 10 Drilling with an identified hydrocarbon objective in the Cooper subregion

Data: Queensland Department of Natural Resources and Mines (Dataset 1, Dataset 2, Dataset 3), SA Department of State Development (Dataset 4, Dataset 5, Dataset 6)

The prospective resource for the southern margin CSG project is 8893 to 23,317 PJ, of which it is estimated that 75% is attributed to CSG (Strike Energy Limited, 2014b). The Pmean (best) estimate of the prospective resource in PEL 96 is reported as 7375 PJ[3] (Strike Energy Limited, 2014a). Production testing is taking place in the Le Chiffre-1, Klebb-1, Klebb-2 and Klebb-3 wells (Figure 9), targeting coal seams in the Patchawarra Formation at depths of up to 2100 m (Hydrogeologic Pty Ltd, 2014).

Current production testing aims to demonstrate a proved plus probable CSG reserve (2P) during 2015. Development of PEL 96 is planned to occur from late 2015, with gas production targeted to commence in 2017. This is planned as a four-phase appraisal and commercialisation program, undertaken during 2014 and 2015, followed by development and production targeted to commence in 2017. PEL 96 development plans are part of a broader appraisal and production development program for CSG and shale gas from PEL 94, 95 and 96, envisaged to come into full production by 2021 (Strike Energy Limited, 2015b).

Water production rates of up to 240 kilolitres per day (kL/d) per well were estimated prior to production testing. This equates to approximately 44 megalitres (ML) per well over the planned six month testing program (JBS&G Australia Pty Ltd and Strike Energy Limited, 2014). Early production data at Klebb-1 and Le Chiffre-1 showed lower than anticipated water production. Klebb-1 produced 32 kL/d, while Le Chiffre-1 was producing 190 kL/d. Both wells showed rapid water production declines (Hydrogeologic Pty Ltd, 2014).

For production testing in PEL 96, produced water was planned to be directed to storage and evaporation ponds. Smaller lined ponds for fracture stimulation (of 4 ML capacity), and a larger lined pond for produced water. Depending on water quality, earthen ponds in an interdune swale were proposed to provide additional water disposal capacity if required. Planning also allowed for produced water to be reused where possible (JBS&G Australia Pty Ltd and Strike Energy Limited, 2014).

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1.2.4 Catalogue of potential resource developments

Summary

There is only one potential stand-alone coal seam gas resource development currently in the Cooper subregion. This is the Strike Energy Limited and Australian Gasfields Ltd Southern Cooper Basin Gas Project (PEL 96). There are no proposed coal mining developments.

Table 7 Catalogue of potential coal seam gas resource developments in the Cooper subregion

Project name	Company	Longitude	Latitude	Record date[a]	2P coal seam gas reserves[b] (PJ)	Status of EIS[c]	Notes
Southern Cooper Basin Gas Project (PEL 96)	Strike Energy Limited (JV with Australian Gasfields Ltd)	129.98°	–29.02°	Prospective resource estimate for 19 February 2014 2C[e] estimate for Klebb-1 Patchawarra Vu Upper zone and Le Chiffre-1 Patchawarra Vu Upper and Vu Lower zones 31 March 2015	Not yet defined	Supplementary EIS	• PEL 96 Prospective CSG resource: 7375 PJ[d] • PEL 96 Le Chiffre-1 Patchawarra Vu Upper and Vu Lower zone 2C[e] CSG resource: 101.1 PJ[f] • PEL 96 Klebb-1 Patchawarra Vu Upper zone 2C[e] CSG resource: 67.5 PJ[f] • SEIS submitted for multi-well appraisal testing • Source: JBS&G Australia Pty Ltd and Strike Energy Limited (2014); Strike Energy Limited (2014a, 2014b, 2015a, 2015b)

