

# **Unconventional Resource Potential of the Taroom Trough in the Southern Surat-Bowen Basin, Queensland, Australia\***

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## **Abstract**

The Bowen-Surat Basin is a well-known petroleum province, with a long history of conventional oil and gas production, primarily from Mesozoic reservoirs. It contains two active petroleum systems which, in the area of ATP 840P within the Taroom Trough, contain condensate- and gas-mature source rocks. The Blackwater Source system includes source rocks of the marine Back Creek Group, and coals and carbonaceous shales of the Blackwater Group. Both source rock intervals are mature to overmature for oil and gas generation throughout the Taroom Trough. Terpane and sterane biomarkers and isotopic data show the major source of conventional oils in Permian-Jurassic reservoirs in the basin to be the Blackwater Group. The Triassic Snake Creek Mudstone was deposited in a lacustrine environment, and is the second source interval. It contains Type II/III kerogen that is mature for oil and gas generation.

A number of over-pressured unconventional tight sand reservoir targets lie adjacent to these mature source intervals, and are generally gas-charged where penetrated. These reservoir intervals include:

- Triassic Showgrounds Sandstone;
- Triassic Lower-Rewan sandstones;
- Permian Kiangra Formation, Tinowon Sandstone and Back Creek Group.

Together, these reservoirs host significant prospective gas and condensate resources in the form of Basin Centred Gas Accumulations (BCGA). High condensate saturations are observed in recovered samples and on log analysis.

Recoverable Resource estimates of hydrocarbons within ATP 840P in the Taroom Trough are:

- Recoverable Gas most likely estimate of 11.8 Tcf;
- Recoverable Condensate most likely estimate of 699 million barrels.

Natural fracturing may enhance reservoir quality within these units, and they may be good candidates for fracture stimulation in vertical or horizontal wellbores. Comparisons with productive analogue plays in other areas of the world suggest that the chance of discovery of gas-condensate reserves within block ATP 840P is high, and that drilling and completions methods can be developed to extract them economically.

### **Location and Brief Exploration History**

ATP 840P is located approximately 180 km southeast of Roma, in the south-central area of the Bowen Basin, a large intra-cratonic basin of Mesozoic age ([Figure 1](#)). In this area, the Bowen Basin is overlain by the younger Surat Basin. The principal exploration targets are deep, low permeability sandstones and siltstones of Late Permian and Early Triassic age. The permit covers an area of 455 km<sup>2</sup> (112,500 acres) in the prospective southern end of the Bowen Basin, near existing oil and gas infrastructure. In 1961 the Moonie oil field was discovered 25 km east of ATP 840P and this discovery started the main phase of oil and gas exploration in the basin. The Moonie oil field remains the largest oil accumulation found in the Bowen/Surat Basin (Cadman et al., 1998).

Today, more than 4000 km of pipelines connect producing fields in the Bowen Basin to market. Since 1990, CSG has grown to supply more than 75% of the Queensland market, and accounts for over 98% of remaining proved and probable reserves (Queensland Department of Natural Resources and Mines, 2013). Conventional fields and discoveries in the southern Bowen Basin are confined to the basin margins, where there are perhaps 12 significant oil and gas fields within 50 km of ATP 840P. Development drilling continues, to provide export gas for three LNG facilities on Curtis Island, near Gladstone (470 km northeast of ATP 840P). The first facility commenced exporting LNG in late 2014 and further trains will begin export during 2015. However, despite the intense conventional and CSG exploration, much of the Southern Trough remains essentially unexplored, particularly in deeper zones.

### **Stratigraphy**

The stratigraphy of the Bowen Basin used in this study is shown in [Figure 2](#). We have examined potential unconventional reservoirs in the stratigraphic interval from the Upper Permian Tinowon Formation to the Middle Triassic Showgrounds Sandstone. Potential unconventional targets include the Tinowon, sandstones and siltstones of the Winathoola and Wallabella coal measures, the Black Alley Shale (Back Creek), the Kianga and the Lower-Rewan ([Figure 5](#)). The Lower-Rewan contains porous sand near the top and base in many wells.

