Assessment of the Potential Scale of Unconventional Gas Development in the Cooper Basin, QLD

Prepared for:

Department of Natural Resources, Mines and Energy

Prepared by:

EHS Support

November 2018

Published on Resources Disclosure Log RTI Act 2009

Document Control

PROJECT DETAILS

Project No.:	AUS##C02434_2018
Report Revision No.:	3
Date of Issue:	22-NOV-18
Project Manager:	sch4p4(6) Personal
Project Director:	

REPORT DETAILS

Title:	Assessment of the Potential Scale of Unconventional Gas Development in the Cooper Basin, QLD
Main Author(s):	sch4p4(6) Personal information
Approved By:	
Client:	Department of Natural Resources, Mines and Energy (DNRME)
Client Contact:	Sean Lim

DISTRIBUTION LIST

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(e) electronic file
(h) hardcopy

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1 Introduction

1.1 Scope

EHS Support was engaged by the Department of Natural Resources, Mines and Energy (DNRME) to provide advice to both DNRME and the Department of the Environment and Energy (DoEE), regarding the potential scale of a 50 year, high-level unconventional gas development within the Queensland (QLD) portion of the Cooper Basin. In the context of this report, unconventional gas refers to shale, tight and deep coal gas plays.

This assessment leverages both industry experience in Australia and also international expertise in unconventional Gas development which has been obtained through EHS Support project work in the United States and Africa.

1.2 Background

Critical to the development of an unconventional Gas scenario is the context of domestic and international demand for gas. It has been estimated by AEMO (2018) that a potential domestic short fall of gas of up to 160 PJ (160,000 terrajoules) per year is projected by 2038, as shown in **Figure 1-1.** This equates to a production requirement of 438 TJ/day of gas.

Overtime, the supply of gas to meet increased domestic demand will likely be achieved through the future development of one or more of the following key sources:

- Increased drilling of conventional gas supplies within the Cooper Basin;
- Potential development of known coal seam gas (CSG) prospective areas for example Narrabri;
- Development of identified Victorian petroleum assets (pending removal of the drilling moratorium);
- Development of Northern Territory and norther QLD unconventional gas resources for example Beetaloo Sub-basin or ISA Superbasin; and
- Development of Cooper Basin unconventional gas resources located in both Queensland and South Australia.

However, it should be noted that in this context it is considered unreasonable to assume that all shortfalls in the market and future demand will be met by a single gas fields development. Nevertheless and for the purposes of this study, if the unconventional gas plays (shale, tight and deep coal gas) of the Cooper Basin (both the Queensland and South Australia portions) provide the most cost effective development alternative, then development on the Queensland portion of the Cooper Basin is anticipated to produce between 250 and 500 TJ per day (or 91.3 PJ to 182.6 PJ/annum) which is more than the current short fall and approximately meets the forecast long term deficit shown in **Figure 1-1.**

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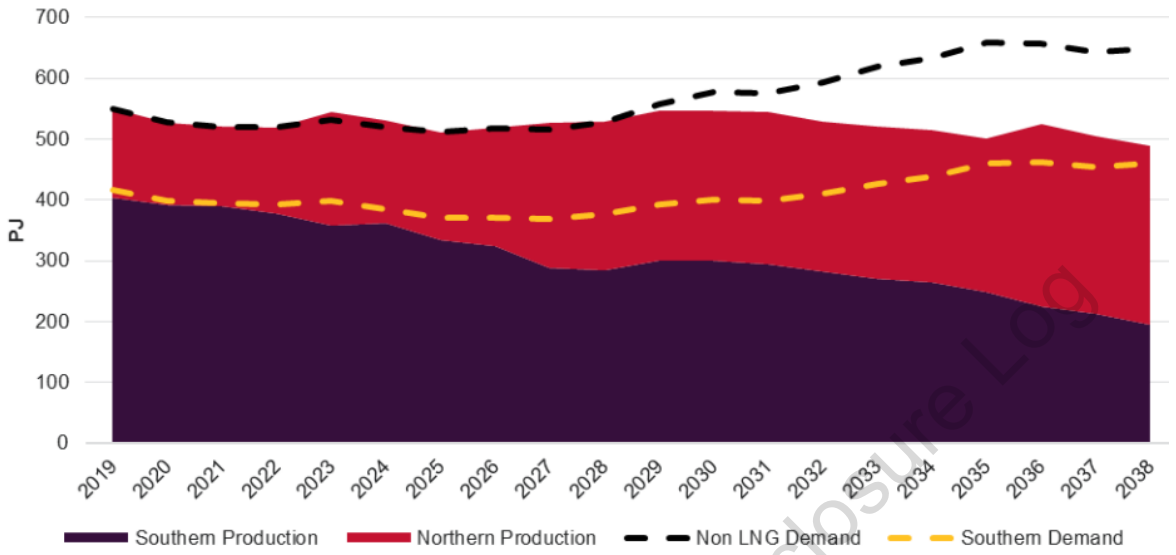


Figure 1-1 Potential Gas Demand 2019-2038 (Source: AEMO 2018)

1.3 Consultative Workshop

In preparation of this report, a workshop was held on Wednesday October 17, 2018. Participants of the workshop included EHS Support, DoEE, CSIRO, DNRME, Geoscience Australia (GA) and industry representatives from Santos, Icon Energy and APPEA.

The objective of the workshop was to update all participants on GA's prospectivity confidence mapping of the key unconventional shale gas, deep coal and basin-centred tight gas plays (refer **Section 1.3.1**, and **Appendix A**) in the Cooper basin as well as EHS Support's proposed methodology.

1.3.1 Prospectivity Confidence Mapping

Through the Australian Government funded Bioregional Assessment Programme for the Cooper basin (lead by DoEE and supported by CSIRO, the Bureau of Meteorology (BOM) and GA), prospectivity confidence mapping was undertaken to map the distribution of the basin's key unconventional shale gas, deep coal and basin-centred tight gas plays.

A draft of the prospectivity confidence mapping was provided to EHS Support in the form of a spatial dataset, presentation and some supporting documentation. The draft prospectivity confidence maps along with a high-level summary regarding the development methodology can be found in **Appendix A**.

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2 Methodology

2.1 Nature and Attributes of Development

In addition to the level or confidence of prospectivity, there are two main primary controls on a gas field development. These are;

1. Demand for gas; and
2. Prospect viability (that is ability to leverage existing infrastructure and logistics to lower exploration, appraisal and development costs).

The methodology and assumptions inherent within each is explained below.

2.1.1 Demand for Gas

During the consultative workshop (refer to **Section 1.3**), EHS Support presented a range of development scenarios ranging from 250 TJ/day to over 1000 TJ/day with a recommendation that the most likely development scenario would fall within the 250 TJ/day to 500 TJ/day. This was agreed by all participants and was primarily driven by key infrastructure attributes such as existing gas treatment and pipeline capacity, the anticipated demand and market requirements (refer **Section 1.2**; **Figure 1-1**), and the anticipated nature of disturbance for the project (refer **Table 3** and **Table 4**, **appended**).

2.1.2 Prospect Viability and Development Assumptions

Gas appraisal and development activities will be focused on high prospect areas but as much as possible near key infrastructure. During the workshop (refer to **Section 1.3**), it was noted that Industry rated exploration of deep coal gas highly with tight gas also a preferred interest play. Despite the apparent large extent of shale gas plays, industry advised they did not see value in exploring these plays primarily due to the main shale plays (Patchawarra Formation, Murteree and Roseneath Shale) unlikely containing enough gas for economic recovery. Therefore, for the purposes of this assessment it is assumed the following hierarchy of prospectivity areas would apply for exploration, appraisal and development activities;

1. Overlapping areas of high tight gas and high deep coal gas, respectively;
2. High deep coal gas only;
3. High tight gas only;
4. Overlapping areas of high deep coal gas and medium tight gas, respectively;
5. Overlapping areas of high tight gas and medium deep coal gas, respectively;
6. Overlapping areas of medium tight gas and medium deep coal gas, respectively;
7. Medium deep coal gas only; and
8. Medium tight gas.

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This hierarchy of prospectivity is shown in **Figure 1 (appended)** and shows within QLD, the relative prospectivity map for those plays listed above indicates the presence of two major areas of development potential being;

- South-west of Ballera, which extends into South Australia; and
- West and north of Eromanga.

Despite the Cooper Basin's remote location, there are a number of key attributes that support potential development of the deep coal and tight gas plays. These include existing logistics hubs (which include airports at Ballera and Moomba), major gas treatment and compression facilities at Moomba and Ballera and critically, remote compression (Barrolka, Challum, Baryullah) and gas transmission pipelines that bisect many of the high prospect areas. Key infrastructure such as roads, gas transmission pipelines, and oil and gas production facilities are shown on **Figure 1 (appended)**.

In addition, a 16 km^2 grid cell (4 km by 4 km) has been applied across the area to reflect the likely development intensity with the latest and evolving unconventional gas drilling technologies that will allow for up to 3 km laterals (incl. stacked laterals).

Multi-well pads will be the preferred technology approach for gas development in the Cooper Basin as it provides the lowest logistical costs and critically lowest capital expenditure (CAPEX) and operating expenditure (OPEX). In addition, the approach minimises the scale of disturbance and leverages infrastructure.

The key attributes of development in the context of an unconventional gas (assumed to consist of deep coal and tight gas) development in the QLD portion of the Cooper Basin are summarised in **Table 2-1.** This logic is also used in a GIS framework to show how development may progress over time.

Table 2-1 Core attributes and assumptions of an Unconventional Gas Development Project

Attribute	Details
Initial Exploration and Appraisal Targets	Focus on high prospect areas with good logistics (proximity to gas gathering infrastructure, roads, camps, etc).
Number of Initial Appraisal Areas	Anticipated to occur around 5 targets with preference provided in this order: 1. quality of prospect; 2. proximity to infrastructure; and 3. future integration potential for asset.
Anticipated Staging and Schedule of Work	Year 1 - 3D Seismic work and core holes.
	Year 2 - Drilling completion and appraisal activities.
	Year 3 - Minor development of better appraisal sites and continuing appraisal.
	Year 4 - Large scale development in logistically favorable sites leveraging capacity of plants.
	Year 5 - Expansion of treatment and compression capacity in combination with major drilling, pipelining projects.
	Year 6+ - Achievement of production capacity and buildout to facilitate maintenance of gas flows to plant.

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Attribute	Details
Well Head Development (away from floodplains)	The concept of appraisal will involve a single directionally drilled hole completed to the maximum distance of technology to advance understanding of the prospects. The well pad area would be initially limited to around 2 ha to accommodate a ground flare etc. If prospect is economic the well would be expanded to around 2.5 ha to accommodate multiple wells (up to 6) and well head infrastructure. In some cases, well pads as large as 4 ha may be required. At these select sites well pads would be larger to accommodate a compression facility and drilling camp. This can be seen in the example below Santos gas compression hub as Fairview.  Image source: www.flickr.com/photos/santosglngproject/20486412579 It is estimated that it would take approximately 6 months to complete this style of well pad (i.e. ~30 day per well) per play. Note: During the workshop discussions (refer **Section 1.3**) a likely development profile would consist of an exploration phase which may last 2-3 years before a ramp up period of over the next 5-7 years (Pers Comm; sch4p4(6) Pe Santos)). During these development stages an aggressive development scenario is defined as no more than 2 rigs (Pers Comm, sch4p4(6) Pers (Santos)).

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Attribute	Details
Well Head Development (on floodplains)	Currently, industry is commonly proposing that all activities are to be located outside of the extent of the flood area for all available mapped flood extents (1989, 1990, 1997, 2000, 2004, 2006 and 2010 flood extents). However, if the resource play does prove to be economic, under the Regional Planning Interests Regulation 2014, petroleum activities are permitted within floodplains or other strategic environmental area (SEA) as long as the development application demonstrates that the prescribed solution s15(1)(a) are acceptable. Where this occurs, it will be assumed that a smaller well pad footprint will result. As such, it is estimated that only one well per well pad will be constructed. In previous occurrences, well pads disturbance areas of 0.4 ha have been defined (such as on these well pads, proposed Santos development on Lot 1, SP209773 within the Channel Country SEA). This implies that within the 16 km^2 grid cell (4 km by 4 km), up to 4 (single well) well pads can be located. It is estimated that it would take approximately 12 months to complete all 4 well pads within a modelled grid cell.
Economic Cutoff for Unconventional Gas Wells	Based on the economics of upstream development there are minimum expectations on a development prospect. This threshold is anticipated to be around 2 TJ/day per well to recover the high cost.
Well Pad Spacing	Based on direction drilling technology anticipate well pads would be 3.5 to 4 km apart. This would provide for a radius (6 -8 wells covering an area of around 8 to 12 km^2 from a well pad location.
Target Production Rates (per well)	As noted above a minimum production threshold of 2 mmscf/d is industry norm for unconventional wells to recover the capital investment and get the desired rate of return. Anticipated design parameters based on a tight formation include a minimum of 20 perforation intervals with a production capacity of 0.15 to 0.25 mmscf/d per perforation interval (note considerably higher production rates could be achieved). In this context normal production expectations (for 20 perforations) are 2.5 and 5.0 million scf/d of gas/ well.
Total Production from a Well Pad	As noted above there are major advantages with placement of multiple wells on a single well pad. Use of “fracc tanks” limits the amount of disturbance. In the context of production from well pads it is anticipated that a minimum of 6 directional wells per pad with a maximum of 10 per well pad. Under the 6 wells per pad scenario we would be looking at 15 to 30 MMscfd production capacity per pad.

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Attribute	Details
Gas Production Curves for Unconventional Gas Wells	Gas decline curves for unconventional gas wells can be steep with production rates dropping below 1 mmscfd per well after 3 to 5 years. Historical gas production curves have shown for 20+ perforation interval wells with production rates of around 0.3 mm scfd persisting around 10 years. In combination with early life cycle choking of wells, well workovers and some production from old wells drilling program cycle time is anticipated to be around 7 years.
Well Pad Infrastructure	Gas on the well pads would be directed to liquids separation (to remove petroleum condensate), water condensers to remove water and then to on-site or an off-site nodal compression facility which would direct gas to the main gas treatment facility. Based on the depth of the gas sources on-well pad compression is unlikely to be required in the short term but may be a future requirement. Based on setting, distances etc, dehydration may be required at a nodal facility or could be accommodated at the main gas treatment and compression facility.
Water and Petroleum Condensate	Water production rates will be limited and sourced from the condensers and can easily be evaporated on-site with minimal infrastructure. Petroleum condensate will be separated and contained in tanks for pickup and transport as part of other petroleum removal activities in the basin. Potentially petroleum condensate could be reintroduced into the gas lines and conveyed to Ballera and Moomba.
Gas Treatment	Anticipated treatment requirements include dehydration, CO^2 removal using conventional amine units and potential removal of mercury or other metals using mole sieves. All of this would be conducted at the central gas processing facility (Moomba or Ballera). It is unknown whether gas cryogenics will be required to remove heavy gases but again existing facilities (Ballera and Moomba) have this capacity and could be utilised for these activities.
Conversion	1 TJ = 947857 scf of gas or 0.947 mmscf

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3 Ecological Resources and Constraints Planning

Within the arid zone, the most important environmental areas are those connected with sites of permanent water and low-lying areas that periodically accumulate water. The permanent water locations provide permanent habitat for a variety of native flora and fauna and are especially important as a refuge during drought conditions. Equally, the flora and fauna in low lying areas (including inundation areas and potential wetlands) have a higher degree of diversity and as such disturbance in these areas must be managed in accordance with environmental regulations. Therefore, and consistent with the current model conditions for petroleum activities, oil and gas development activities are precluded, restricted and controlled from specific areas of environmental/ecological significance.

Potential impacts from petroleum development in the Cooper Basin include:

- Habitat loss, degradation and fragmentation;
- Disturbance of ecology from light, noise and construction;
- Water extraction and loss of habitat; and
- Contamination of water, land and air.

Other key concerns identified (consistent with these key modes of impact discussed above) include the placement of infrastructure in a manner that it obstructs surface water flows and critically the filling of low lying areas which provide temporary or more permanent habitat to ecological receptors.

As a result of the above, spatial datasets of environmentally sensitive areas (ESA) have been incorporated into this assessment. Where an ESA occurs, it is assumed that no development will occur within 200m. The ESA and the source of the spatial data used) are as follows:

- National Groundwater Dependent Ecosystems:
  Source: *http://www.bom.gov.au/water/groundwater/gde/map.shtml*
- Communities of National Environmental Significance Database:
  Source: *http://www.environment.gov.au/science/erin/databases-maps/ecnes*
- Queensland wetland data version 4 (Wetlands):
  Source: http://qldspatial.information.qld.gov.au/catalogue/custom/index.page
  Queensland Spatial Catalogue Data Request (JobID: 20181121_044158147000-24760, Date: 20/11/2018)
- Geofabric Surface Network - V2.1.1 (Major Stream and Waterbody):
  Source: https://data.gov.au/dataset/d84e51f0-c1c1-4cf9-a23c-591f66be0d40

The location of all combined ESA (with a 200m buffer applied) are shown on **Figure 2 (appended).**

Note: The application of Strategic Environmental Areas (SEA) was not seen as a constraint. Numerous Santos compressor stations, production facilities, stock yards etc, all exist within this mapped area (e.g. Challum Gas, Ballera Plant, Naccowlah Oil, Baryulah Gas).

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4 Assessment of Development Layout

On the basis of these key attributes and the anticipated demand and market requirements (refer **Section 2**), the anticipated nature of disturbance for the project has been determined based on the following assumptions:

- Likely development scenario – 250 to 500 TJ/day;
- Away from floodplains, 112 well pads with a minimum of 6 wells per pad in production initially;
- Overlying floodplains (up to 24) well pads, with a minimum of 1 well per pad in production;
- A maximum of 4 additional nodal compression facilities to transport gas to main gas processing center (separate to some nominal on well pad activities if and when required);
- Some limited upgrades to gas transmission to gas processing facilities, and;
- Full utilisation of capacity at existing gas processing plants and upgrades to support additional flows.
- The requirements the creation of firebreaks in excess of the current well pad disturbance area, was not considered due to the natural setting of Cooper Basin (i.e. land is sparsely vegetated).

A summary of the anticipated number of wells and magnitude of disturbance after 50 years of operational activities is provided in **Table 1** and **Table 2 (appended)**.

The temporal progression of the number of wells has also been hypothesised. This time series of development is shown in **Figure 3** to **Figure 13 (appended)**. **Figure 3 (appended)** presents a likely initial development and appraisal 3-year program where coring, geophysical and appraisal activities are undertaken on some high prospectivity areas adjacent to existing infrastructure. **Figures 4** to **Figures 14 (appended)** then present a 5-yearly progression of development. **Figure 14 (appended)** summarises this progression with each grid labelled with a numeric identifier which can be cross referenced to a grid. This is also summarised in **Table 1 (appended)**.

The basis of expansion is built upon the key attributes in the basin such as beginning out from remote compression (Barrolka, Challum, Baryullah) and gas transmission pipelines that bisect many of the high prospect areas. This infrastructure as well as existing roads, gas transmission pipelines, and oil and gas production facilities are shown in **Figure 1 (appended)**.

Based on the anticipated size of infrastructure and the projected development program using the key attributes discussed above, the magnitude of disturbance has been estimated over the strategic review period (50 years). The detailed calculations used to develop this are presented in **Table 3** (0-25 years) and **Table 4** (26 to 50 years), **appended**.

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5 Conclusions

Based on the anticipated nature of development activities over a 50-year period, a potential development plan was developed for the Queensland portion of the Cooper Basin. The development plan focused meeting a gas demand of 250 TJ/day to 500 TJ/day from the development of two major high prospect areas (south of Ballera and west and north of Eromanga). The smaller high prospect areas were not considered for initial development due to their size and, in the northern most areas their remote nature.

Through this high-level assessment it is anticipated that development of a gas project in the Cooper Basin to deliver on domestic gas requirements will not require a large number of well pads. It is estimated that over the 50-year strategic review period, approximately 136 well pad locations are only needed to support gas production. This equates to approximately 790 wells.

Assessment of the high-level constraints (inundation and wetland areas) associated with development indicates that the project can be successfully implemented without well pads and access tracks being construction in sensitive areas.

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6 Limitations

EHS Support Pty Ltd (EHS) has prepared this report in accordance with the usual care and thoroughness of the consulting profession for the use of the Department of Natural Resources, Mines and Energy and only those third parties who have been authorised in writing by EHS to rely on the report. It is based on generally accepted practices and standards at the time it was prepared. No other warranty, expressed or implied, is made as to the professional advice included in this report. It is prepared in accordance with the scope of work and for the purpose outlined in the Proposal dated 14 September 2018.

The methodology adopted, and sources of information used by EHS are outlined in this report. EHS has made no independent verification of this information beyond the agreed scope of works and EHS assumes no responsibility for any inaccuracies or omissions. No indications were found during our investigations that information contained in this report as provided to EHS was false.

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Tables

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Table 1 QLD Cooper Basin Unconventional Gas Development (Refer to Figures 2-13 to match Development Year with Development location)

Exploration Year	Development Year	row	col	Grid Index	Formation Target
2020		BF	15	BF-15	High Tight Gas and High Coal Gas
2020		BD	27	BD-27	High Coal Gas
2021		BL	44	BL-44	High Coal Gas
2021		AQ	52	AQ-52	High Coal Gas
2022		AF	52	AF-52	High Coal Gas
2022		I	62	I-62	High Coal Gas
	2023	BF	15	BF-15	High Tight Gas and High Coal Gas
	2023	BD	26	BD-26	High Coal Gas
	2023	BD	27	BD-27	High Coal Gas
	2024	BF	14	BF-14	High Tight Gas and High Coal Gas
	2024	BF	16	BF-16	High Tight Gas
	2024	BE	27	BE-27	High Coal Gas
	2025	BG	14	BG-14	High Tight Gas
	2025	BG	15	BG-15	High Tight Gas
	2025	BE	28	BE-28	High Coal Gas
	2025	BD	28	BD-28	High Coal Gas
	2026	BG	16	BG-16	High Tight Gas
	2026	BC	25	BC-25	High Coal Gas
	2026	BC	26	BC-26	High Coal Gas
	2026	BC	27	BC-27	High Coal Gas
	2027	BH	14	BH-14	High Tight Gas
	2027	BH	15	BH-15	High Tight Gas and Medium Coal Gas
	2027	BH	36	BH-36	High Coal Gas
	2028	BI	37	BI-37	High Coal Gas
	2028	BH	16	BH-16	High Tight Gas and Medium Coal Gas
	2028	BH	37	BH-37	High Coal Gas
	2029	BM	44	BM-44	High Coal Gas
	2029	BL	44	BL-44	High Coal Gas
	2029	BH	35	BH-35	High Coal Gas
	2030	BL	45	BL-45	High Coal Gas
	2030	BK	44	BK-44	High Coal Gas

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Exploration Year	Development Year	row	col	Grid Index	Formation Target
	2030	BG	17	BG-17	High Tight Gas
	2030	BF	17	BF-17	High Tight Gas
	2031	BK	45	BK-45	High Coal Gas
	2031	BK	46	BK-46	High Coal Gas
	2031	BF	18	BF-18	High Tight Gas
	2031	BE	17	BE-17	High Tight Gas
	2032	BE	18	BE-18	High Tight Gas
	2032	BD	17	BD-17	High Tight Gas
	2032	BD	18	BD-18	High Tight Gas
	2032	AR	52	AR-52	High Coal Gas
	2033	BG	18	BG-18	High Tight Gas
	2033	BD	19	BD-19	High Tight Gas
	2033	AQ	52	AQ-52	High Coal Gas
	2033	AP	52	AP-52	High Coal Gas
	2034	BF	19	BF-19	High Tight Gas
	2034	BE	19	BE-19	High Tight Gas
	2034	AQ	51	AQ-51	High Coal Gas
	2034	AP	51	AP-51	High Coal Gas
	2035	BI	15	BI-15	High Tight Gas
	2035	AR	51	AR-51	High Coal Gas
	2035	AQ	50	AQ-50	High Coal Gas
	2035	AP	50	AP-50	High Coal Gas
	2036	BI	13	BI-13	High Tight Gas
	2036	BI	14	BI-14	High Tight Gas
	2036	AI	51	AI-51	High Coal Gas
	2036	AI	52	AI-52	High Coal Gas
	2037	BH	13	BH-13	High Tight Gas
	2037	BG	13	BG-13	High Tight Gas
	2037	AI	54	AI-54	High Coal Gas
	2037	AH	53	AH-53	High Coal Gas
	2038	BF	12	BF-12	High Tight Gas
	2038	BF	13	BF-13	High Tight Gas