[a]The record date is the most recent date for updated coal seam gas resource numbers.
[b]The Petroleum Resource Management System of the Society of Petroleum Engineers (PRMS-SPE) code 2P refers to estimated quantities of proved reserves plus probable reserves (See Appendix A).
[c]The status of the project within an environmental impact statement (EIS): pre-EIS, EIS in preparation, EIS submitted, EIS closed, supplementary EIS, EIS approved
[d]The prospective resource has been reported for PEL 96 as 6.8 trillion cubic feet (Tcf). This was converted to PJ using the conversion factor for SA and NSW natural gas of 1.0845 PJ/Bcf from Geoscience Australia and BREE (2012).
[e]The Society for Petroleum Engineers Petroleum Resource Management System (SPE-PRMS) code 2C refers to estimated quantities of Contingent resources. Contingent Resource Estimates are those quantities of gas (produced gas less carbon dioxide and fuel gas) that are recoverable from known accumulations but which are not yet considered commercially recoverable (See Appendix A).
[f]The 2C resource estimates have been reported as 93.2 and 62.2 Billion cubic feet (Bcf) for the Le Chiffre and Klebb-1 wells respectively (for a combined 2C resource estimate of 155.4 Bcf). This was converted to PJ using the conversion factor for SA and NSW natural gas of 1.0845 PJ/Bcf from Geoscience Australia and BREE (2012)

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Appendix A Coal and coal seam gas resource and reserve classification schemes and coal classifications

A.1 Society for Petroleum Engineers Petroleum Resource Management Scheme resource and reserve types

The Society for Petroleum Engineers Petroleum Resource Management System (SPE-PRMS) classification scheme is for petroleum resources (including CSG) referred to throughout this report, standardises the approach to classifying and reporting for petroleum and gas reserves and resources (SPE et al., 2011). The SPE-PRMS resource classification framework is compatible with the Australia national classification system, and the classifications are included in Figure 11 as petroleum resource and reserve descriptions.

A.2 Australian resource classification scheme

The classification of Australia's coal resources is based on the national system for classifying identified mineral resources (Geoscience Australia and BREE, 2014). This classification scheme provides a suitable and readymade framework that is used as the initial basis for helping to determine the coal resource development pathway in each bioregion and subregion.

The publicly reported data and information are compiled, evaluated and aggregated into the various categories of the national classification scheme to provide a reliable estimate of the national resource base. The national resource classification scheme recognises resources based on the degree of geological assurance of the commodity, coupled with the economic feasibility of extracting the resource (either now or into the future). The former is based on the type, tonnage and grade of the resource, whereas the latter is based on economic considerations such as commodity prices, capital and operating costs, and any applicable discount rates. These concepts are illustrated in Figure 11.