### **Southern Bowen Basin Shows and Tests**

Most wells surrounding ATP 840P have hydrocarbon shows, or have tested gas and/or condensate from all the target reservoirs, including the Showgrounds Sandstone, Lower Rewan, and Permian (Kianga Fm., Back Creek Fm., Tinowon sandstones). Wells drilled on the flanks of the basin have flowed gas and condensate from unstimulated reservoirs, while wells toward the basin centre have flowed small amounts of gas on

DST from the more deeply buried reservoirs without stimulation. Stimulation, as performed at Daydream-1, Fantome-1 and Tasmania-1, is required to produce gas and condensate from these deep tight reservoirs at commercial rates.

### **Depositional Setting**

Hoffman, et. al., (1997) presented an overview of the depositional setting of the Taroom Trough, drawing upon numerous studies conducted by the Queensland Department of Mines and Energy. Their work revealed that the Trough did not exist as a structural feature during the Permian, and that the Permian succession represents a series of four stacked transgressive system-highstand system tracts deposited in a back-arc sea. The Trough began to subside in the Early Triassic, providing accommodation space for the deposition of a thick succession of fluvial and lacustrine sediments.

#### Tinowon Formation

The Tinowon Formation conformably overlies marine strata of the Muggleton Formation, and consists of shale, siltstone, sandstone, limestone and coal, including the Wallabella Coal Member ([Figure 2](#) and [Figure 3](#)). Deltas built out into the Trough from the west, and south, with depositional environments ranging from deltaic to marine in a highland systems tract (HST) setting. Coal measures indicate extensive coal swamp development associated with deltaic progradation (Green, 1997); Beeston et al. (1995); and Hoffmann et al. (1997)). Conditions reverted to a transgressive systems tract (TST) setting as the sea returned at the close of Tinowon deposition. The cores in Tasmania 1 and Daydream 1 were below the best reservoir facies at the delta tops (as evidenced by the GR log), however core analysis shows good tight sandstone reservoir properties, with the presence of significant microporosity and a lack of kaolinite, particularly at the delta tops ([Figure 6](#)). This is expected to improve up section and be replicated multiple times during the depositional cycles. In ATP 840P, distal shallow marine facies are expected to exist in the lower Tinowon, and deltaic facies in the upper Tinowon.

#### Black Alley Shale/Upper Back Creek Group

In the southern Taroom Trough, the Black Alley Shale / Back Creek Group are marine to restricted marine deposits, consisting of shale, siltstone, sandstone, tuff and coal deposited in a transgressive setting (Hoffmann et al., 1997). The top of the Black Alley Shale represents a transition from marine to deltaic/fluvial deposition in the overlying Kianga (Bandanna) Formation ([Figure 2](#) and [Figure 6](#)).

#### Kianga/Bandanna Formation

The Kianga Formation represents the last Permian deposition in this part of the Bowen Basin. It consists of mudstone, siltstone, sandstone and coal, and conformably overlies the Black Alley Shale. During this time, deltas built out from the west, south and possible from the east, gradually filling the trough northwards. In ATP 840P, we expect deposition of the Kianga/Bandanna to reflect the final transition from marine to deltaic/fluvial and coal swamp settings.

### Triassic Rewan Formation

The Rewan Formation is the product of widespread fluvial deposition in a rapidly subsiding basin ([Figure 2](#) and [Figure 4](#)). In the lower Rewan, the Sagittarius Sandstone consists of fine- to very coarse-grained lithic sandstone interbedded with siltstones and mudstones, while the overlying Arcadia contains a higher proportion of mudstones. The southeastern part of the basin contains alluvial fan conglomerates associated with faulting and uplift to the east (Hoffmann et al., 1997). In ATP 840P, we expect that fluvial / deltaic sandstones to dominate in the Lower Rewan, and to gradually fine upwards in the Upper Rewan.