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Exploration Year	Development Year	row	col	Grid Index	Formation Target
	2038	AH	51	AH-51	High Coal Gas
	2038	AG	51	AG-51	High Coal Gas
	2039	BH	12	BH-12	High Tight Gas
	2039	BG	12	BG-12	High Tight Gas
	2039	AG	52	AG-52	High Coal Gas
	2039	AG	53	AG-53	High Coal Gas
	2040	BJ	11	BJ-11	High Tight Gas
	2040	BI	12	BI-12	High Tight Gas
	2040	AH	54	AH-54	High Coal Gas
	2040	AG	54	AG-54	High Coal Gas
	2041	BJ	12	BJ-12	High Tight Gas
	2041	BI	11	BI-11	High Tight Gas
	2041	AF	53	AF-53	High Coal Gas
	2041	AF	54	AF-54	High Coal Gas
	2042	BH	11	BH-11	High Tight Gas
	2042	BG	11	BG-11	High Tight Gas
	2042	AF	51	AF-51	High Coal Gas
	2042	AF	52	AF-52	High Coal Gas
	2043	BG	10	BG-10	High Tight Gas
	2043	BF	11	BF-11	High Tight Gas
	2043	AE	50	AE-50	High Coal Gas
	2043	AE	51	AE-51	High Coal Gas
	2044	BI	10	BI-10	High Tight Gas
	2044	BH	10	BH-10	High Tight Gas
	2044	AE	49	AE-49	High Coal Gas
	2044	AD	49	AD-49	High Coal Gas
	2045	BJ	10	BJ-10	High Tight Gas
	2045	AE	52	AE-52	High Coal Gas
	2045	AD	50	AD-50	High Coal Gas
	2045	AD	51	AD-51	High Coal Gas
	2046	BK	10	BK-10	High Tight Gas
	2046	BK	11	BK-11	High Tight Gas

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Exploration Year	Development Year	row	col	Grid Index	Formation Target
	2046	AE	53	AE-53	High Coal Gas
	2046	AD	52	AD-52	High Coal Gas
	2047	BK	9	BK-9	High Tight Gas
	2047	AE	54	AE-54	High Coal Gas
	2047	AD	53	AD-53	High Coal Gas
	2048	BJ	9	BJ-9	High Tight Gas
	2048	AF	60	AF-60	High Coal Gas
	2048	AF	61	AF-61	High Coal Gas
	2048	AD	61	AD-61	High Coal Gas
	2049	BI	9	BI-9	High Tight Gas
	2049	BH	9	BH-9	High Tight Gas
	2049	BG	9	BG-9	High Tight Gas
	2049	AC	61	AC-61	High Coal Gas
	2050	BH	8	BH-8	High Tight Gas
	2050	AE	60	AE-60	High Coal Gas
	2050	AD	60	AD-60	High Coal Gas
	2050	AC	60	AC-60	High Coal Gas
	2051	BJ	8	BJ-8	High Tight Gas
	2051	BI	8	BI-8	High Tight Gas
	2051	AB	60	AB-60	High Coal Gas
	2051	AB	61	AB-61	High Coal Gas
	2052	BL	8	BL-8	High Tight Gas
	2052	BK	8	BK-8	High Tight Gas
	2052	AA	59	AA-59	High Coal Gas
	2052	AA	60	AA-60	High Coal Gas
	2053	BL	9	BL-9	High Tight Gas
	2053	BL	10	BL-10	High Tight Gas
	2053	I	61	I-61	High Coal Gas
	2053	I	62	I-62	High Coal Gas
	2054	BL	11	BL-11	High Tight Gas
	2054	BL	12	BL-12	High Tight Gas
	2054	J	61	J-61	High Coal Gas

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Exploration Year	Development Year	row	col	Grid Index	Formation Target
	2054	J	62	J-62	High Coal Gas
	2055	BL	13	BL-13	High Tight Gas
	2055	BL	14	BL-14	High Tight Gas
	2055	J	63	J-63	High Coal Gas
	2055	I	63	I-63	High Coal Gas
	2056	BM	12	BM-12	High Tight Gas
	2056	BM	13	BM-13	High Tight Gas
	2056	BM	14	BM-14	High Tight Gas
	2056	J	64	J-64	High Coal Gas
	2057	BM	15	BM-15	High Tight Gas
	2057	BM	16	BM-16	High Tight Gas
	2057	I	64	I-64	High Coal Gas
	2057	H	64	H-64	High Coal Gas
	2058	BL	16	BL-16	High Tight Gas
	2058	BL	17	BL-17	High Tight Gas
	2058	H	62	H-62	High Coal Gas
	2058	H	63	H-63	High Coal Gas
	2059	BN	17	BN-17	High Tight Gas
	2059	BM	17	BM-17	High Tight Gas
	2059	G	62	G-62	High Coal Gas
	2059	G	63	G-63	High Coal Gas
	2060	BO	16	BO-16	High Tight Gas
	2060	BN	16	BN-16	High Tight Gas
	2060	K	62	K-62	High Coal Gas
	2060	K	63	K-63	High Coal Gas
	2061	BP	16	BP-16	High Tight Gas
	2061	BO	17	BO-17	High Tight Gas
	2061	K	60	K-60	High Coal Gas
	2061	K	61	K-61	High Coal Gas
	2062	BP	17	BP-17	High Tight Gas
	2062	BP	18	BP-18	High Tight Gas
	2062	L	60	L-60	High Coal Gas

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Exploration Year	Development Year	row	col	Grid Index	Formation Target
	2062	L	61	L-61	High Coal Gas
	2063	BQ	16	BQ-16	High Tight Gas
	2063	BQ	17	BQ-17	High Tight Gas
	2063	BQ	18	BQ-18	High Tight Gas
	2063	L	62	L-62	High Coal Gas
	2064	BO	18	BO-18	High Tight Gas
	2064	BN	18	BN-18	High Tight Gas
	2064	M	62	M-62	High Coal Gas
	2064	L	63	L-63	High Coal Gas
	2065	M	60	M-60	High Coal Gas
	2065	M	61	M-61	High Coal Gas
	2066	BN	19	BN-19	High Tight Gas
	2066	BM	18	BM-18	High Tight Gas
	2066	N	60	N-60	High Coal Gas
	2066	N	61	N-61	High Coal Gas
	2067	BP	19	BP-19	High Tight Gas
	2067	BP	20	BP-20	High Tight Gas
	2068	BO	19	BO-19	High Tight Gas
	2068	BO	20	BO-20	High Tight Gas
	2069	BQ	15	BQ-15	High Tight Gas
	2069	BP	15	BP-15	High Tight Gas
	2070	BO	15	BO-15	High Tight Gas
	2070	BN	15	BN-15	High Tight Gas

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Table 2 QLD Cooper Basin Unconventional Gas Development (Cumulative Assessment)

Year Integer	Exploration Year	Development Year	Cumulative No. Well Pads	Cumulative No. Wells
1	2020		0	0
2	2021		3	4
3	2022		6	10
4		2023	10	34
5		2024	14	58
6		2025	18	82
7		2026	22	106
8		2027	26	130
9		2028	30	154
10		2029	34	178
11		2030	38	202
12		2031	41	220
13		2032	44	238
14		2033	47	256
15		2034	50	274
16		2035	53	292
17		2036	56	310
18		2037	59	328
19		2038	62	346
20		2039	65	364
21		2040	68	382
22		2041	71	400
23		2042	74	418
24		2043	77	436
25		2044	80	454
26		2045	83	472
27		2046	86	490
28		2047	89	508
29		2048	92	526
30		2049	95	544
31		2050	98	562

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Year Integer	Exploration Year	Development Year	Cumulative No. Well Pads	Cumulative No. Wells
32		2051	100	574
33		2052	102	586
34		2053	104	598
35		2054	106	610
36		2055	108	622
37		2056	110	634
38		2057	112	646
39		2058	114	658
40		2059	116	670
41		2060	118	682
42		2061	120	694
43		2062	122	706
44		2063	124	718
45		2064	126	730
46		2065	128	742
47		2066	130	754
48		2067	132	766
49		2068	134	778
50		2069	136	790

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Table 3 Development Plan Cumulative Disturbance (0-25 years)

Investments/Assets	Disturbance (ha)	Year of Initiation																							
		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25
3D Seismic	0	x																								
Coring	1	x	x			x			x						x				x				x			
Well Pad	nr	0	3	3	4	4	4	4	4	4	4	4	3	3	3	3	3	3	3	3	3	3	3	3	3	3
Wells Drilling	nr	0	4	6	24	24	24	24	24	24	24	24	18	18	18	18	18	18	18	18	18	18	18	18	18	18
Nodal Compression Facility Construction	nr			1	1															1						
Roads (5 km per well pad) - km	km		15	15	20	20	20	20	20	20	20	20	15	15	15	15	15	15	15	15	15	15	15	15	15	15
Drilling Camps	nr		3										1	1						1	1					
Well Pad Rehabilitation	nr													14			20			3	3	3	3	3	3	3
Well Pad Disturbance Area (ha)	2.5		7.5	7.5	10	10	10	10	10	10	10	10	7.5	7.5	7.5	7.5	7.5	7.5	7.5	7.5	7.5	7.5	7.5	7.5	7.5	7.5
Nodal Compressor Disturbance Area (ha)	3	0	0	3	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3	0	0	0	0	0	0
Road Disturbance Area (ha)	10		30	30	40	40	40	40	40	40	40	40	30	30	30	30	30	30	30	30	30	30	30	30	30	30
Drilling Camp Disturbance ha			3										1	1						1	1	0	0	0	0	0
Final Well Pad Rehabilitation Area (ha)	-2.5		0	0	0	0	0	0	0	0	0	0	0	-35	0	0	-50	0	0	-7.5	-7.5	-7.5	-7.5	-7.5	-7.5	-7.5
Nodal Compressor Rehabilitation Area	-3																			-3						
Road Partial Rehabilitation (reduce to 10 m access track) - ha					-15	-15	-20	-20	-20	-20	-20	-20	-20	-20	-15	-15	-15	-15	-15	-15	-15	-15	-15	-15	-15	-15
Drilling Camp Rehabilitation - ha	1												-3							-2						
Total Disturbance (ha) by year (with rehab)			40.5	40.5	38	35	30	30	30	30	30	30	15.5	-16.5	22.5	22.5	-27.5	22.5	22.5	14	16	15	15	15	15	15
Total Disturbance (ha) by year (without rehab)			40.5	40.5	53	50	50	50	50	50	50	50	35.5	38.5	37.5	37.5	37.5	37.5	37.5	36.5	38.5	37.5	37.5	37.5	37.5	37.5
Cumulative disturbance by year (ha) with rehab			**40.5**	**81**	**119**	**154**	**184**	**214**	**244**	**274**	**304**	**334**	**350**	**333**	**356**	**378**	**351**	**373**	**396**	**410**	**426**	**441**	**456**	**471**	**486**	**501**
Cumulative disturbance by year (ha) without rehab			**40.5**	**81**	**134**	**184**	**234**	**284**	**334**	**384**	**434**	**484**	**520**	**558**	**596**	**633**	**671**	**708**	**746**	**782**	**821**	**858**	**896**	**933**	**971**	1008

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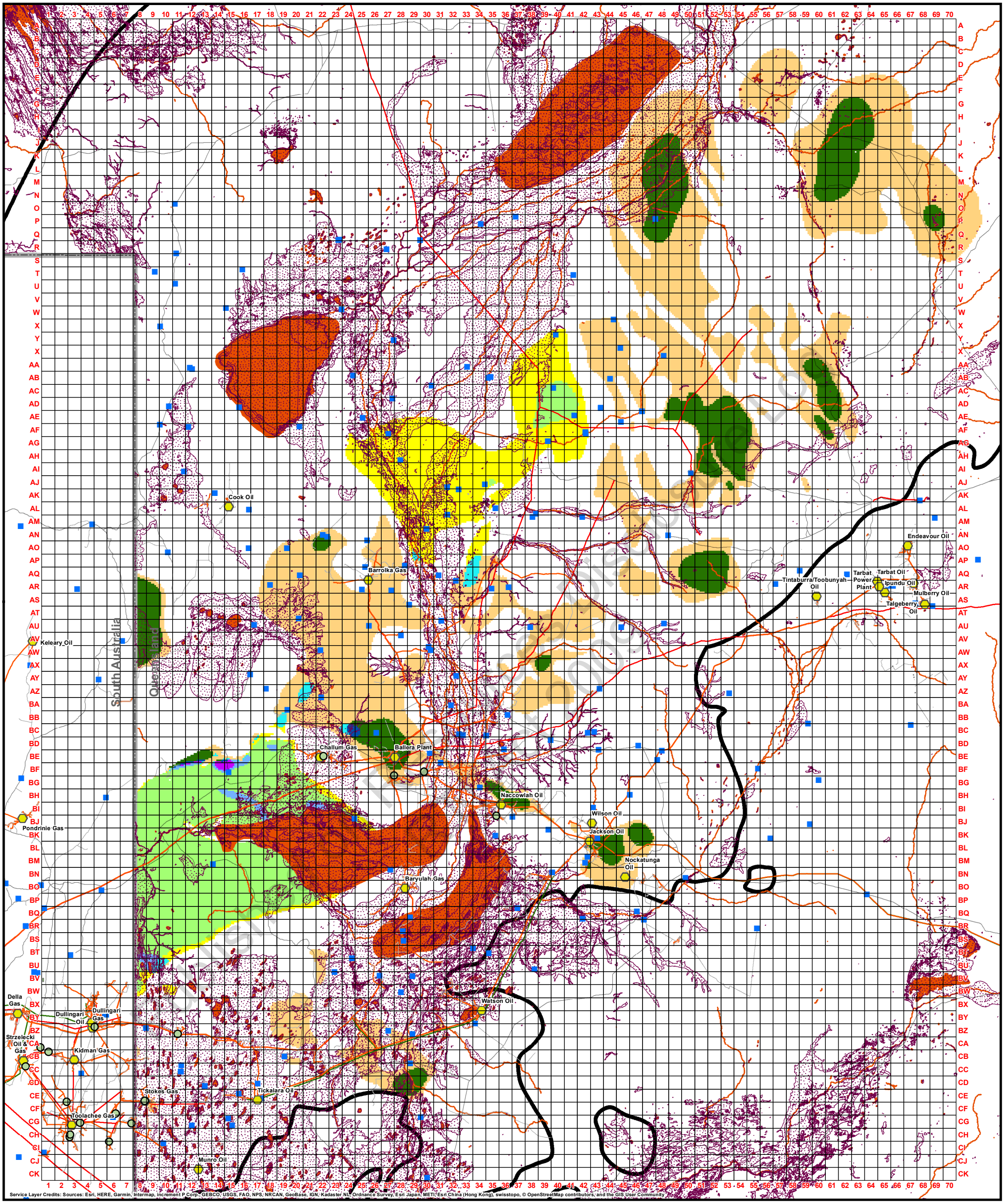
Table 4 Development Plan Cumulative Disturbance (26-50 years)

Investments/Assets	Disturbance (ha)	Year of Initiation																								
		26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48	49	50
3D Seismic	0	x																								
Coring	1	x	x			x			x						x				x				x			
Well Pad	nr	3	3	3	3	3	3	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2
Wells Drilling	nr	18	18	18	18	18	18	12	12	12	12	12	12	12	12	12	12	12	12	12	12	12	12	12	12	12
Nodal Compression Facility Construction	nr											1														
Roads (5 km per well pad) - km	km		15	15	15	15	15	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10
Drilling Camps	nr					1	1						1	1						1	1					
Well Pad Rehabilitation	nr													12			10			2	2	2	2	2	2	2
Well Pad Disturbance Area (ha)	2.5		7.5	7.5	7.5	7.5	7.5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5
Nodal Compressor Disturbance Area (ha)	3	0	0	0	0	0	0	0	0	0	0	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Road Disturbance Area (ha)	10		30	30	30	30	30	20	20	20	20	20	20	20	20	20	20	20	20	20	20	20	20	20	20	20
Drilling Camp Disturbance ha			0										1	1						1	1	0	0	0	0	0
Final Well Pad Rehabilitation Area (ha)	-2.5		0	0	0	0	0	0	0	0	0	0	0	-30	0	0	-25	0	0	-5	-5	-5	-5	-5	-5	-5
Nodal Compressor Rehabilitation Area	-3																			-3						
Road Partial Rehabilitation (reduce to 10 m access track) - ha					-15	-15	-15	-15	-15	-10	-10	-10	-10	-10	-10	-10	-10	-10	-10	-10	-10	-10	-10	-10	-10	-10
Drilling Camp Rehabilitation - ha	1												-3							-2						
Total Disturbance (ha) by year (with rehab)			37.5	37.5	22.5	22.5	22.5	10	10	15	15	18	13	-14	15	15	-10	15	15	6	11	10	10	10	10	10
Total Disturbance (ha) by year (without rehab)			37.5	37.5	37.5	37.5	37.5	25	25	25	25	28	23	26	25	25	25	25	25	21	26	25	25	25	25	25
Cumulative disturbance by year (ha) with rehab			**538**	**576**	**598**	**621**	**643**	**653**	**663**	**678**	**693**	**711**	**724**	**710**	**725**	**740**	**730**	**745**	**760**	**766**	**777**	**787**	**797**	**807**	**817**	**827**
Cumulative disturbance by year (ha) without rehab			**1046**	**1083**	**1121**	**1158**	**1196**	**1221**	**1246**	**1271**	**1296**	**1324**	**1347**	**1373**	**1398**	**1423**	**1448**	**1473**	**1498**	**1519**	**1545**	**1570**	**1595**	**1620**	**1645**	**1670**

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Figures

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Figure 1 - Max Relative Prospectivity
50 Year Development

Legend

- Compressor
- Santos Production Facility
- Tank Farm
- Facility Area
- Stockyard

Santos-Owned Infrastructure

- Pipeline(Santos)
- Road(Santos)
- Roads
- Gas Well
- Oil Well
- Oil and Gas Well

GA Pipelines

- Gas
- Gas - Under Cons
- Oil

- Wetlands
- Cooper Basin

Restricted Areas

- 200m Buffer from ESAs

Prospectivity

- High Tight Gas and High Coal Gas
- High Coal Gas Only
- High Tight Gas Only
- High Coal Gas and Medium Tight Gas
- High Tight Gas and Medium Coal Gas
- Medium Tight Gas and Medium Coal Gas
- Medium Coal Gas Only
- Medium Tight Gas

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Cooper River Basin
South Australia

DATE:	19/09/2018
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REVIEWED BY:	[EHS Support]
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MAP PROJECTION:	GDA94
SCALE:	1:1,062,206

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Cook Oil
Barrolka Gas
Endeavour Oil
Tintaburra/Toobunyah Oil
Tarbat Power Plant
Tarbat Oil
Ipundu Oil
Mulberry Oil
Talgeberry Oil
Keleary Oil
South Australia
Queensland
Challum Gas
Ballera Plant
Naccowlah Oil
Wilson Oil
Jackson Oil
Nockatunga Oil
Pondrinie Gas
Baryulah Gas
Watson Oil
Della Gas
Dullingari Oil
Dullingari Gas
Strzelecki Oil & Gas
Kidman Gas
Stokes Gas
Tickalara Oil
Toolachee Gas
Munro Oil

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Figure 2 - Environmenally Sensitive Areas

Legend

- Exploration Area
- Compressor
- Santos Production Facility
- Tank Farm
- Facility Area
- Stockyard

Santos-Owned Infrastructure

- Pipeline(Santos)
- Road(Santos)
- Roads
- Gas Well
- Oil Well
- Oil and Gas Well

GA Pipelines

- Gas
- Gas - Under Cons
- Oil

- Topo250k Lakes (200m Buffer)
- Topo250k Springs (200m Buffer)
- Topo250k Waterholes (200m Buffer)
- Topo250k Watercourses (200m Buffer)
- DIWA Important Wetlands (200m Buffer)
- Topo250k Watercourse Areas (200m Buffer)
- Cooper Basin

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Talgeberry Oil
Keleary Oil
South Australia
Queensland
Challum Gas
Ballera Plant
Naccowlah Oil
Wilson Oil
Jackson Oil
Nockatunga Oil
Pondrinie Gas
Baryulah Gas
Watson Oil
Della Gas
Dullingari Oil
Dullingari Gas
Strzelecki Oil & Gas
Kidman Gas
Stokes Gas
Tickalara Oil
Toolachee Gas
Munro Oil

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Figure 3 - Max Relative Prospectivity
Year 2020-2022 Exploratory Period

Legend

- Exploration Area
- Compressor
- Santos Production Facility
- Tank Farm
- Facility Area
- Stockyard

Santos-Owned Infrastructure

- Pipeline(Santos)
- Road(Santos)
- Roads
- Gas Well
- Oil Well
- Oil and Gas Well

GA Pipelines

- Gas
- Gas - Under Cons
- Oil

- Wetlands
- Cooper Basin

Restricted Areas

- 200m Buffer from ESAs

Prospectivity

- High Tight Gas and High Coal Gas
- High Coal Gas Only
- High Tight Gas Only
- High Coal Gas and Medium Tight Gas
- High Tight Gas and Medium Coal Gas
- Medium Tight Gas and Medium Coal Gas
- Medium Coal Gas Only
- Medium Tight Gas

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Kilometers

Cook Oil
Barrolka Gas
Endeavour Oil
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Tarbat Power Plant
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Mulberry Oil
Talgeberry Oil
Keleary Oil
South Australia
Queensland
Challum Gas
Ballera Plant
Naccowlah Oil
Wilson Oil
Jackson Oil
Nockatunga Oil
Pondrinie Gas
Baryulah Gas
Watson Oil
Della Gas
Dullingari Oil
Dullingari Gas
Strzelecki Oil & Gas
Kidman Gas
Stokes Gas
Tickalara Oil
Toolachee Gas
Munro Oil

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Figure 4 - Max Relative Prospectivity
Year 2023-2027 Development Period

Legend

- Compressor
- Santos Production Facility
- Tank Farm
- Facility Area
- Stockyard

Santos-Owned Infrastructure

- Pipeline(Santos)
- Road(Santos)
- Roads
- Gas Well
- Oil Well
- Oil and Gas Well

GA Pipelines

- Gas
- Gas - Under Cons
- Oil

- Wetlands
- Cooper Basin

Restricted Areas

- 200m Buffer from ESAs

Prospectivity

- High Tight Gas and High Coal Gas
- High Coal Gas Only
- High Tight Gas Only
- High Coal Gas and Medium Tight Gas
- High Tight Gas and Medium Coal Gas
- Medium Tight Gas and Medium Coal Gas
- Medium Coal Gas Only
- Medium Tight Gas

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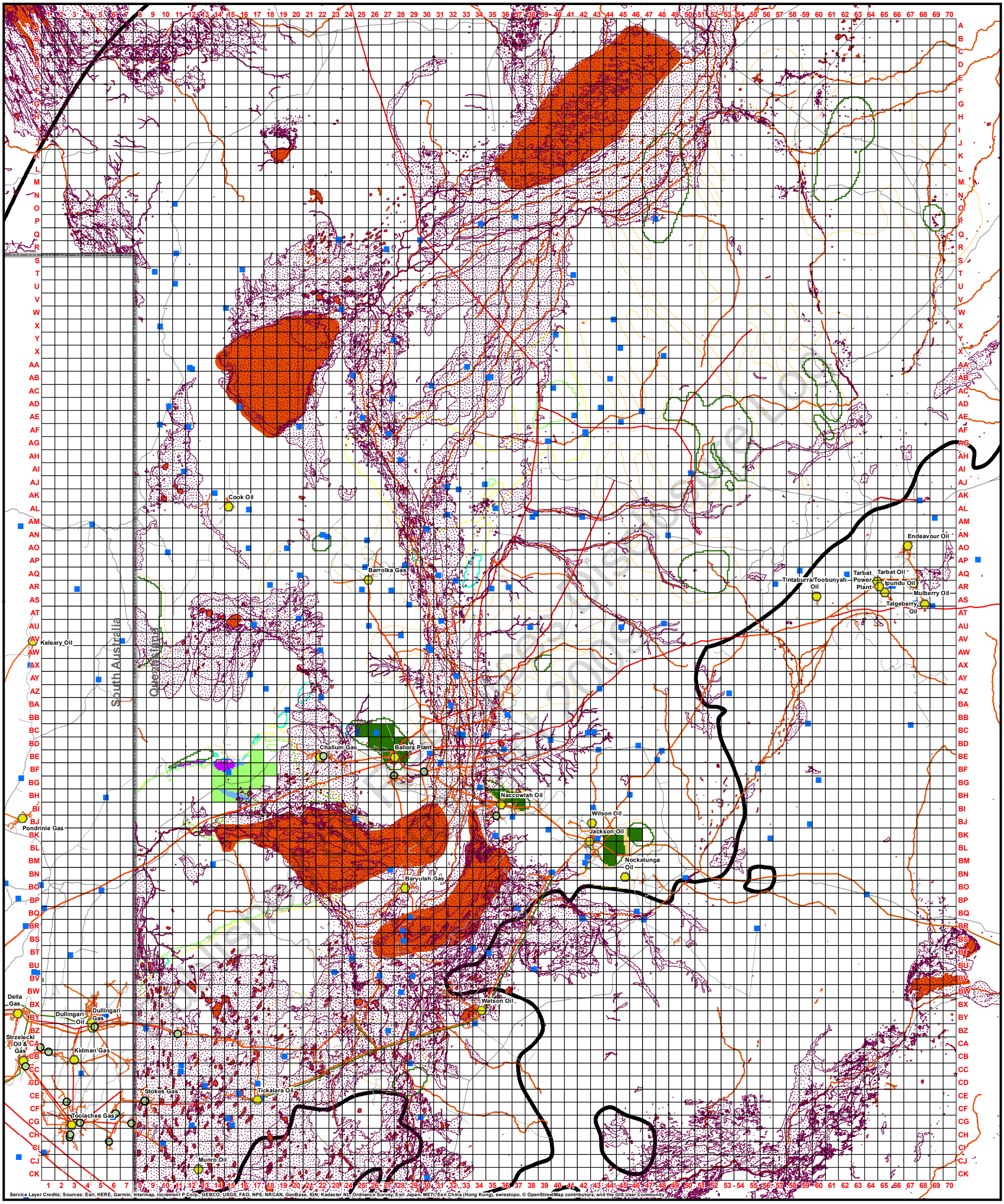
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Figure 5 - Max Relative Prospectivity
Year 2028-2032 Development Period