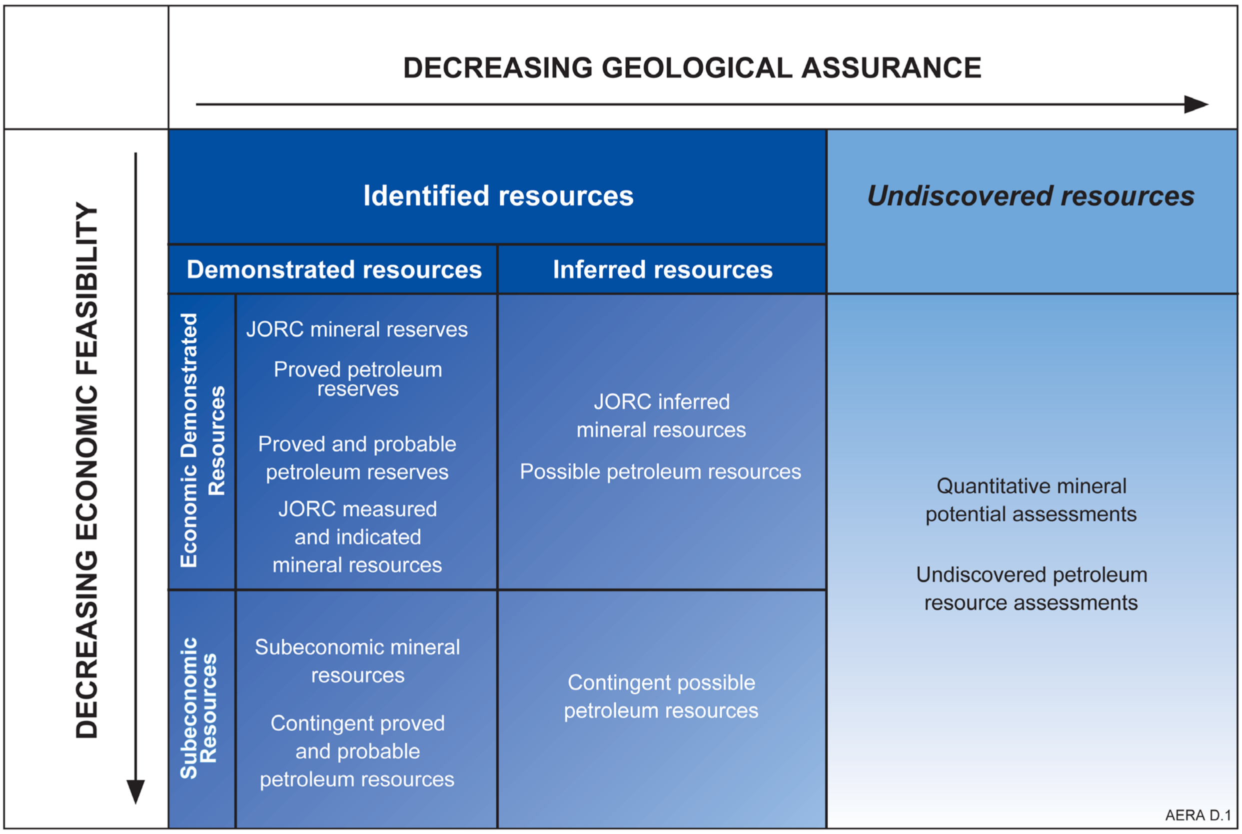

Figure 11 Australia's national classification system for resources, including coal and coal seam gas (petroleum)

Source: Geoscience Australia and BREE (2014)

A.3 Classification scheme for coal

The American Society for Testing and Materials (ASTM) classification scheme for coal rank, referred to in places throughout this report, is shown in Figure 12.

Class	Group	Fixed Carbon Limits (Dry, Mineral-Matter-Free Basis) (%)		Volatile Matter Limits (Dry, Mineral-Matter-Free Basis) (%)		Calorific Value Limits (Moist[A], Mineral-Matter-Free Basis) (Mj/kg)		Agglomerating Character
		Equal or greater than	Less than	Greater than	Equal or less than	Equal or greater than	Less than	
Anthracite	Meta-anthracite	98			2			Nonagglomerating
	Anthracite	92	98	2	8			
	Semianthracite[B]	86	92	8	14			
Bituminous	Low volatile bituminous coal	78	86	14	22			Commonly agglomerating[D]
	Medium volatile bituminous coal	69	78	22	31			
	High volatile A bituminous coal		69	31		32.6[C]		
	High volatile B bituminous coal					30.2[C]	32.6	
	High volatile C bituminous coal					26.7	30.2	
						24.4	26.7	Agglomerating
Subbituminous	Subbituminous A coal					24.4	26.7	Nonagglomerating
	Subbituminous B coal					22.1	24.4	
	Subbituminous C coal					19.3	22.1	
Lignite	Lignite A					14.7	19.3	
	Lignite B						14.7	

A. Moist refers to coal containing its natural inherent moisture but not including visible water on the surface of the coal.

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B. If agglomerating, classify in low volatile group of the bituminous class.

C. Coals having 69% or more fixed carbon on a dry, mineral-matter-free basis are classified according to fixed carbon, regardless of calorific value.

D. There may be nonagglomerating varieties in these groups of the bituminous class, with notable exceptions in the high volatile C bituminous group.

Figure 12 Classification of coals by rank

Source: modified after Wood et al. (1983). This figure is not covered by a Creative Commons Attribution licence as it is in the public domain.

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