Legend

- Compressor
- Santos Production Facility
- Tank Farm
- Facility Area
- Stockyard

Santos-Owned Infrastructure

- Pipeline(Santos)
- Road(Santos)
- Roads
- Gas Well
- Oil Well
- Oil and Gas Well

GA Pipelines

- Gas
- Gas - Under Cons
- Oil

- Wetlands
- Cooper Basin

Restricted Areas

- 200m Buffer from ESAs

Prospectivity

- High Tight Gas and High Coal Gas
- High Coal Gas Only
- High Tight Gas Only
- High Coal Gas and Medium Tight Gas
- High Tight Gas and Medium Coal Gas
- Medium Tight Gas and Medium Coal Gas
- Medium Coal Gas Only
- Medium Tight Gas

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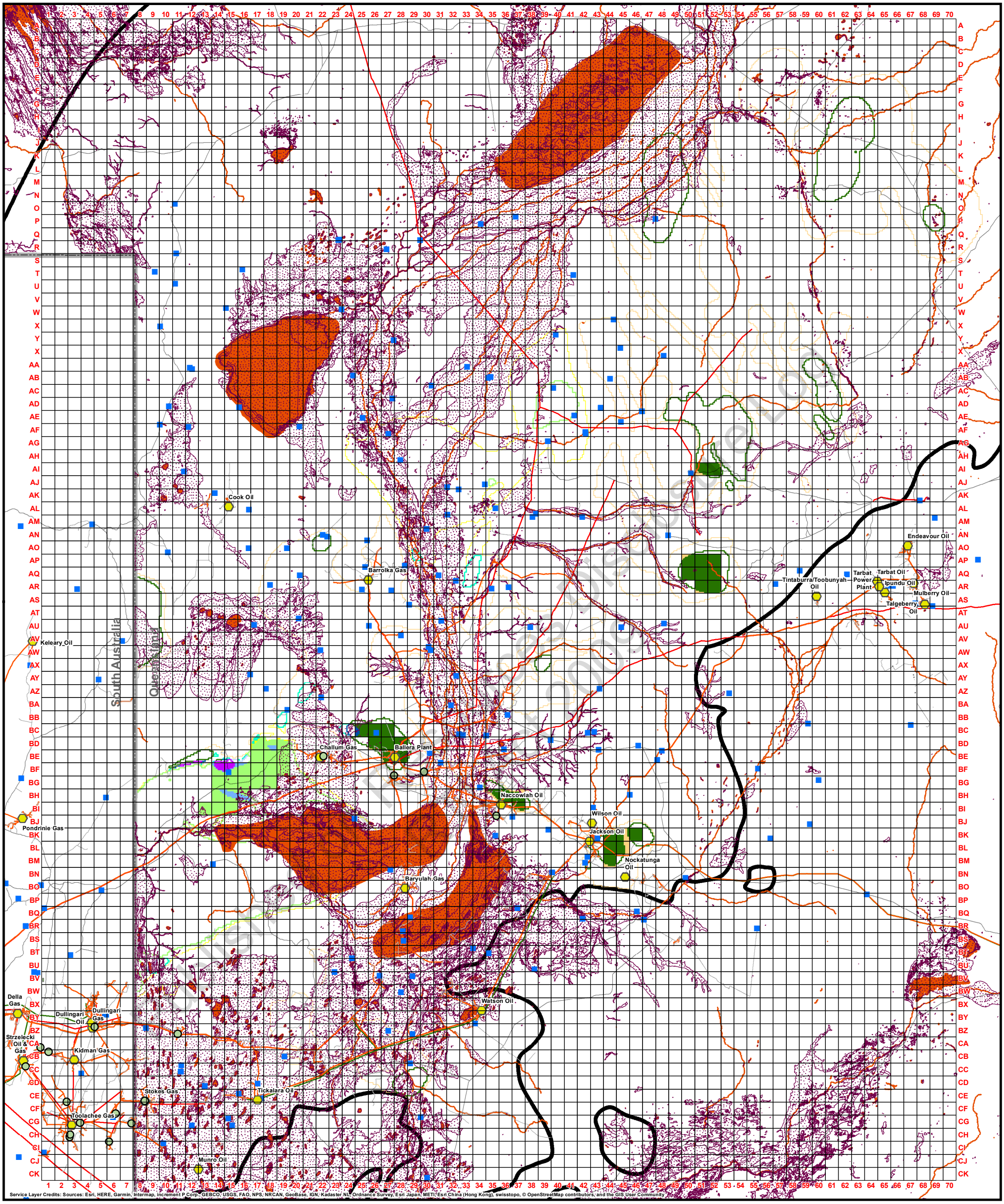
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10 5 0 10
Kilometers



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Figure 6 - Max Relative Prospectivity
Year 2033-2037 Development Period

Legend

- Compressor
- Santos Production Facility
- Tank Farm
- Facility Area
- Stockyard

Santos-Owned Infrastructure

- Pipeline(Santos)
- Road(Santos)
- Roads
- Gas Well
- Oil Well
- Oil and Gas Well

GA Pipelines

- Gas
- Gas - Under Cons
- Oil

- Wetlands
- Cooper Basin

Restricted Areas

- 200m Buffer from ESAs

Prospectivity

- High Tight Gas and High Coal Gas
- High Coal Gas Only
- High Tight Gas Only
- High Coal Gas and Medium Tight Gas
- High Tight Gas and Medium Coal Gas
- Medium Tight Gas and Medium Coal Gas
- Medium Coal Gas Only
- Medium Tight Gas

EHS Support

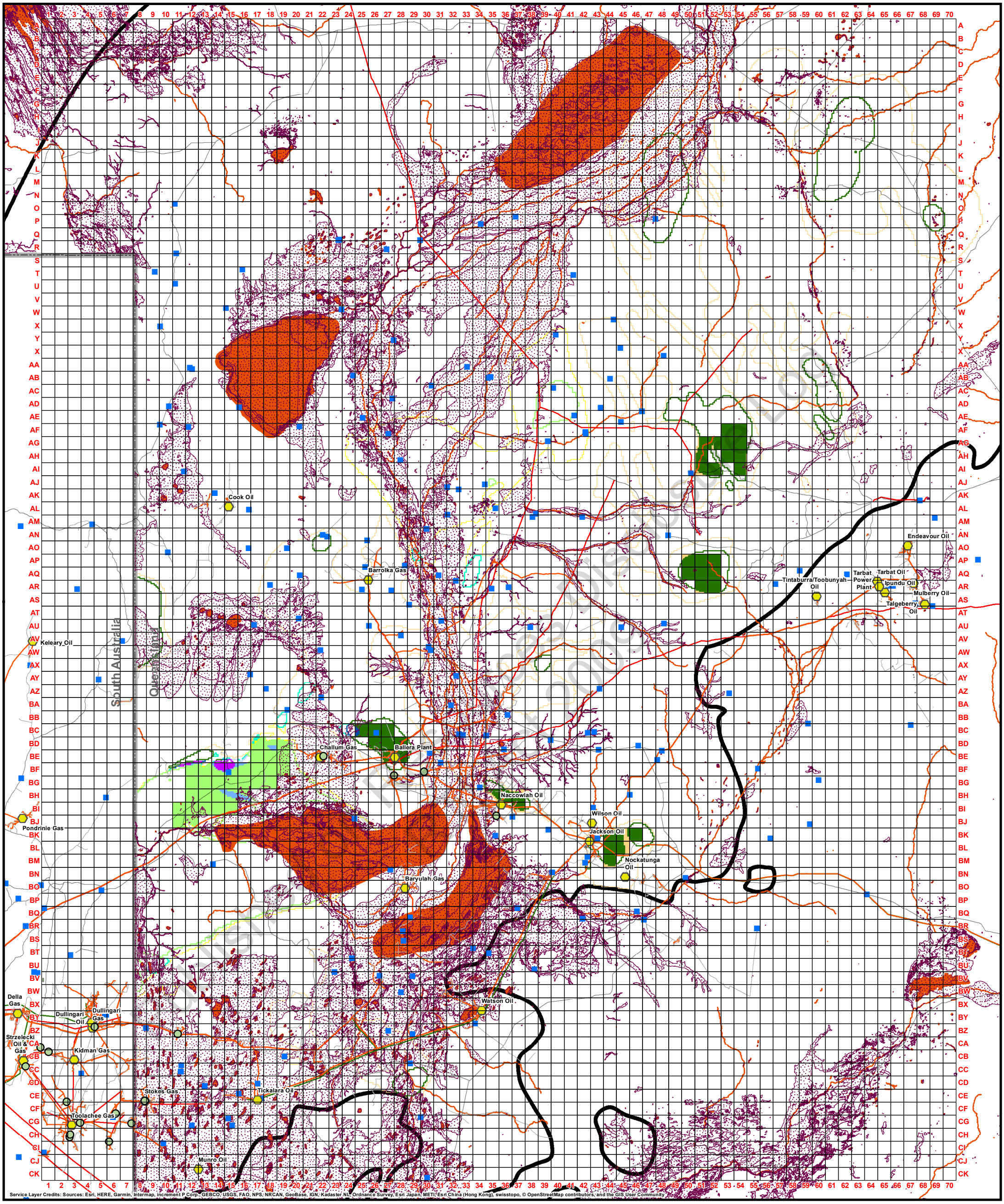
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10 5 0 10
Kilometers



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Figure 7 - Max Relative Prospectivity
Year 2038-2042 Development Period

Legend

- Compressor
- Santos Production Facility
- Tank Farm
- Facility Area
- Stockyard

Santos-Owned Infrastructure

- Pipeline(Santos)
- Road(Santos)
- Roads
- Gas Well
- Oil Well
- Oil and Gas Well

GA Pipelines

- Gas
- Gas - Under Cons
- Oil

- Wetlands
- Cooper Basin

Restricted Areas

- 200m Buffer from ESAs

Prospectivity

- High Tight Gas and High Coal Gas
- High Coal Gas Only
- High Tight Gas Only
- High Coal Gas and Medium Tight Gas
- High Tight Gas and Medium Coal Gas
- Medium Tight Gas and Medium Coal Gas
- Medium Coal Gas Only
- Medium Tight Gas

EHS Support

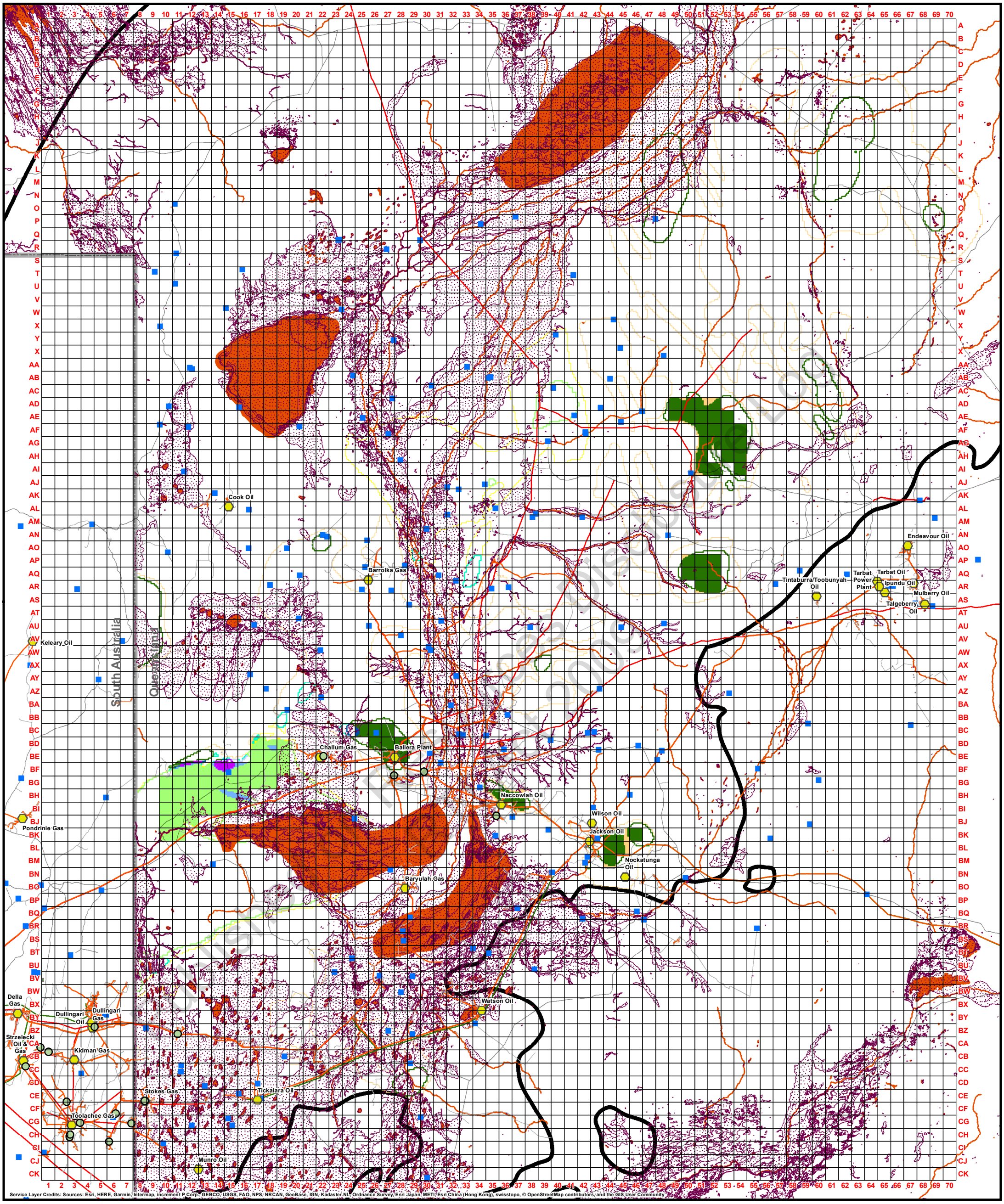
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Kilometers



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Figure 8 - Max Relative Prospectivity
Year 2043-2047 Development Period

Legend

- Compressor
- Santos Production Facility
- Tank Farm
- Facility Area
- Stockyard

Santos-Owned Infrastructure

- Pipeline(Santos)
- Road(Santos)
- Roads
- Gas Well
- Oil Well
- Oil and Gas Well

GA Pipelines

- Gas
- Gas - Under Cons
- Oil

- Wetlands
- Cooper Basin

Restricted Areas

- 200m Buffer from ESAs

Prospectivity

- High Tight Gas and High Coal Gas
- High Coal Gas Only
- High Tight Gas Only
- High Coal Gas and Medium Tight Gas
- High Tight Gas and Medium Coal Gas
- Medium Tight Gas and Medium Coal Gas
- Medium Coal Gas Only
- Medium Tight Gas

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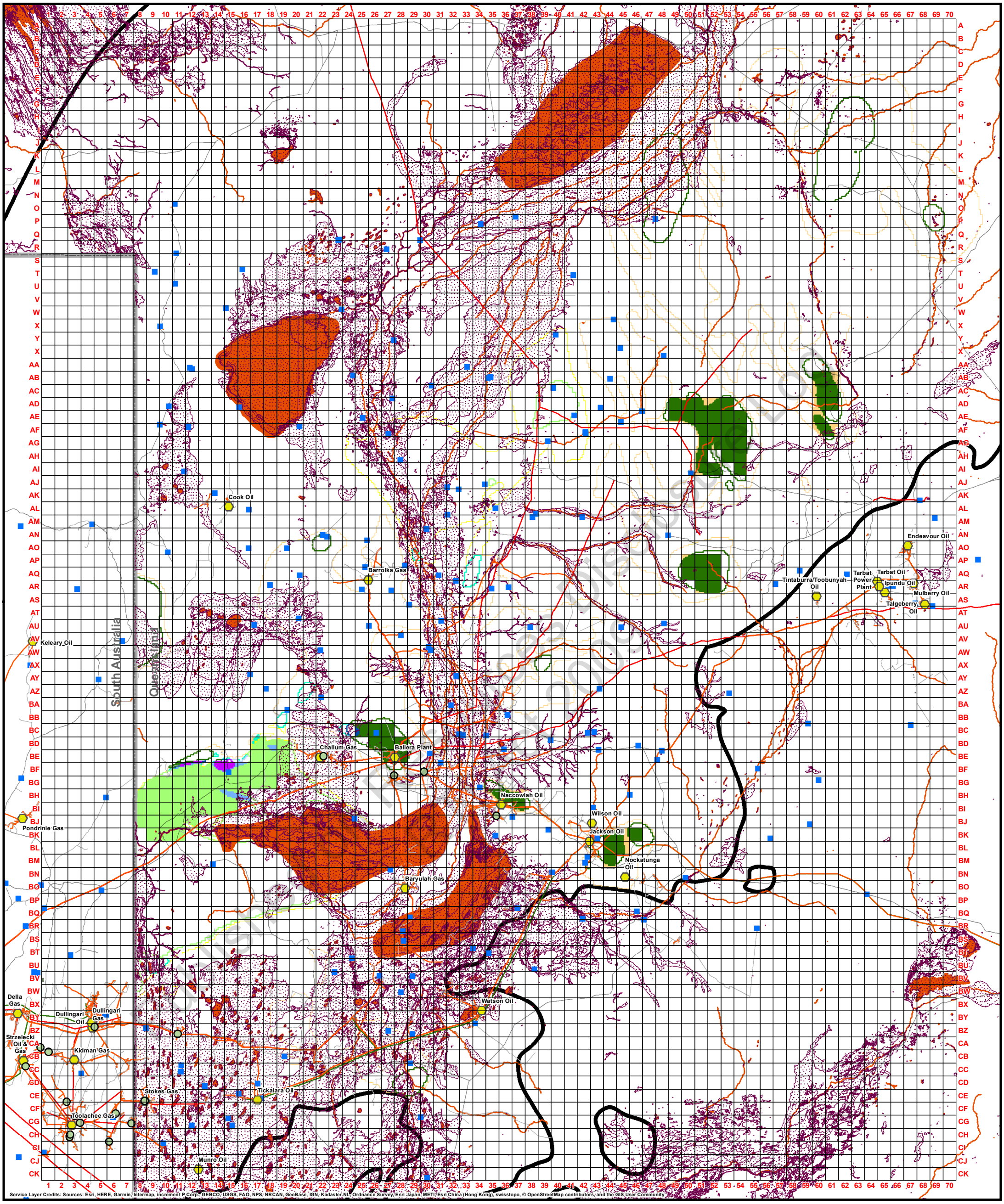
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Kilometers



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Figure 9 - Max Relative Prospectivity
Year 2048-2052 Development Period

Legend

- Compressor
- Santos Production Facility
- Tank Farm
- Facility Area
- Stockyard

Santos-Owned Infrastructure

- Pipeline(Santos)
- Road(Santos)
- Roads
- Gas Well
- Oil Well
- Oil and Gas Well

GA Pipelines

- Gas
- Gas - Under Cons
- Oil

- Wetlands
- Cooper Basin

Restricted Areas

- 200m Buffer from ESAs

Prospectivity

- High Tight Gas and High Coal Gas
- High Coal Gas Only
- High Tight Gas Only
- High Coal Gas and Medium Tight Gas
- High Tight Gas and Medium Coal Gas
- Medium Tight Gas and Medium Coal Gas
- Medium Coal Gas Only
- Medium Tight Gas

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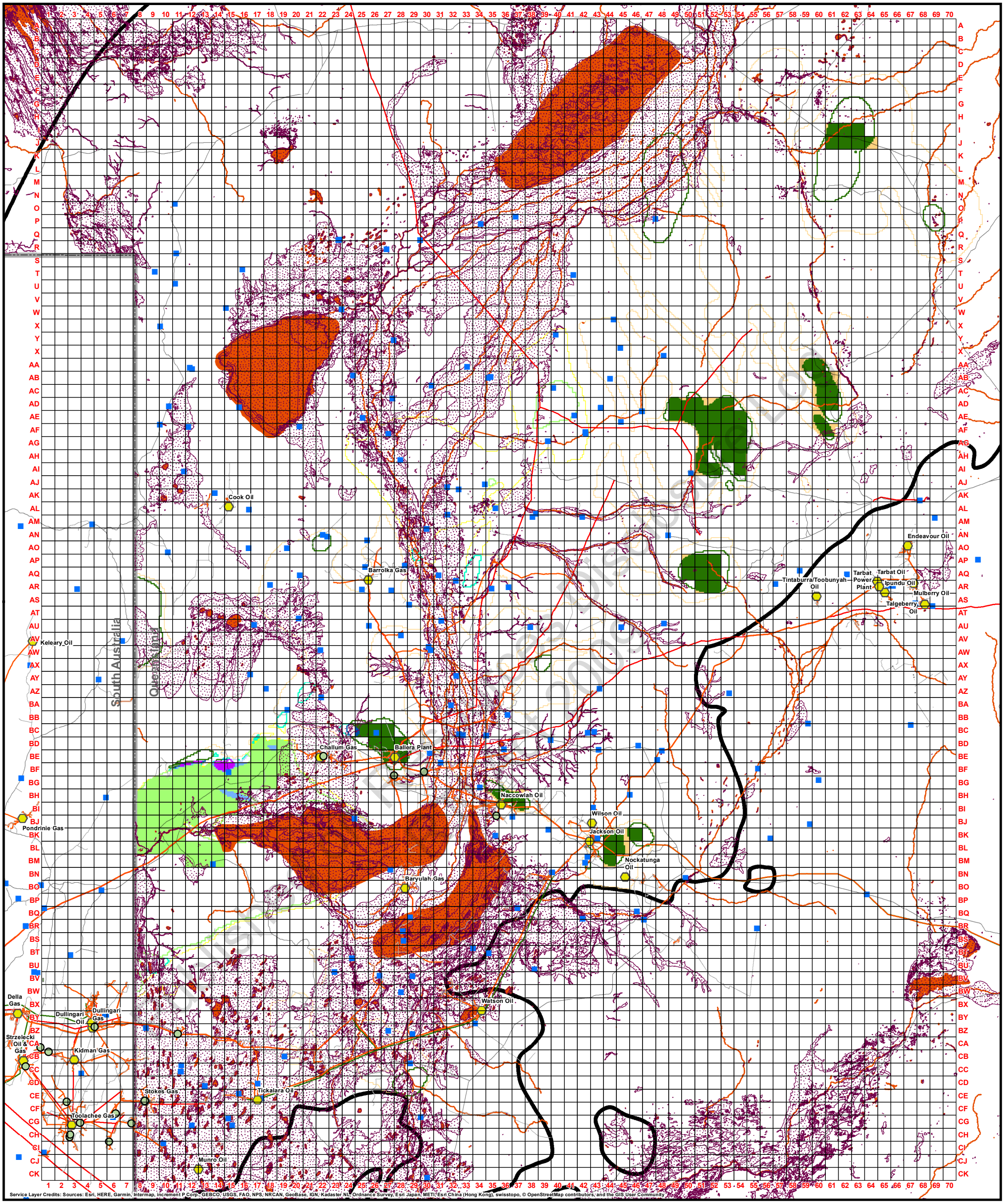
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10 5 0 10
Kilometers



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Figure 10 - Max Relative Prospectivity
Year 2053-2057 Development Period

Legend

- Compressor
- Santos Production Facility
- Tank Farm
- Facility Area
- Stockyard

Santos-Owned Infrastructure

- Pipeline(Santos)
- Road(Santos)
- Roads
- Gas Well
- Oil Well
- Oil and Gas Well

GA Pipelines

- Gas
- Gas - Under Cons
- Oil

- Wetlands
- Cooper Basin

Restricted Areas

- 200m Buffer from ESAs

Prospectivity

- High Tight Gas and High Coal Gas
- High Coal Gas Only
- High Tight Gas Only
- High Coal Gas and Medium Tight Gas
- High Tight Gas and Medium Coal Gas
- Medium Tight Gas and Medium Coal Gas
- Medium Coal Gas Only
- Medium Tight Gas

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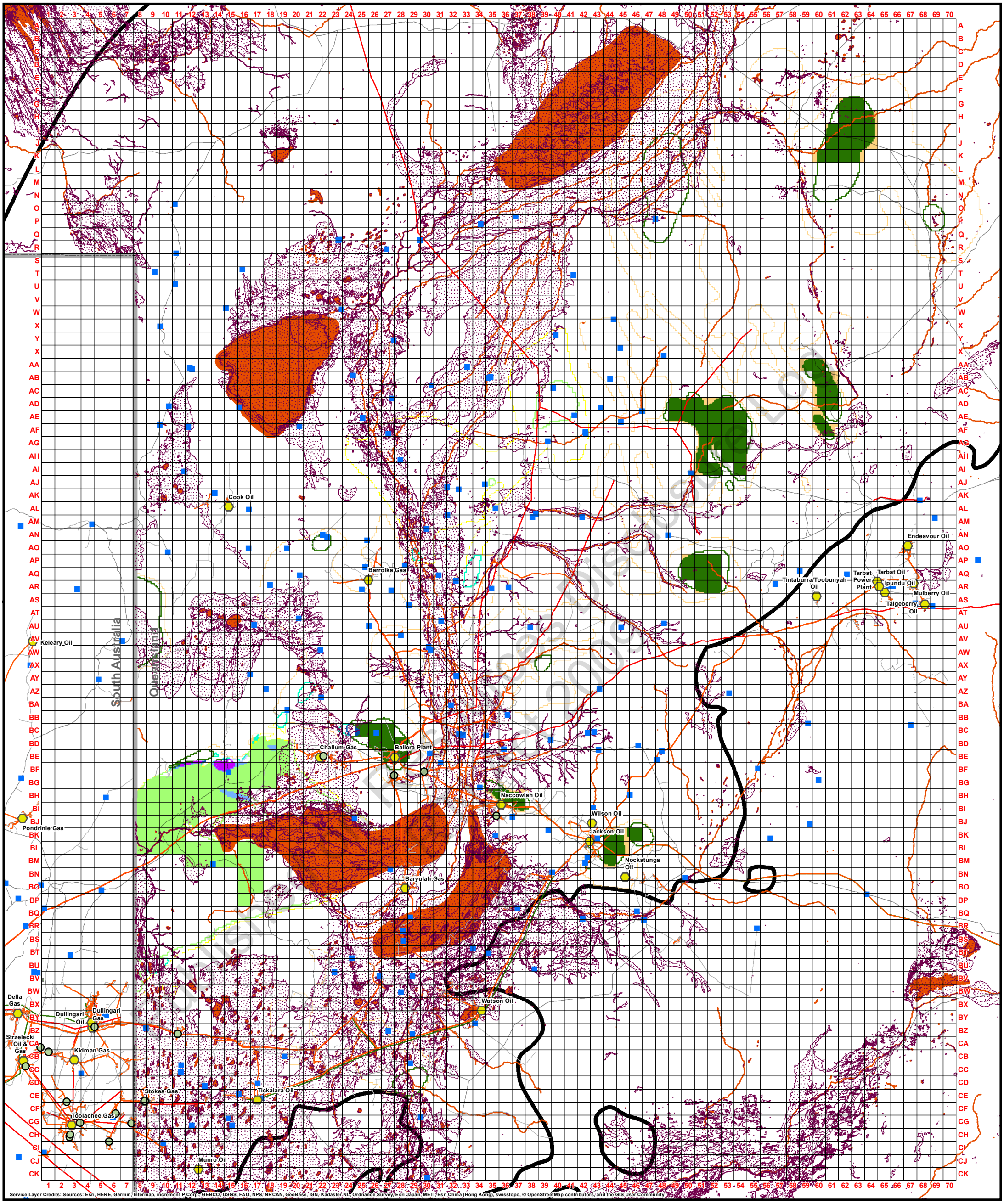
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10 5 0 10
Kilometers



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Figure 11 - Max Relative Prospectivity Year 2058-2062 Development Period

Legend

- Compressor
- Santos Production Facility
- Tank Farm
- Facility Area
- Stockyard

Santos-Owned Infrastructure

- Pipeline(Santos)
- Road(Santos)
- Roads
- Gas Well
- Oil Well
- Oil and Gas Well

GA Pipelines

- Gas
- Gas - Under Cons
- Oil

- Wetlands
- Cooper Basin

Restricted Areas

- 200m Buffer from ESAs

Prospectivity

- High Tight Gas and High Coal Gas
- High Coal Gas Only
- High Tight Gas Only
- High Coal Gas and Medium Tight Gas
- High Tight Gas and Medium Coal Gas
- Medium Tight Gas and Medium Coal Gas
- Medium Coal Gas Only
- Medium Tight Gas

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10 5 0 10
Kilometers

Cook Oil
Barrolka Gas
Endeavour Oil
Tintaburra/Toobunyah Oil
Tarbat Power Plant
Tarbat Oil
Ipundu Oil
Mulberry Oil
Talgeberry Oil
Keleary Oil
South Australia
Queensland
Challum Gas
Ballera Plant
Naccowlah Oil
Wilson Oil
Jackson Oil
Nockatunga Oil
Pondrinie Gas
Baryulah Gas
Watson Oil
Della Gas
Dullingari Oil
Dullingari Gas
Strzelecki Oil & Gas
Kidman Gas
Stokes Gas
Tickalara Oil
Toolachee Gas
Munro Oil

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Figure 12 - Max Relative Prospectivity
Year 2063-2067 Development Period

Legend

- Compressor
- Santos Production Facility
- Tank Farm
- Facility Area
- Stockyard

Santos-Owned Infrastructure

- Pipeline(Santos)
- Road(Santos)
- Roads
- Gas Well
- Oil Well
- Oil and Gas Well

GA Pipelines

- Gas
- Gas - Under Cons
- Oil

- Wetlands
- Cooper Basin

Restricted Areas

- 200m Buffer from ESAs

Prospectivity

- High Tight Gas and High Coal Gas
- High Coal Gas Only
- High Tight Gas Only
- High Coal Gas and Medium Tight Gas
- High Tight Gas and Medium Coal Gas
- Medium Tight Gas and Medium Coal Gas
- Medium Coal Gas Only
- Medium Tight Gas

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10 5 0 10
Kilometers

Cook Oil
Barrolka Gas
Endeavour Oil
Tintaburra/Toobunyah Oil
Tarbat Power Plant
Tarbat Oil
Ipundu Oil
Mulberry Oil
Talgeberry Oil
Keleary Oil
South Australia
Queensland
Challum Gas
Ballera Plant
Naccowlah Oil
Wilson Oil
Jackson Oil
Nockatunga Oil
Pondrinie Gas
Baryulah Gas
Watson Oil
Della Gas
Dullingari Oil
Dullingari Gas
Strzelecki Oil & Gas
Kidman Gas
Stokes Gas
Tickalara Oil
Toolachee Gas
Munro Oil

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Figure 13 - Max Relative Prospectivity
Year 2068-2070 Development Period

Legend

- Compressor
- Santos Production Facility
- Tank Farm
- Facility Area
- Stockyard

Santos-Owned Infrastructure

- Pipeline(Santos)
- Road(Santos)
- Roads
- Gas Well
- Oil Well
- Oil and Gas Well

GA Pipelines

- Gas
- Gas - Under Cons
- Oil

- Wetlands
- Cooper Basin

Restricted Areas

- 200m Buffer from ESAs

Prospectivity

- High Tight Gas and High Coal Gas
- High Coal Gas Only
- High Tight Gas Only
- High Coal Gas and Medium Tight Gas
- High Tight Gas and Medium Coal Gas
- Medium Tight Gas and Medium Coal Gas
- Medium Coal Gas Only
- Medium Tight Gas

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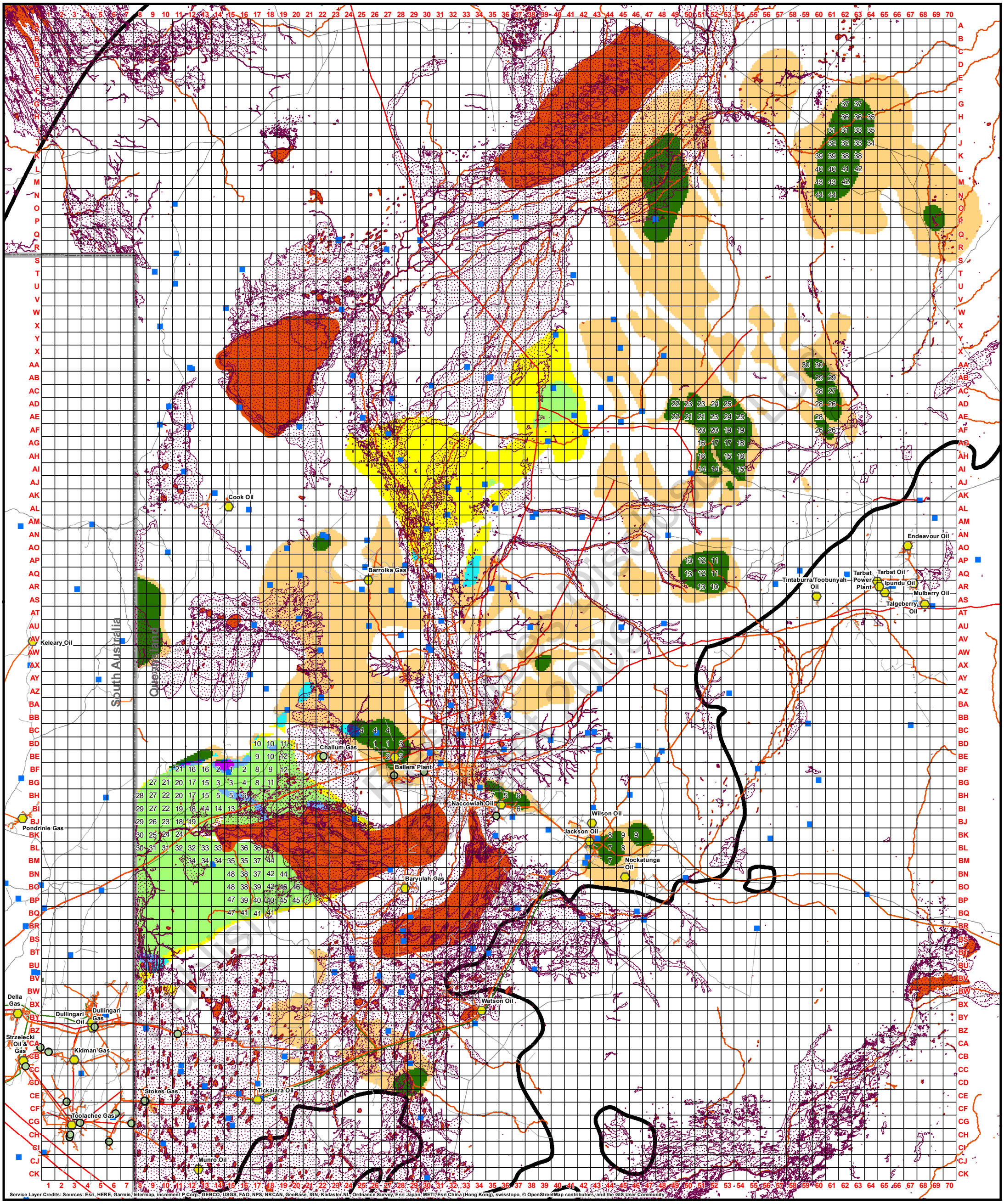
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10 5 0 10
Kilometers



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Figure 14 - 50 Year Development with Order

Legend

- Compressor
- Santos Production Facility
- Tank Farm
- Facility Area
- Stockyard

Santos-Owned Infrastructure

- Pipeline(Santos)
- Road(Santos)
- Roads
- Gas Well
- Oil Well
- Oil and Gas Well

GA Pipelines

- Gas
- Gas - Under Cons
- Oil

- Wetlands
- Cooper Basin

Restricted Areas

- 200m Buffer from ESAs

Prospectivity

- High Tight Gas and High Coal Gas
- High Coal Gas Only
- High Tight Gas Only
- High Coal Gas and Medium Tight Gas
- High Tight Gas and Medium Coal Gas
- Medium Tight Gas and Medium Coal Gas
- Medium Coal Gas Only
- Medium Tight Gas



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10 5 0 10
Kilometers

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Appendix A Draft Relative Prospectivity Mapping and Area Calculations – Cooper Basin (Source: Geoscience Australia)

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Cooper Basin Relative Prospectivity Mapping – Deep Coal Play Update

Prospectivity confidence mapping, sometimes referred to as 'chance of success' or 'common risk segment' mapping was used to map the distribution of the basin's key unconventional shale gas, deep coal and basin-centred tight gas plays.

Deep coal gas is a relatively new and underutilised resource in the Cooper Basin. Since the viability of this play was demonstrated by Santos Limited in 2007 (Dunlop et al., 2017), gas saturated deep coal plays in the Permian Toolachee, Epsilon and Patchawarra formations (that do not require dewatering) have become additional exploration targets (Department of the Premier and Cabinet (SA), 2018c; Goldstein et al., 2012; Greenstreet, 2015a; Menpes and Hill, 2012). The primary deep coal gas fairways are defined where net cumulative coal thickness exceeds 25 m thickness and the formation is thermally mature. Both wet and dry gas play extents are mapped, reflecting the significance of gas condensate production as an economic driver for deep coal play development.

Change in workflow

- Old workflow:
  - The initial workflow used a geometric mean to combine individual maps (https://en.wikipedia.org/wiki/Geometric_mean).
  - A geometric mean is typically used to compare items, when each item has multiple properties that have different numeric ranges.

$$C = \left[\prod_{i=1}^{n} a_i\right]^{\frac{1}{n}}$$

Where:

C =	Combined prospectivity confidence (relative likelihood of success)
n =	Total number of input parameters used
i =	Index of multiplication
a =	Input parameter

  - Issue: although the purpose of these maps is to only show relative prospectivity, normalisation by 1/n gave the perception to the end user that areas of low-to moderate prospectivity were actually moderate to high.
- New workflow:
  - Maps were combined by simple multiplication.

$$C = (c_1 \times c_2 \times c_3 \ldots c_n)$$

  - Each input item was normalised to a consistent range representing relative level of risk; to determine total relative prospectivity, items were multiplied together.
  - The new result provides a simpler more intuitive output for the end user.

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Change in criteria defining deep coal plays

- Criteria used to define deep coal plays have been updated based on feedback from Santos sch4p4(6) Personal infor.
- Wet gas and dry gas plays are now mapped separately, as per the following tables:

Wet gas play Parameter (P)	Classified input parameter cut-offs (CP)		
	None (0)	Medium (0.5)	High (1)
Net coal thickness	< 10 m	≥ 10 – < 25 m	≥ 25 m
Thermal maturity	< 0.75 %Ro or ≥ 1.4 %Ro	≥0.75-0.9 %Ro	≥0.9-1.4 %Ro
Distance from faults	< 433 m	≥ 433 – < 895 m	≥ 895 m

Dry gas play Parameter (P)	Classified input parameter cut-offs (CP)		
	None (0)	**Medium (0.5)**	**High (1)**
Net coal thickness	**< 10 m**	**≥ 10** – < 25 m	≥ 25 m
Thermal maturity	**< 1.4 %Ro or ≥ 2.5 %Ro**	**≥2-2.5 %Ro**	**≥1.4-2 %Ro**
Distance from faults	< 433 m	≥ 433 – < 895 m	≥ 895 m

Note all results presented in this document have not yet been fully peer reviewed and are still in draft format.

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Deep coal wet gas mapping results by formation

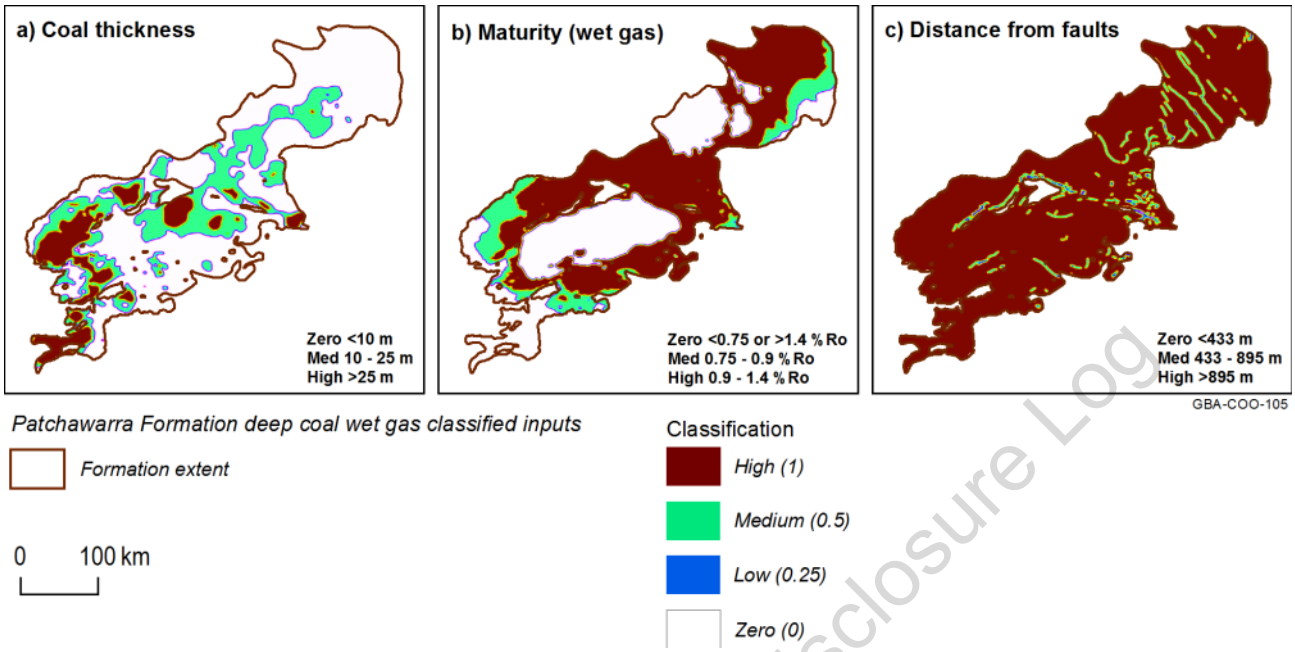


Figure B-1 Patchawarra Formation deep coal wet gas classified mappable prospectivity confidence input parameters.

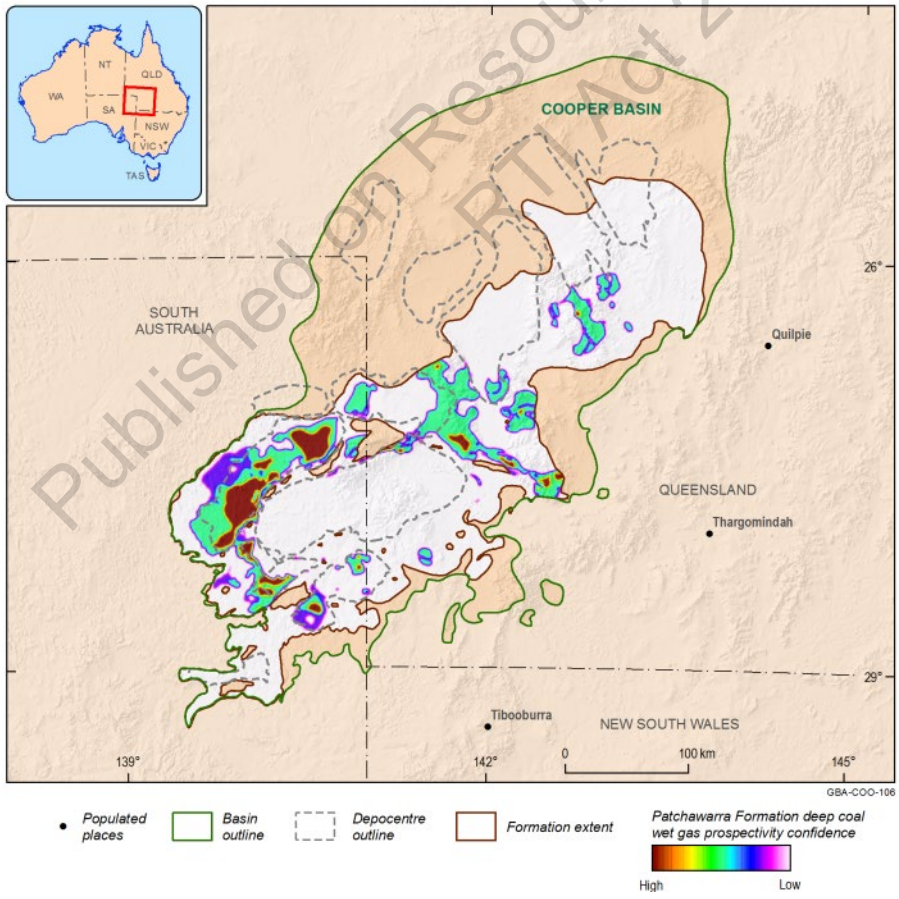


Figure B-2 Patchawarra Formation deep coal wet gas prospectivity confidence.

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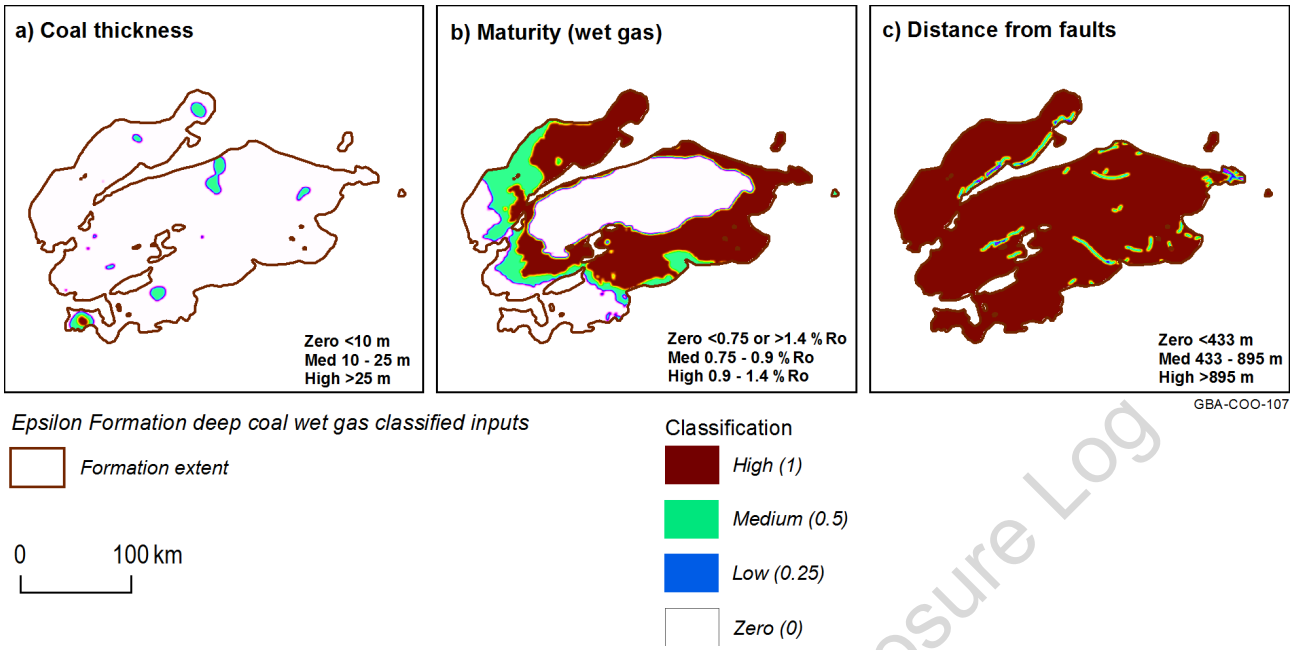


Figure B-3 Epsilon Formation deep coal wet gas classified mappable prospectivity confidence input parameters.

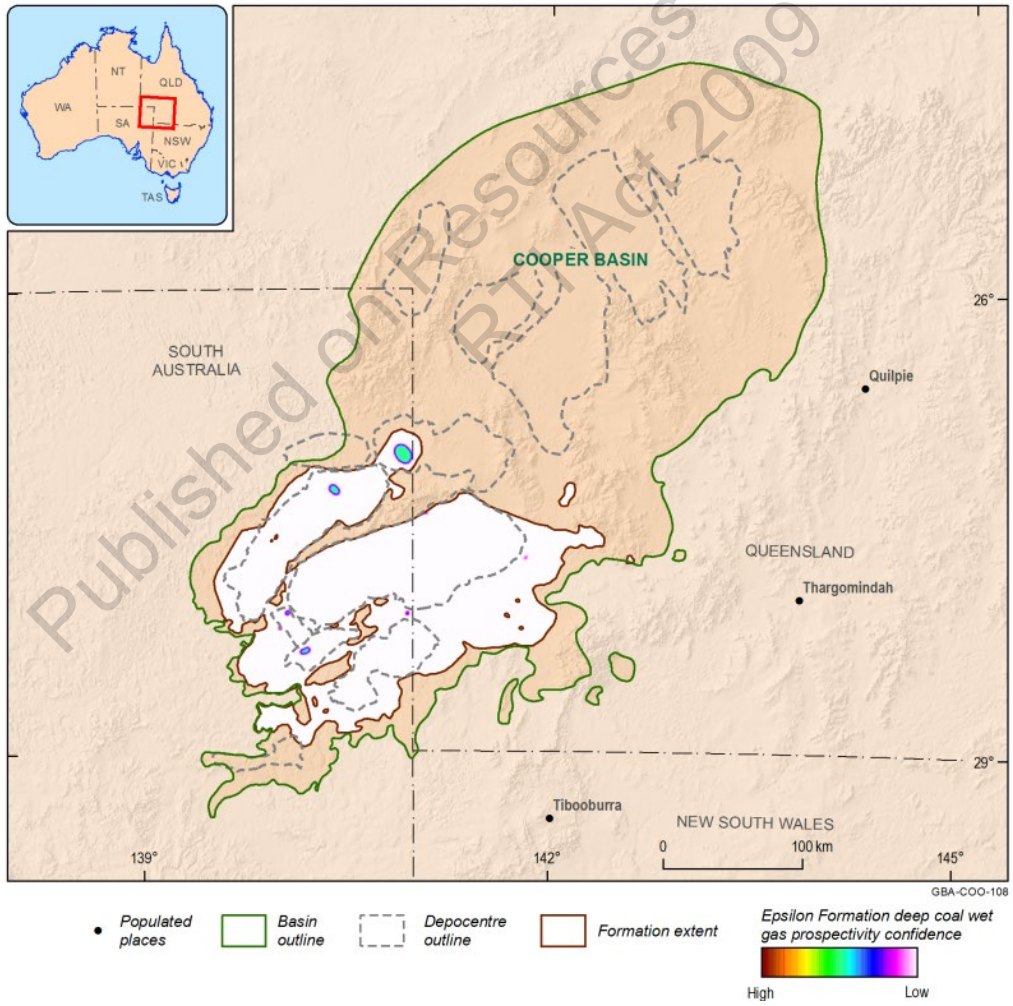


Figure B-4 Epsilon Formation deep coal wet gas prospectivity confidence.

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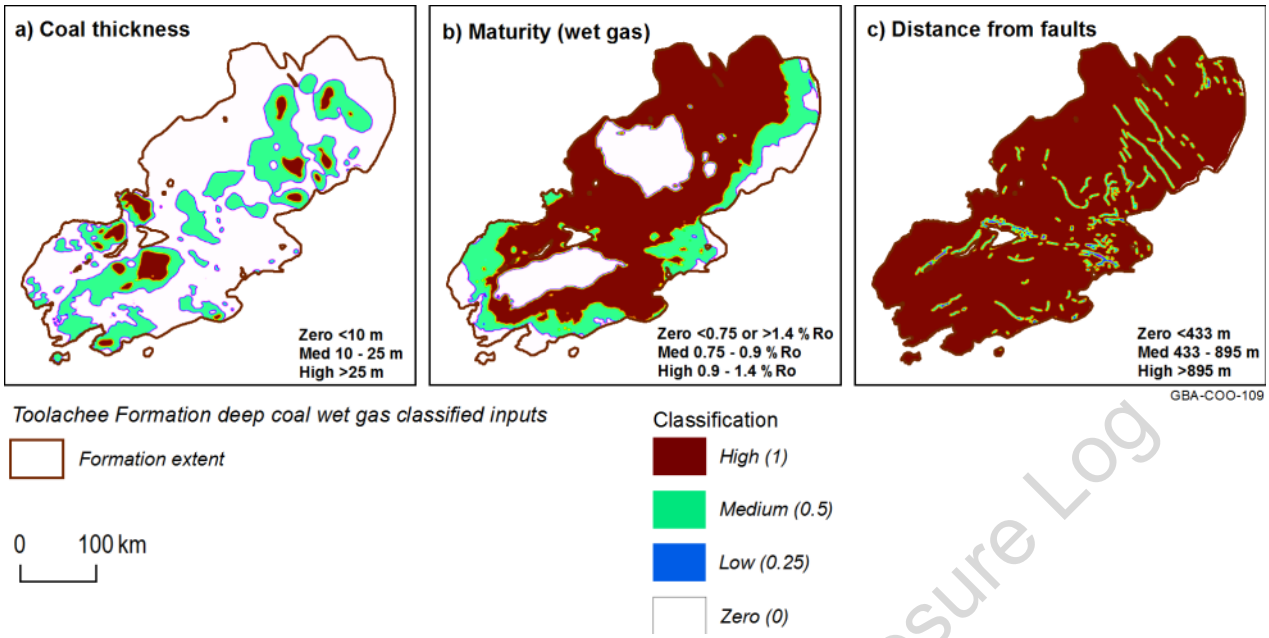


Figure B-5 Toolachee Formation deep coal wet gas classified mappable prospectivity confidence input parameters.

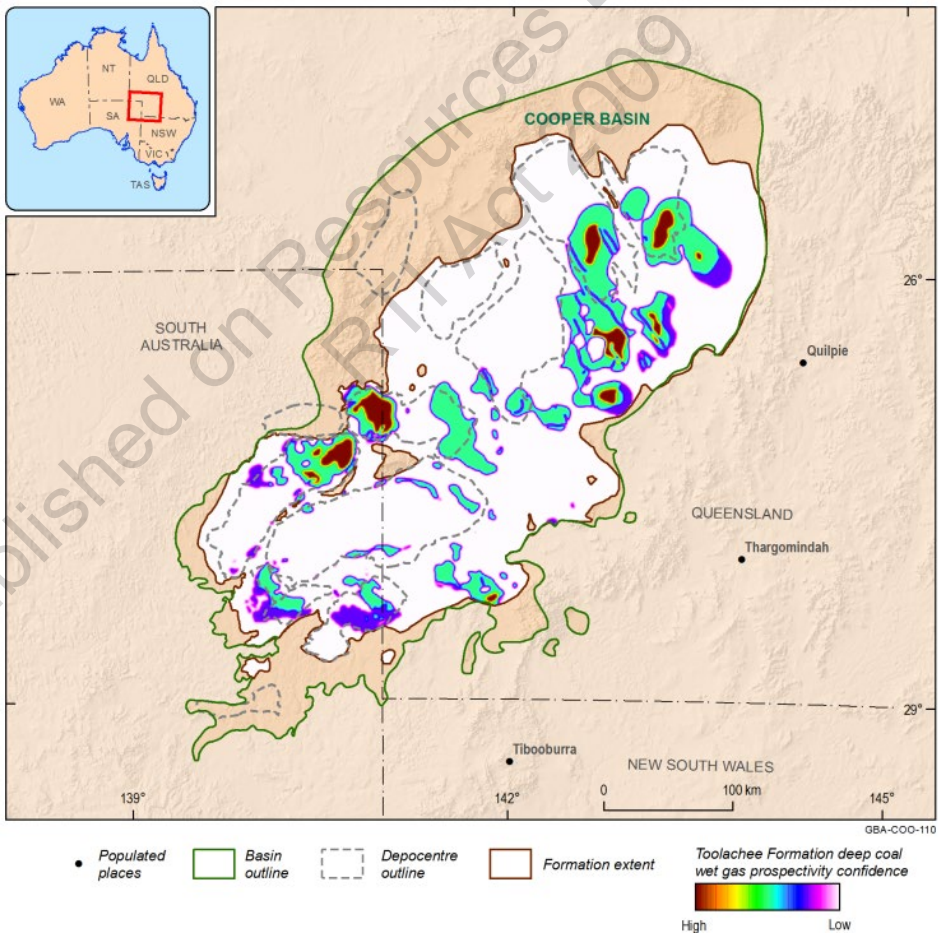


Figure B-6 Toolachee Formation deep coal wet gas prospectivity confidence.

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Deep coal dry gas mapping results by formation

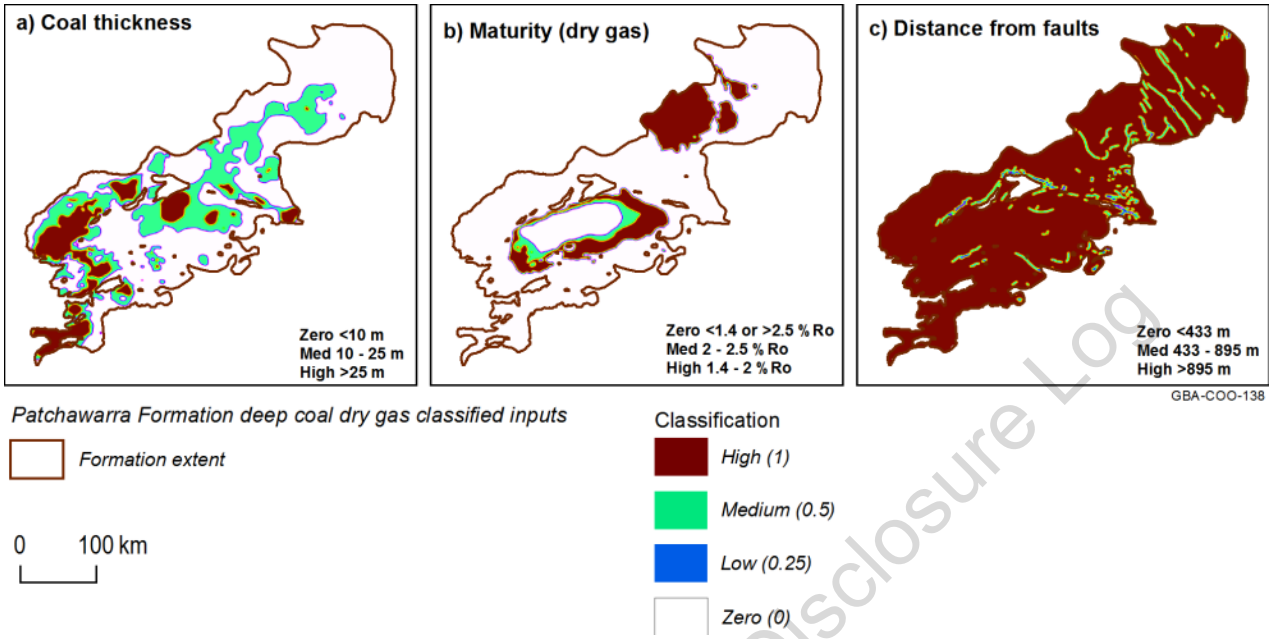


Figure B-7 Patchawarra Formation deep coal dry gas classified mappable prospectivity confidence input parameters.

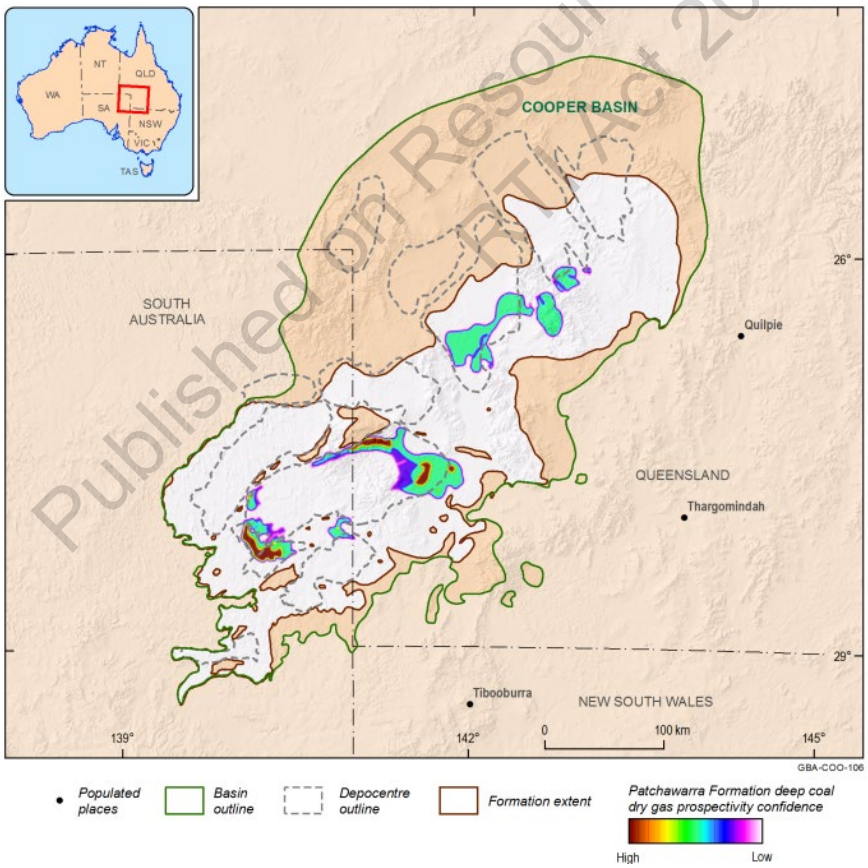


Figure B-8 Patchawarra Formation deep coal dry gas prospectivity confidence.

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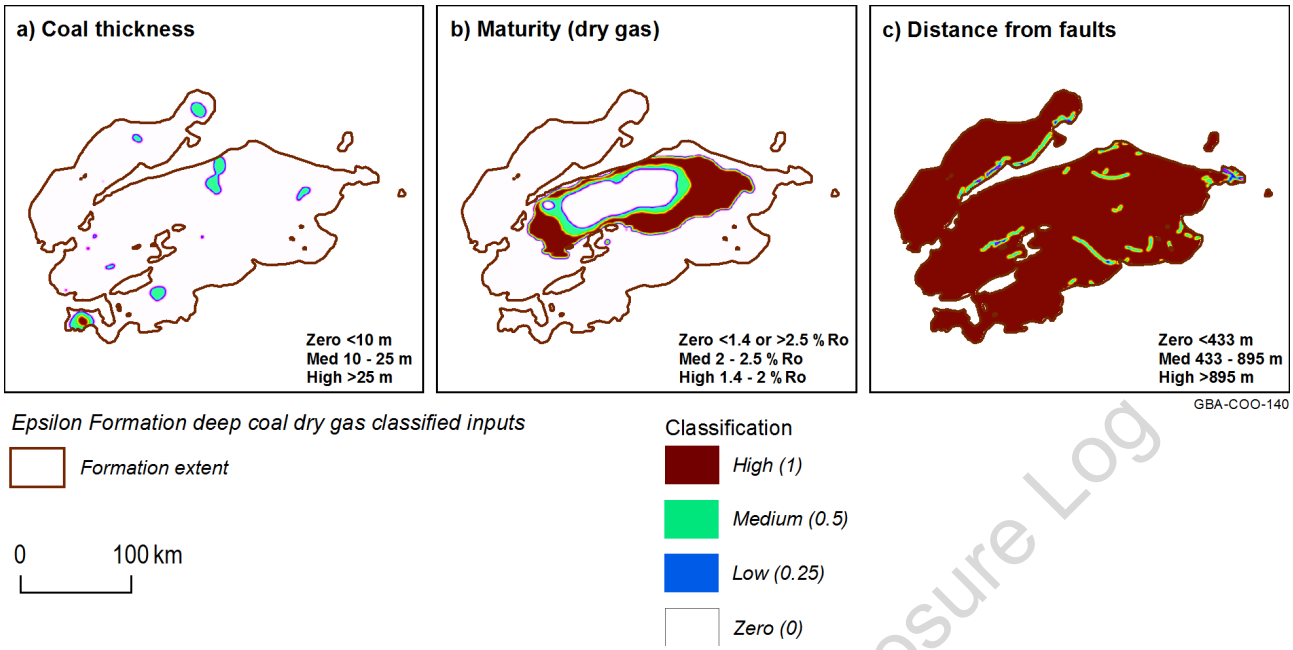


Figure B-9 Epsilon Formation deep coal dry gas classified mappable prospectivity confidence input parameters.

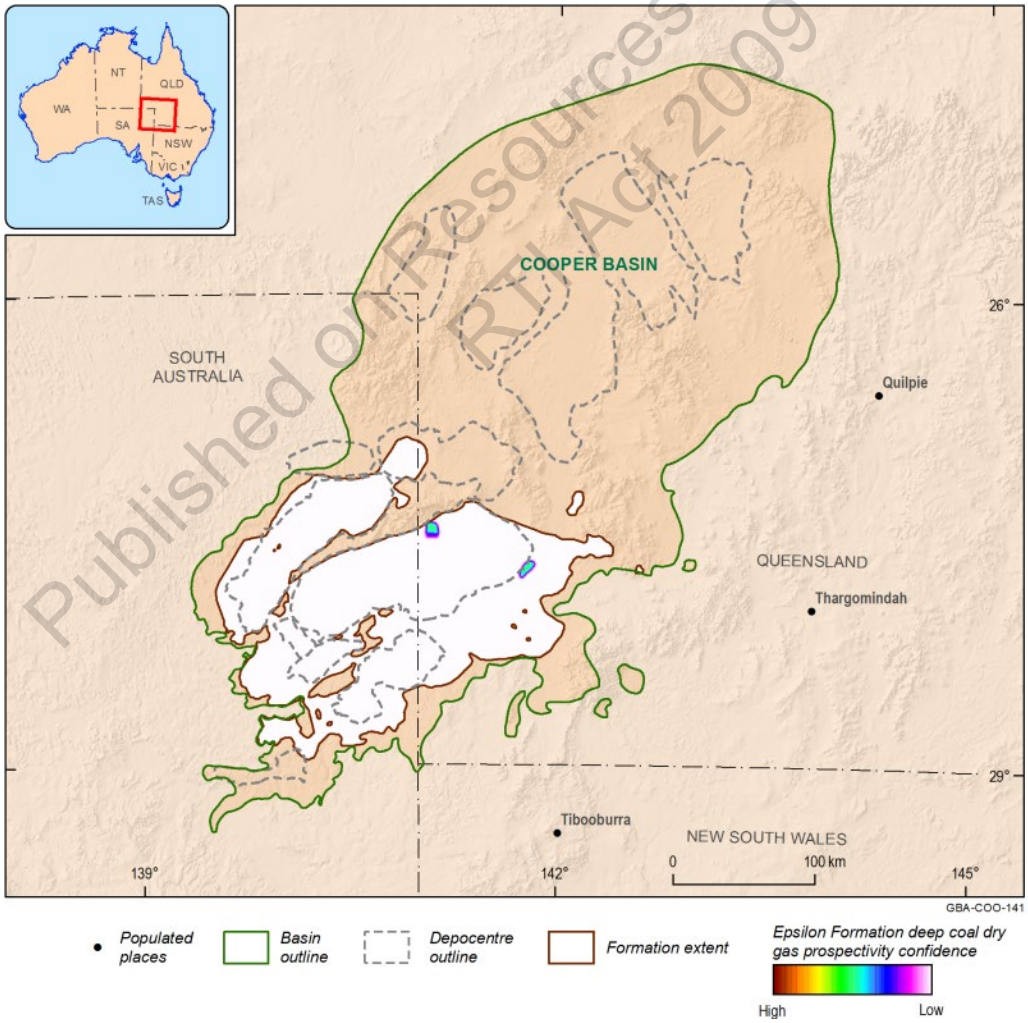


Figure B-10 Epsilon Formation deep coal dry gas prospectivity confidence.

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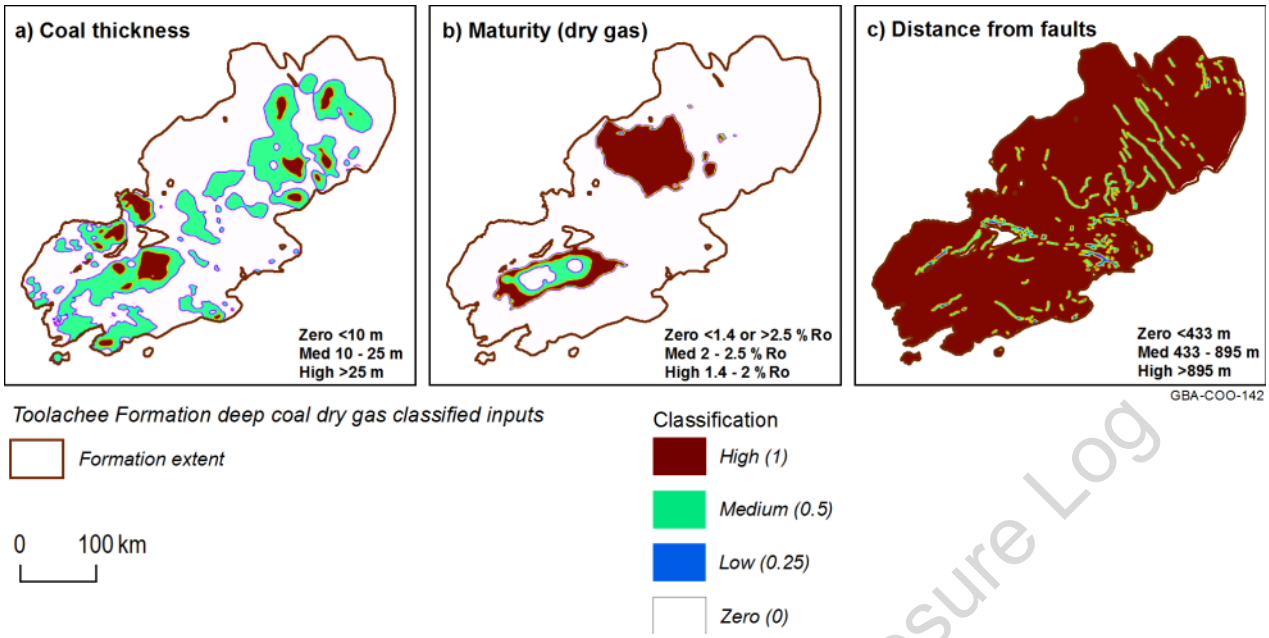


Figure B-11 Toolachee Formation deep coal dry gas classified mappable prospectivity confidence input parameters.

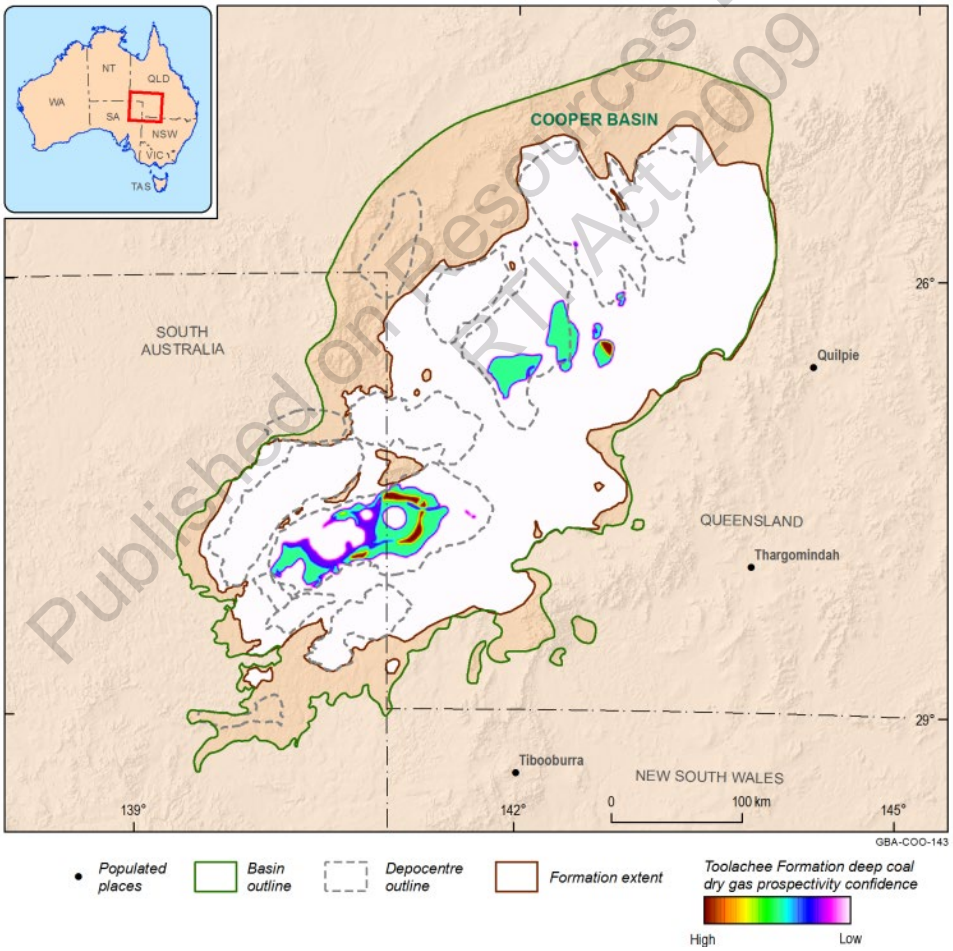
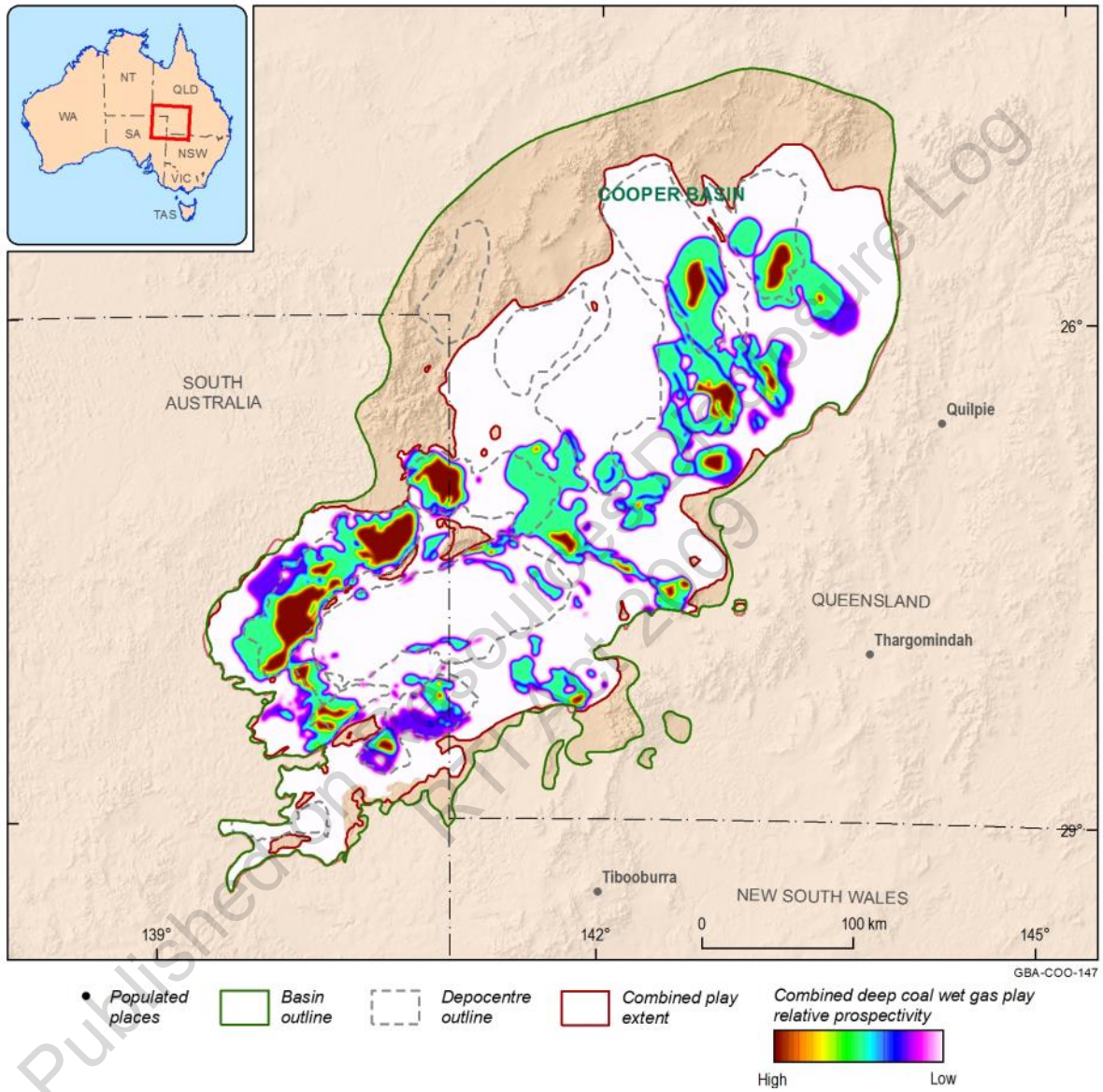


Figure B-12 Toolachee Formation deep coal dry gas prospectivity confidence.

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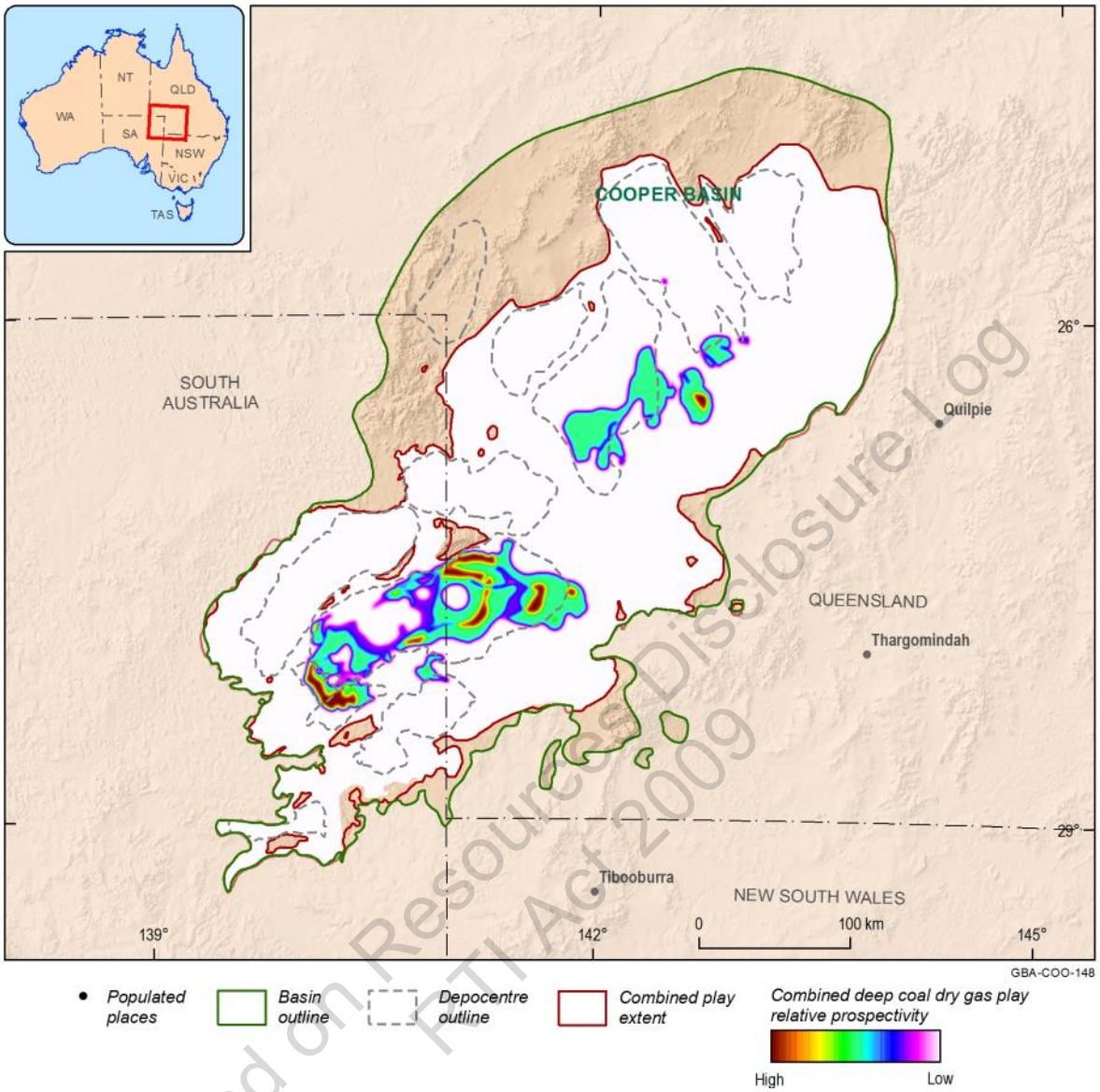
Overall deep coal gas prospectivity confidence results

In order to understand each play type as a whole, prospectivity confidence results were combined to develop an overall maximum play prospectivity confidence map for each play type.



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Figure B-13 Combined relative prospectivity confidence for prospective deep coal wet gas plays.



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Figure B-14 Combined relative prospectivity confidence for prospective deep coal gas dry plays.

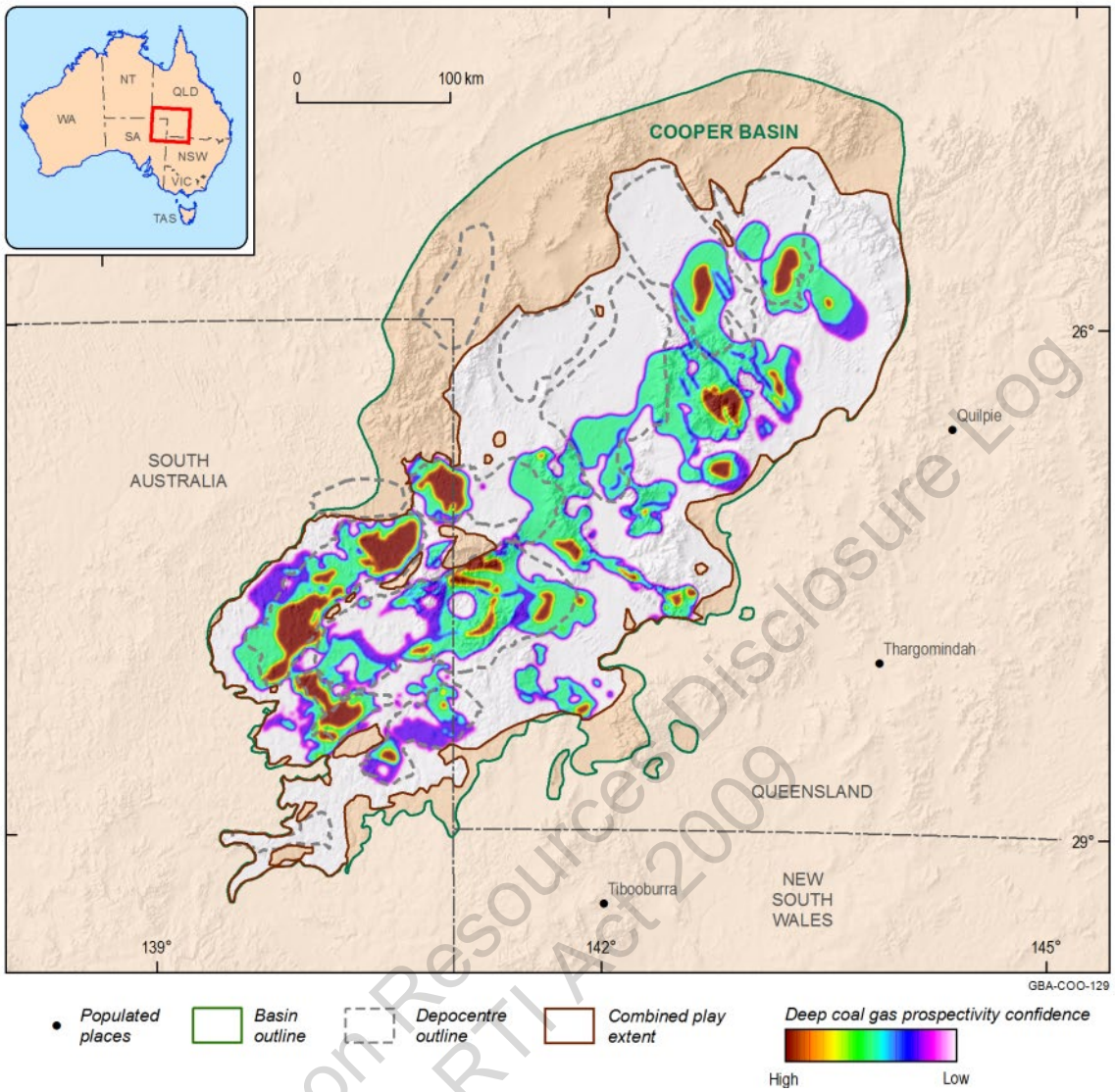


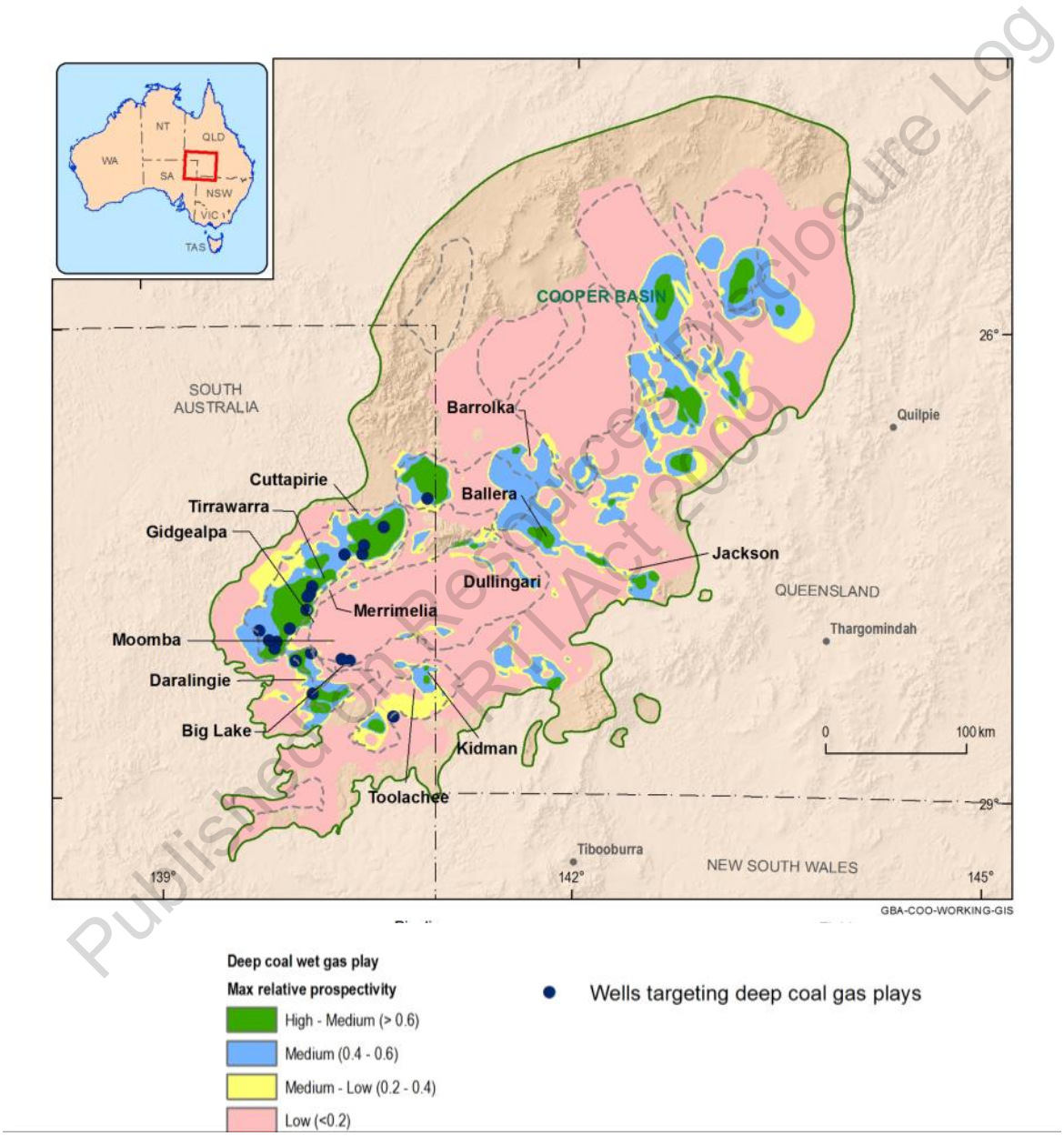
Figure B-15 Combined relative prospectivity confidence for prospective deep coal gas plays (wet and dry gas).

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Use of simple multiplication rather than geometric mean, requires updated guidelines to interpreting relative prospectivity.

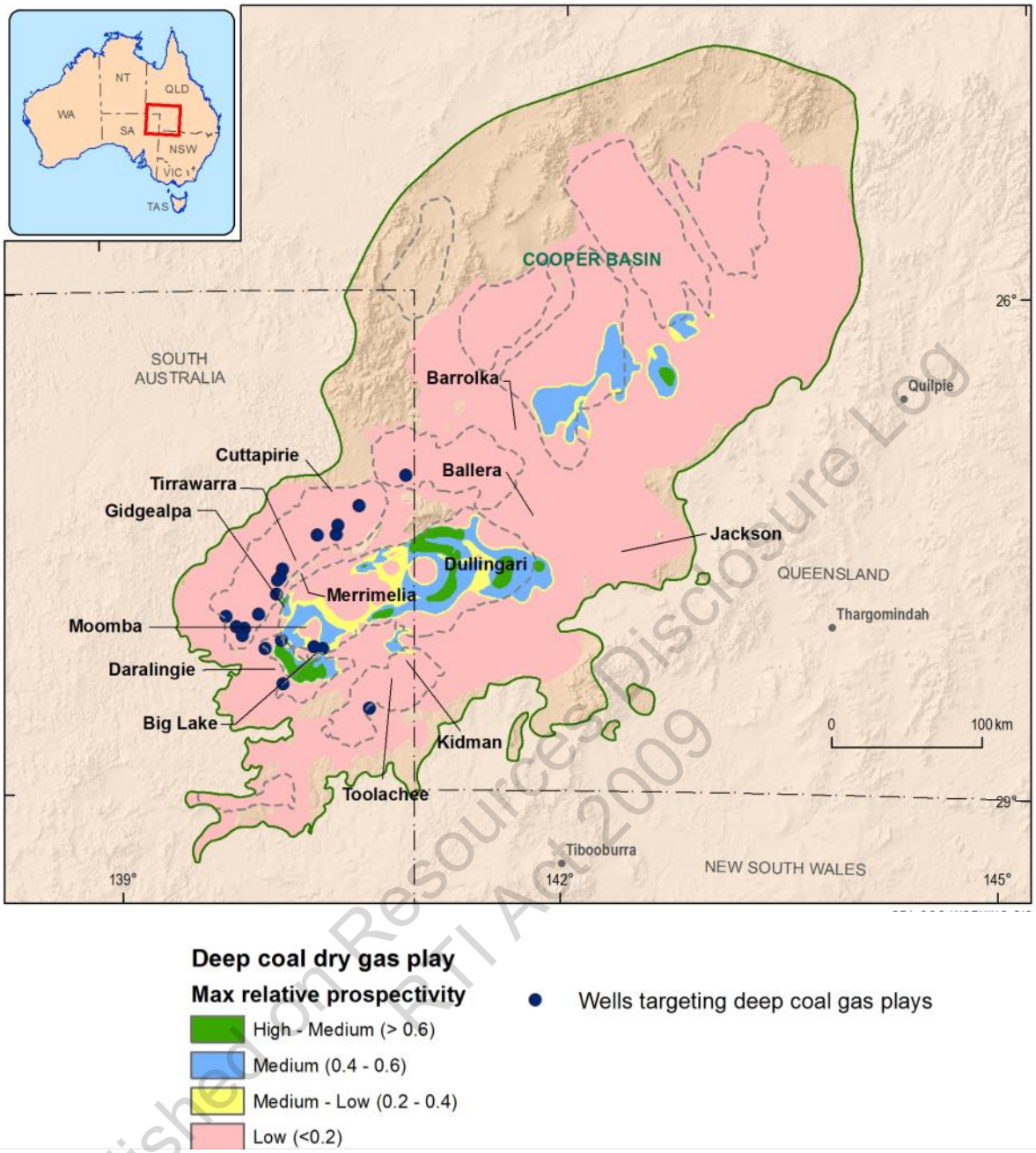
Table 1 Guideline to interpreting relative prospectivity confidence map (Note: Numbers are not probability of success)

Relative prospectivity	Prospectivity map value
High	0.8 - 1
High - medium	0.6 - 0.8
Medium	0.4 - 0.6
Medium - low	0.2 - 0.4
Low	< 0.2



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Figure B-16 Combined relative prospectivity confidence for prospective deep coal wet gas plays



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Figure B-17 Combined relative prospectivity confidence for prospective deep coal dry gas plays

Cooper Basin Relative Prospectivity Mapping – Shale Play Update

Prospectivity confidence mapping, sometimes referred to as 'chance of success' or 'common risk segment' mapping was used to map the distribution of the basin's key unconventional shale gas, deep coal and basin-centred tight gas plays.

For shale gas plays, the Murteree and Roseneath shales, and the Patchawarra Formation were chosen for assessment primarily based on formation thickness and spatial extent, source rock amount, quality and thermal maturity, and pressure regime. The areas of highest shale gas relative prospectivity are defined where net shale thickness exceeds 30 m thickness, TOC is greater than 2% and the formation is overpressured.

Change in workflow

- Old workflow:
  - The initial workflow used a geometric mean to combine individual maps (https://en.wikipedia.org/wiki/Geometric_mean).
  - A geometric mean is typically used to compare items, when each item has multiple properties that have different numeric ranges.

$$C = \left[\prod_{i=1}^{n} a_i\right]^{\frac{1}{n}}$$

Where:

C =	Combined prospectivity confidence (relative likelihood of success)
n =	Total number of input parameters used
i =	Index of multiplication
a =	Input parameter

  - Issue: although the purpose of these maps is to only show relative prospectivity, normalisation by 1/n gave the perception to the end user that areas of low-to moderate prospectivity were actually moderate to high.
- New workflow:
  - Maps were combined by simple multiplication.

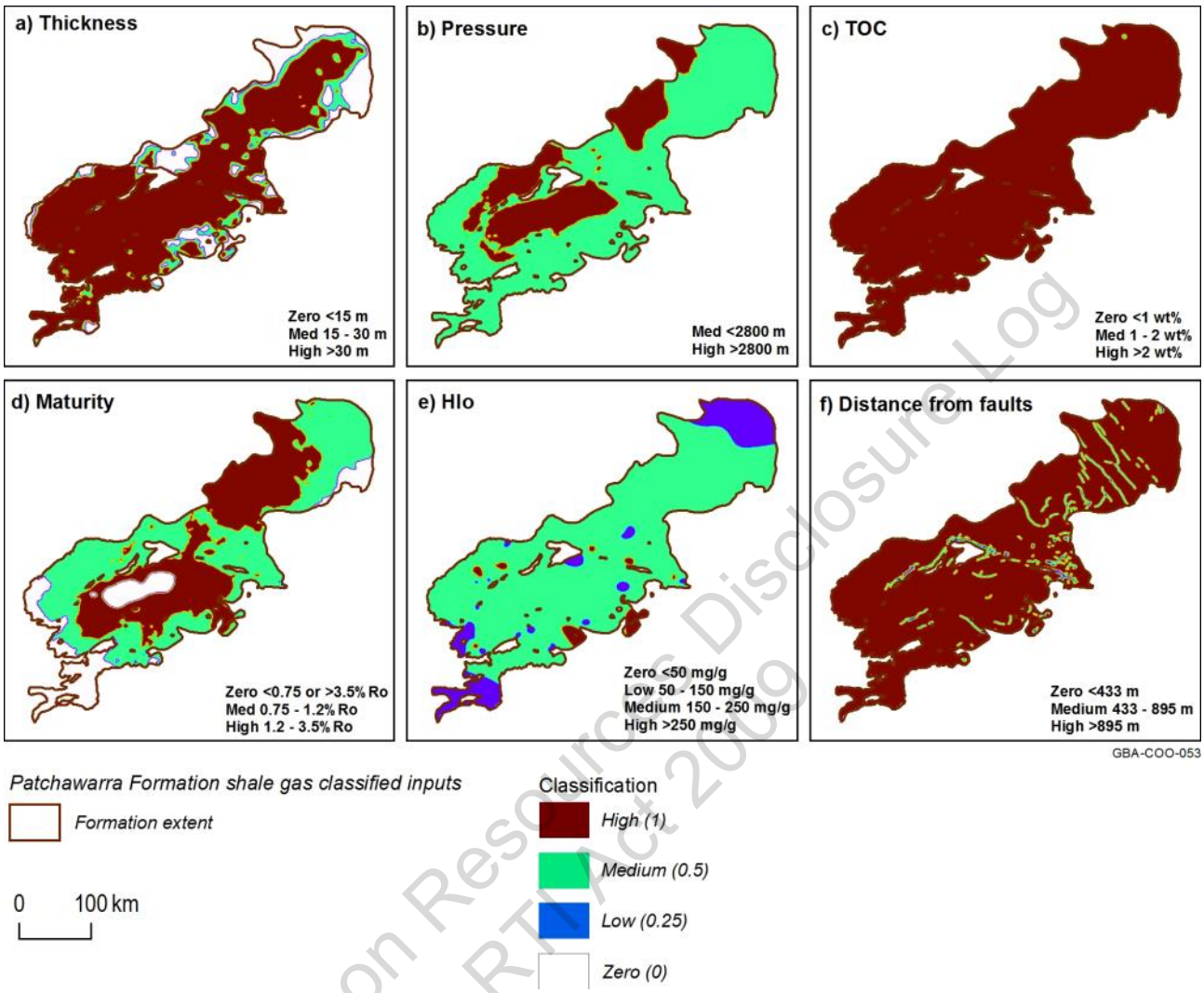
$$C = (a \times b \times c \ldots n)$$

  - Each input item was normalised to a consistent range representing relative level of risk; to determine total relative prospectivity, items were multiplied together.
  - The new result provides a simpler more intuitive output for the end user.

Note all results presented in this document have not yet been fully peer reviewed and are still in draft format.

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Shale gas mapping results by formation



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Figure B-1 Patchawarra Formation shale gas classified mappable prospectivity confidence input parameters.

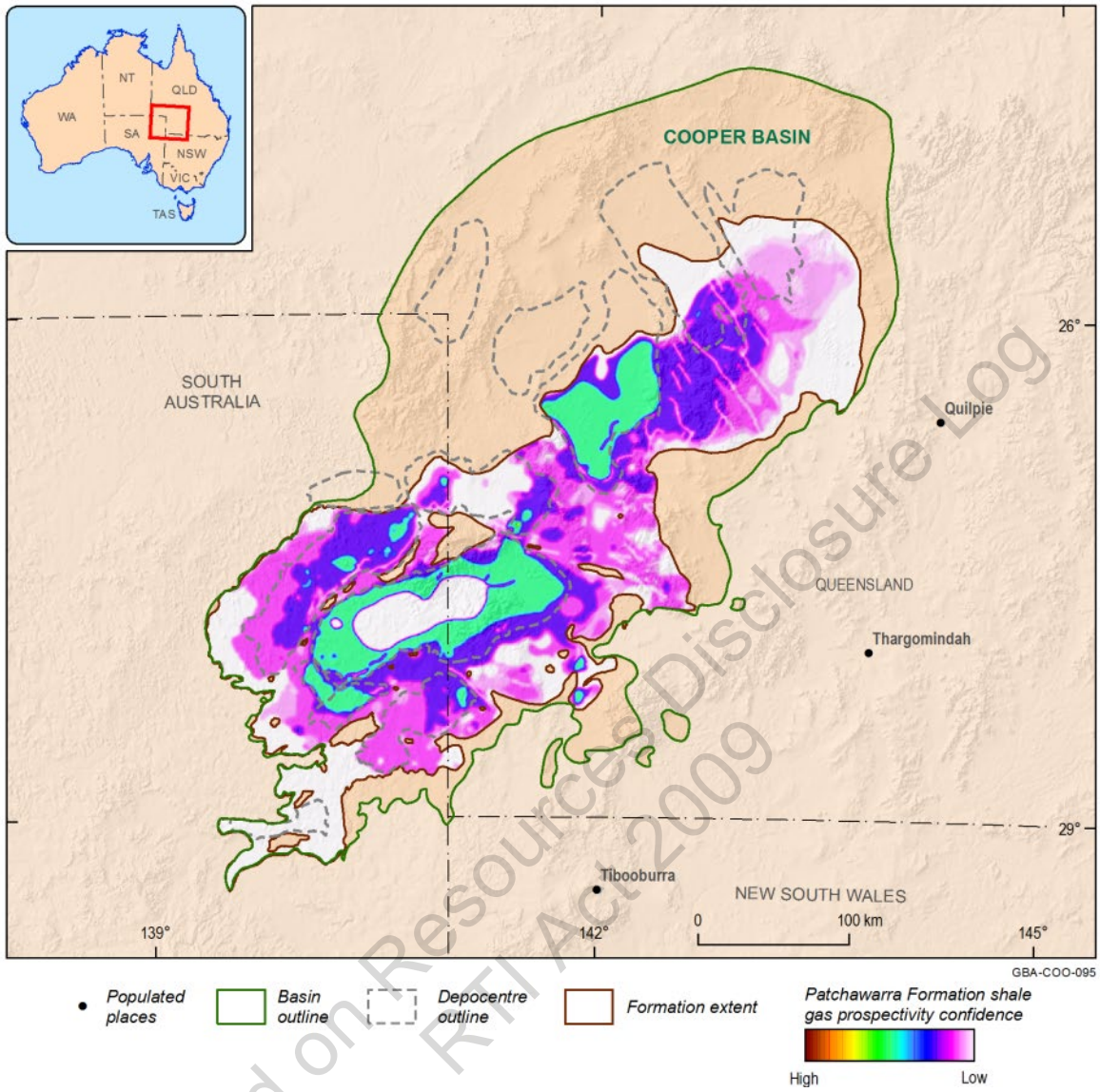


Figure B-2 Patchawarra Formation shale gas prospectivity confidence.

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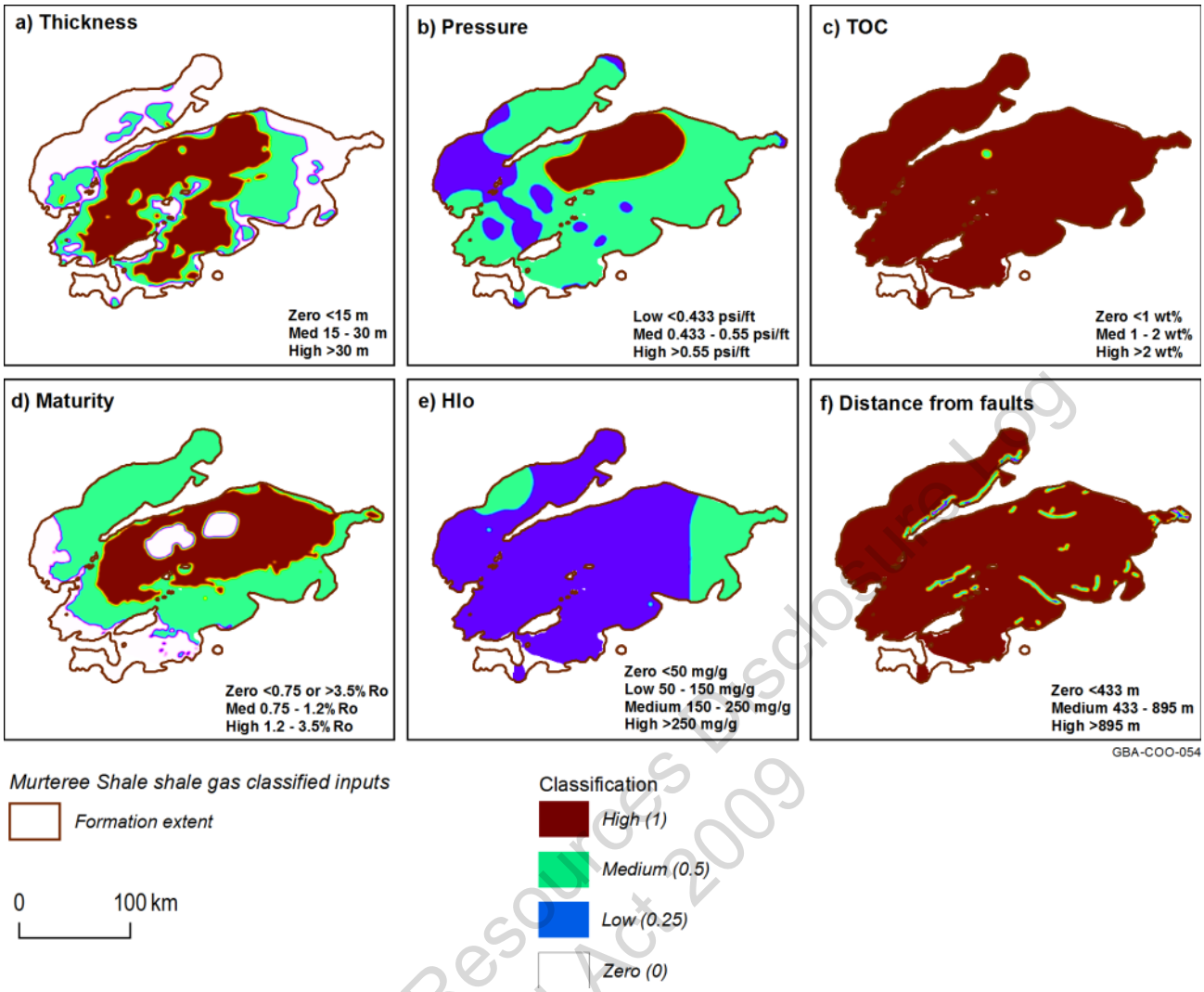


Figure B-3 Murteree Shale shale gas classified mappable prospectivity confidence input parameters.

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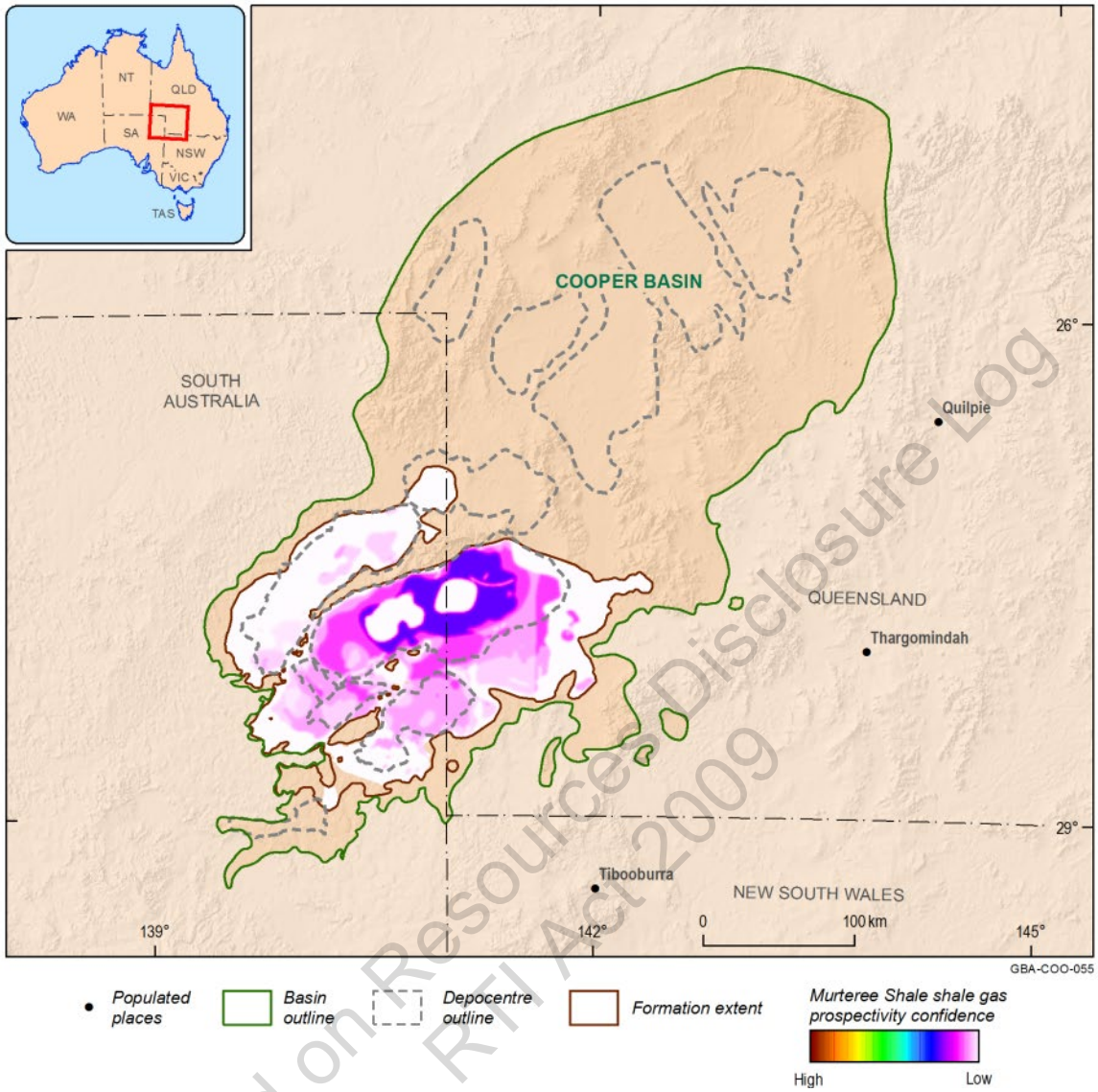


Figure B-4 Murteree Shale shale gas prospectivity confidence.

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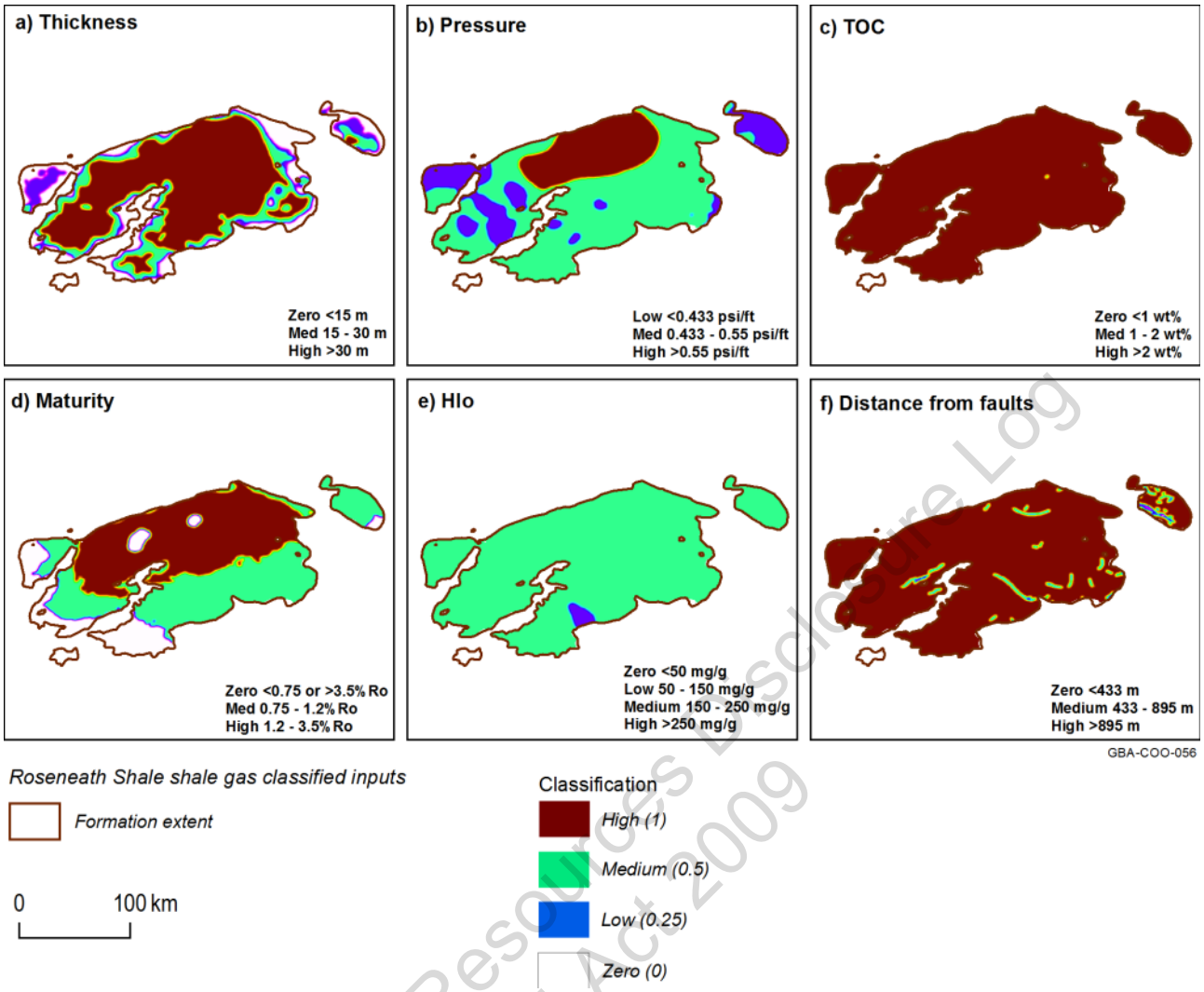
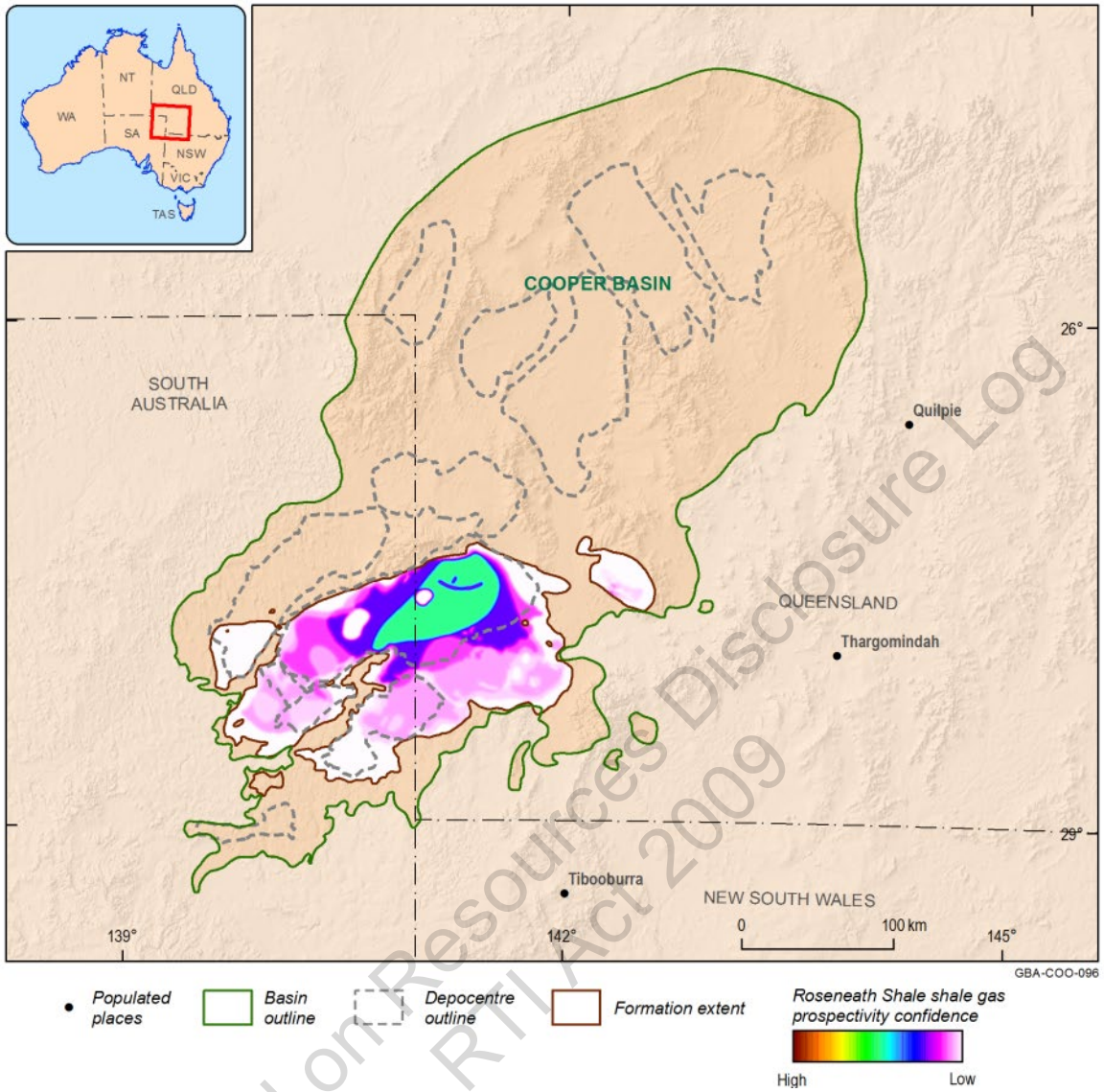


Figure B-5 Roseneath Shale shale gas classified mappable prospectivity confidence input parameters.

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Figure B-6 Roseneath Shale shale gas prospectivity confidence.

Overall shale gas prospectivity confidence results

In order to understand each play type as a whole, prospectivity confidence results were combined to develop an overall maximum play prospectivity confidence map for each play type.

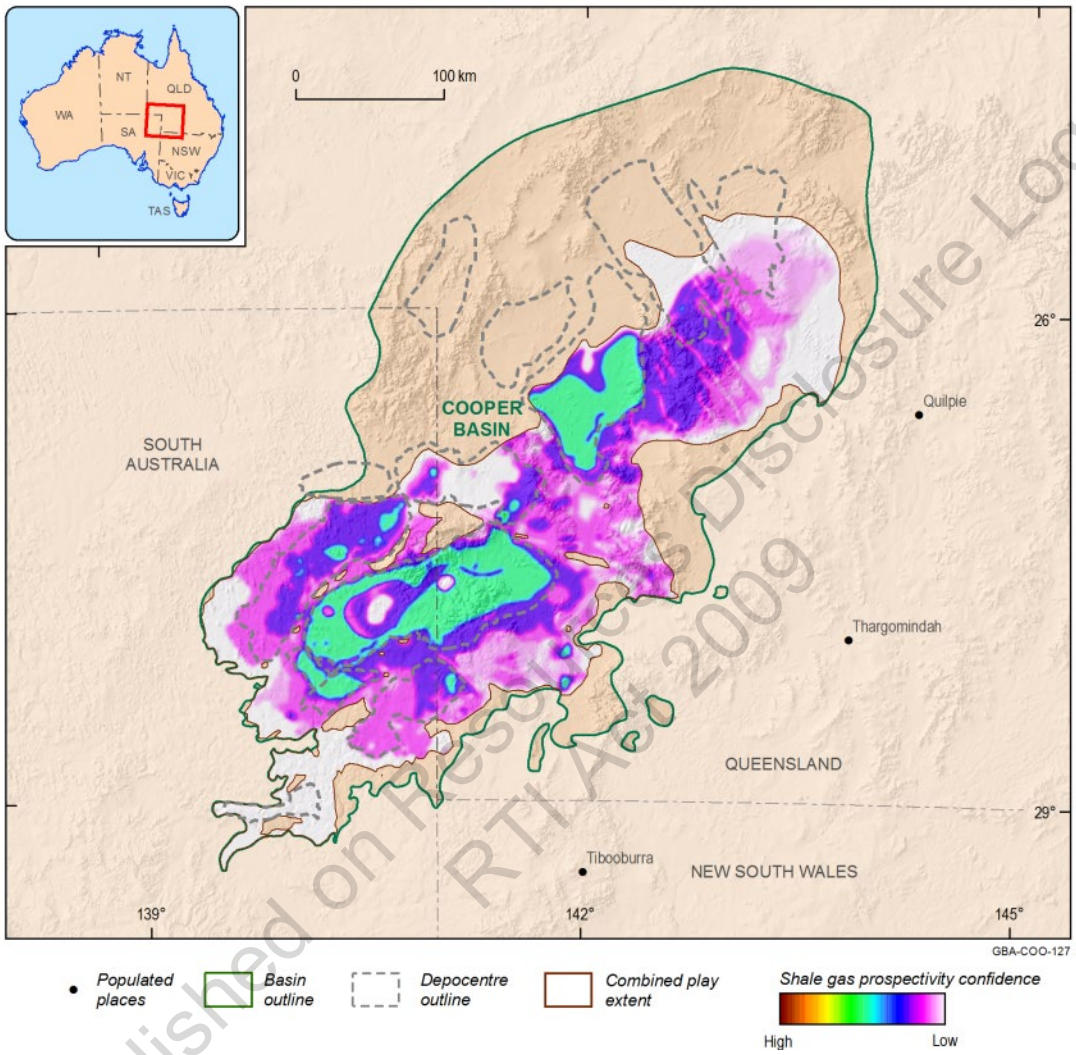


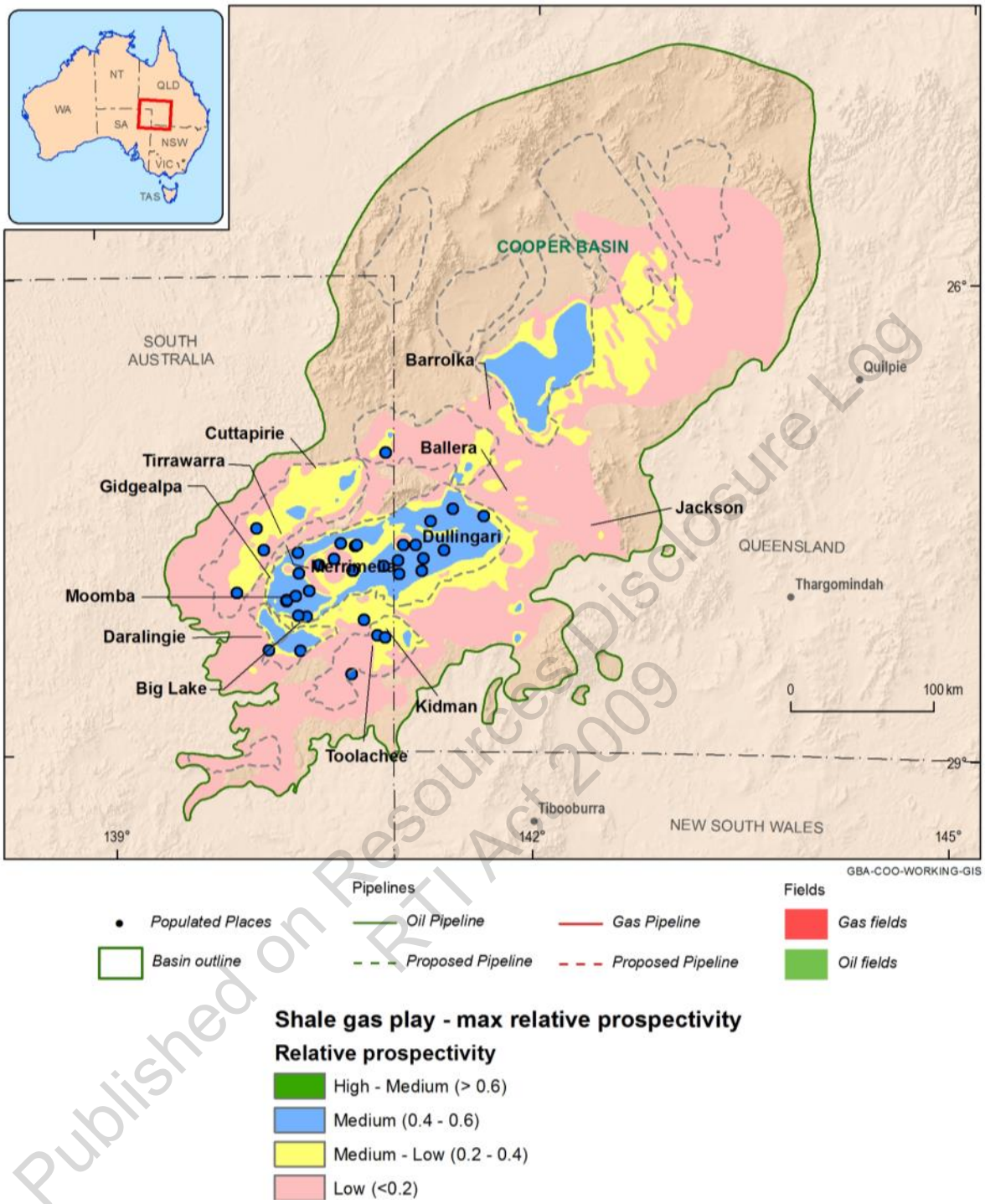
Figure B-7 Combined relative prospectivity confidence for prospective shale gas plays.

Use of simple multiplication rather than geometric mean, requires updated guidelines to interpreting relative prospectivity.

Table 1 Guideline to interpreting relative prospectivity confidence map (Note: Numbers are not probability of success)

Relative prospectivity	Prospectivity map value
High	0.8 - 1
High - medium	0.6 - 0.8
Medium	0.4 - 0.6
Medium - low	0.2 - 0.4
Low	< 0.2

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Figure B-8 Combined relative prospectivity confidence for prospective shale gas plays

Cooper Basin Relative Prospectivity Mapping – Tight Gas Play Update

Prospectivity confidence mapping, sometimes referred to as 'chance of success' or 'common risk segment' mapping was used to map the distribution of the basin's key unconventional shale gas, deep coal and basin-centred tight gas plays.

Basin-centred tight gas plays are present in multiple depocentres across the Cooper Basin (Figure) (Department of the Premier and Cabinet (SA), 2018c; Goldstein et al., 2012; Greenstreet, 2015a; Menpes and Hill, 2012). The most extensive of these is located in the Nappamerri Trough, where the Permian succession reaches over 1.3 km thick and comprises very thermally mature, gas-prone source rocks with interbedded sands (Department of the Premier and Cabinet (SA)). Regionally this play is defined where there is a significant sandstone thickness within the Gidgealpa Group (including the Patchawarra, Epsilon, Daralingie and Toolachee formations and the Tirrawarra Sandstone) in the zone of hard overpressure (below approximately 2900 m).

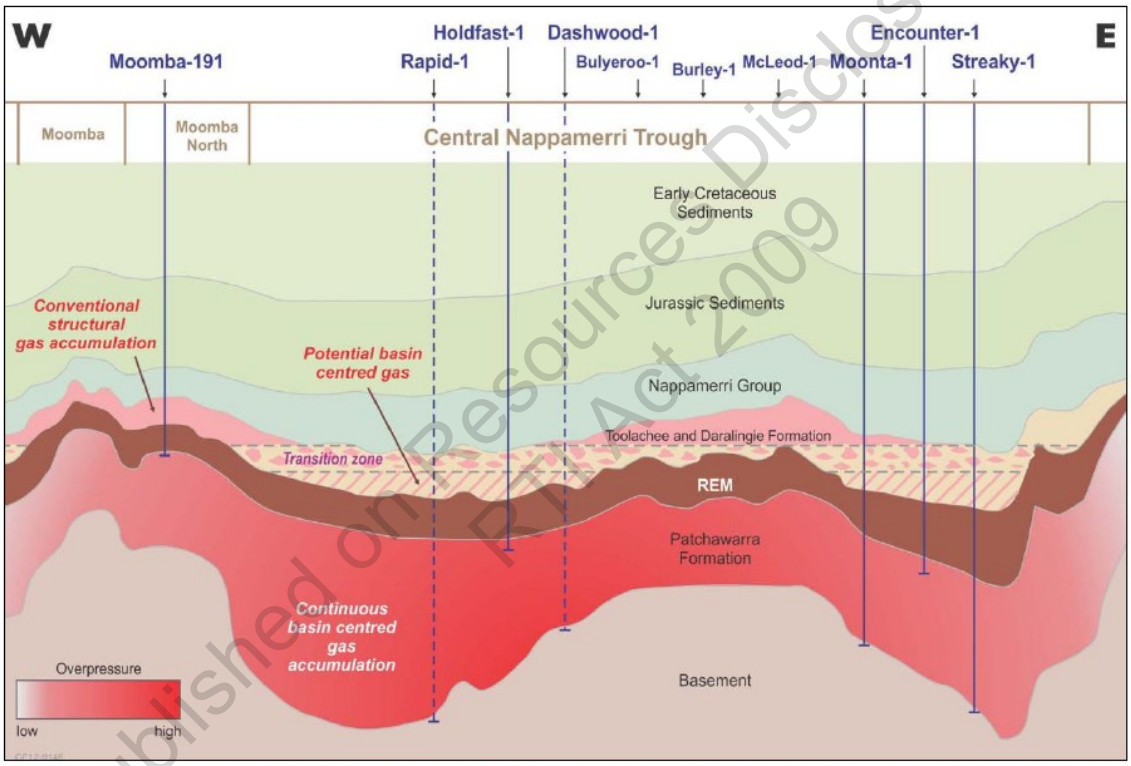


Figure 3: Schematic section through the Nappamerri Trough showing the extent of the continuous gas accumulation and unconventional exploration wells (figure provided by Beach Energy)

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Discrete tight gas sources are also present in the basin; however these are located within and surrounding conventional fields, including Early Permian Patchawarra Formation tight gas sands in the Moomba and Big Lake fields on the southern end of the Nappamerri Trough. Development of these discrete tight gas plays are hard linked to conventional gas field development, so are not considered in the prospectivity mapping presented below, which is targeting development of unconventional gas plays only.

Change in workflow

- Old workflow:
  - The initial workflow used a geometric mean to combine individual maps (https://en.wikipedia.org/wiki/Geometric_mean).
  - A geometric mean is typically used to compare items, when each item has multiple properties that have different numeric ranges.

$$C = \left[\prod_{i=1}^{n} a_i\right]^{\frac{1}{n}}$$

Where:

C =	Combined prospectivity confidence (relative likelihood of success)
n =	Total number of input parameters used
i =	Index of multiplication
a =	Input parameter

  - Issue: although the purpose of these maps is to only show relative prospectivity, normalisation by 1/n gave the perception to the end user that areas of low-to moderate prospectivity were actually moderate to high.
- New workflow:
  - Individual parameter maps were combined by simple multiplication.

$$C = (c_1 \times c_2 \times c_3 \ldots c_n)$$

  - Each input item was normalised to a consistent range representing relative level of risk; to determine total relative prospectivity, items were multiplied together.
  - The new result provides a simpler more intuitive output for the end user.

Change to how basin centred gas play is definition

- Consider the pervasive basin-centred tight gas play in the Gidgealpa Group as a single tight gas composite play, rather than as a series of individual plays characterised by formation.
- Updated draft criteria defining the basin centred tight gas play are shown below.
  - Net sand thickness includes sand intervals in the following formations: Toolachee, Daralingie, Epsilon, Patchawarra formations, Tirrawarra Sandstone.
  - The top of the hard over pressure is defined using a depth proxy of 2800m.

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Table 1 Gidgealpa Gp pervasive gas tight gas criteria

Parameter	None (0)	Low (0.25)	Medium (0.5)	High (1)
Gidgepala Gp net sand thickness in overpressure zone (below a depth of 2900 m)	< 10 m	10 – < 50 m	≥ 50 – < 100 m	≥ 100 m
Presence of effective source rock	Ro < 0.75 % or TOC > 2%		Ro 0.75-1.2 % and TOC > 2%	Ro > 1.2 % and TOC > 2%
Distance from major faults	<433 m		≥ 433 – < 895 m	≥ 895 m

Inclusion of additional data

- South Australian government have now provided an additional Tirrawarra Sst thickness map. This has now been integrated into the Gidgealpa Group combined tight gas play.

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Note all results presented in this document have not yet been fully peer reviewed and are still in draft format.

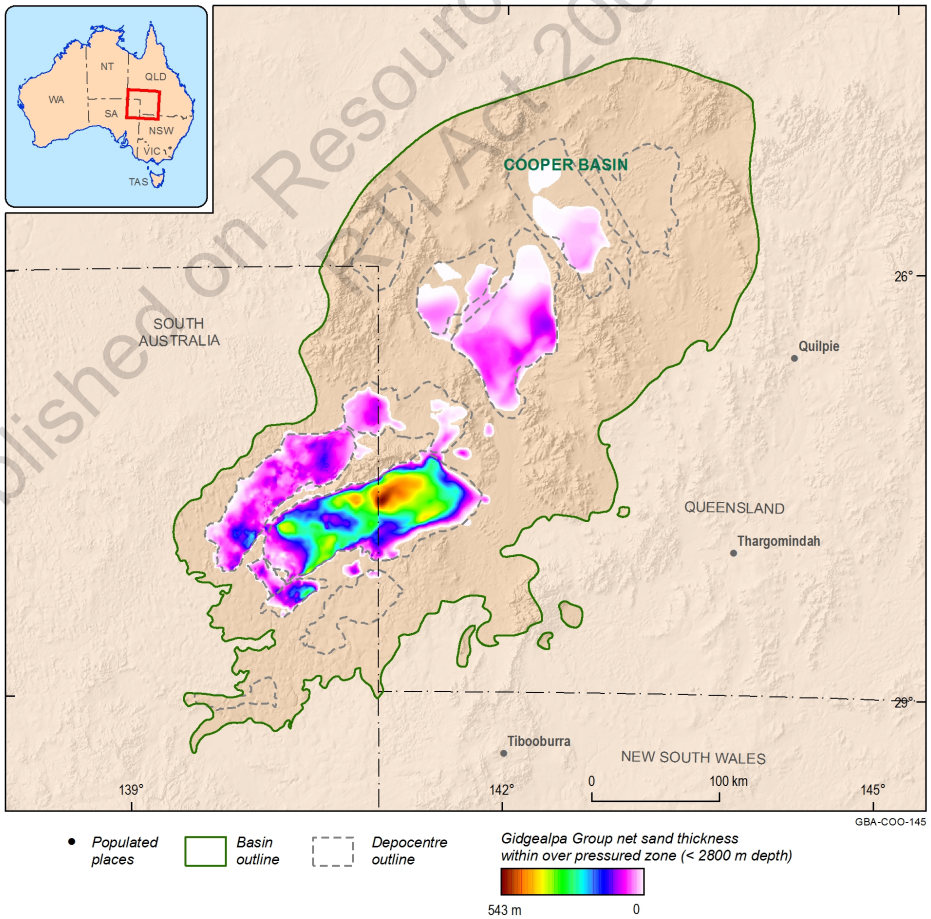


Figure: net sand thickness in the Gidgealpa Group in the zone of hard overpressure (below a depth of 2800 m).

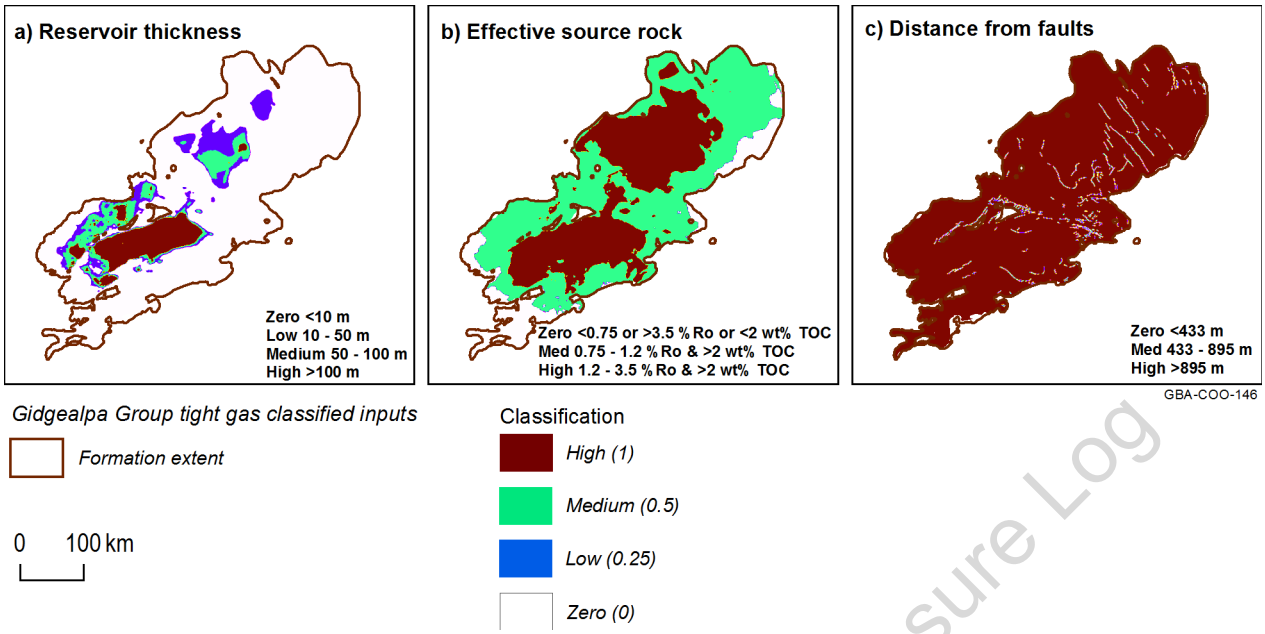
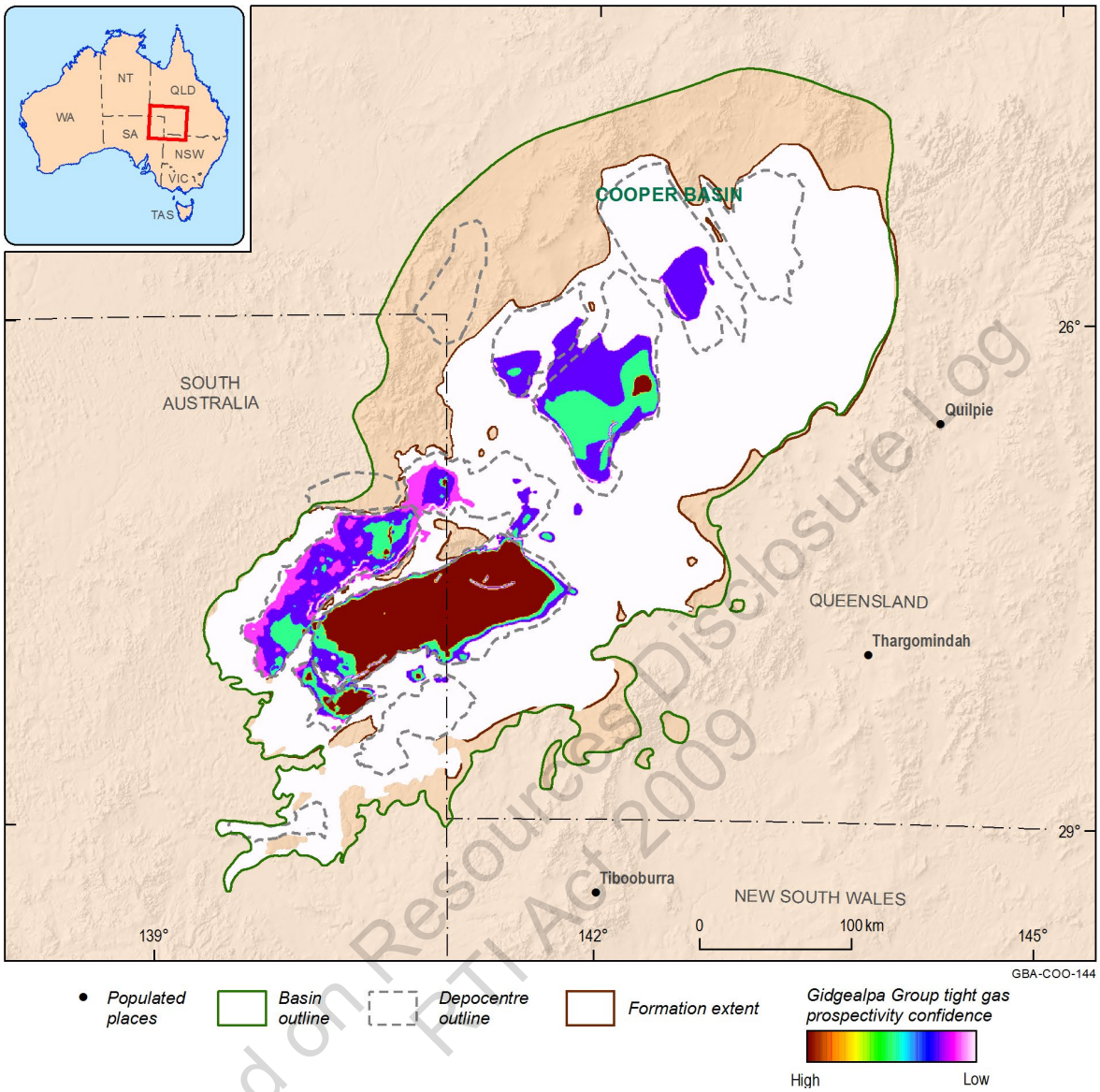


Figure B-1 Gidgealpa Group basin-centred tight gas classified mappable prospectivity confidence input parameters.

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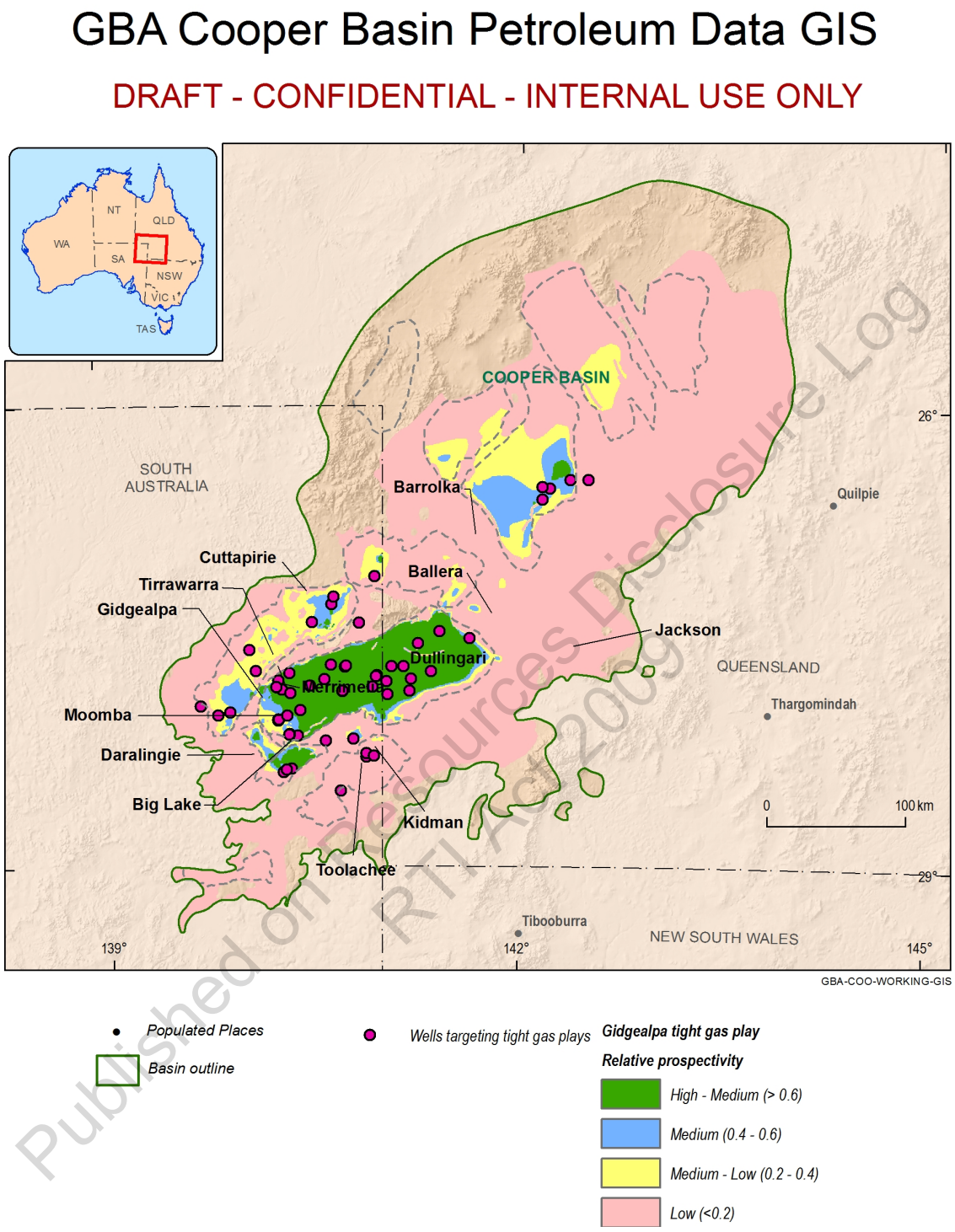
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Figure Combined relative prospectivity confidence for prospective tight gas plays.

Use of simple multiplication rather than geometric mean, requires updated guidelines to interpreting relative prospectivity.

Table 1 Guideline to interpreting relative prospectivity confidence map (Note: Numbers are not probability of success)

Relative prospectivity	Prospectivity map value
High	0.8 - 1
High - medium	0.6 - 0.8
Medium	0.4 - 0.6
Medium - low	0.2 - 0.4
Low	< 0.2



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Figure: Combined Gidgealpa Gp tight gas prospectivity confidence map, overlain by wells targeting tight gas plays.