### Showgrounds Sandstone

The Showgrounds Sandstone is interpreted to be of fluvial /lacustrine origin, deposited by eastward flowing streams arising on the western side of the Taroom Trough (Green, 1997). The Showgrounds is a gradually fining-upwards succession of quartzose sandstones capped by dark, lacustrine shales of the Snake Creek Mudstone. It is interpreted as a single depositional system of a lowstand systems tract (Hoffman et al., 1997). While the Showgrounds Sandstone lies unconformably on the Rewan Formation on the Roma Shelf (western flank of the Taroom Trough), it is mostly conformable in the central part of the Trough.

## **Petroleum Systems and Source Rock Maturity**

Detailed geochemical studies and thermal maturity modeling have been conducted by Al Arouri et al. (1998) on Permian and Triassic petroleum systems (source rocks and crude oils) in the Bowen Basin, including determination of thermal maturity and timing of petroleum generation. Carmichael and Boreham (1997) indicated that the Burunga Group (including the Tinowon Formation, Black Alley Shale and Back Creek Group) has potential to produce oil and condensate from the coals, and oil, condensate and gas from the mudstones.

Both source rock intervals are mature to overmature for oil and gas generation throughout the Taroom Trough. Terpane and sterane biomarkers and isotopic data show the major source of conventional oils in the Precipice Sandstone and other Permian-Jurassic reservoirs to be the Blackwater Group. In the southern Taroom Trough, Permian source rocks expelled their hydrocarbons between 175 Ma and about 95 Ma (Jurassic-Cretaceous). Triassic rocks expelled their hydrocarbons later, between 125 and 75 Ma (Cretaceous). Based on this information, Al Arouri et al. (1998) indicated that conventional oil and gas prospectivity is best in the southern portion of the Taroom Trough, as hydrocarbon generation and migration post-dated trap formation during the Triassic.

## **Petrophysical Analysis**

Quantitative petrophysical analysis was performed on all formations from the Triassic Moolayember Formation to total depth on six wells: Daydream-1, Fantome-1, Overston-1, Inglestone-1, Palmerston-1 and Ungabila-1. Three well (Daydream-1, Fantome-1 and Inglestone-1) are of particular interest, as they are located in the Taroom Trough, while the other three wells analysed are on the flanks of the trough. The net sand and average porosities for the reservoir units in these wells is shown in [Table 1](#).

## **Reservoir Overpressure in the Taroom Trough**

One of the most important characteristics of Basin Centred Gas Accumulations (BCGA) is abnormal reservoir pressure (Law et al 2014). The mechanism of abnormal pressure in a BCGA is always hydrocarbon generation (Spencer, 1987) Regional work indicates the onset of overpressure is estimated to begin at 2500m depth in the Bowen Basin. Daydream 1, Fantome 1 and Tasmania 1 all exhibit overpressure below about 2500m, with significant increases recorded near the top of the Permian. This is also accompanied by a significant increase in gas concentration in the drilling mud ([Figure 7](#)), similar to wells within the Pinedale field in the Green River Basin, Wyoming.

## **Play Fairway Mapping**

Unconventional play fairway maps were created for each of the main target reservoirs, in order to illustrate their areal extents within the southern Taroom Trough and over ATP 840P. Each was made using a combination of regional facies maps, well control, and seismic depth mapping. An upper depth limit for each map was defined by the 2500m onset of overpressure. A lower depth limit of 4000m was imposed on each map to represent reasonable economic limits on potential unconventional play development. In the future, additional upside may be recognized by developments at deeper depths. Play fairways for the Showgrounds Sandstone, Lower Rewan, Kianga (Bandanna) and Back Creek Group/Tinowon are shown on [Figure 8](#), which shows that all four are expected to be present over ATP 840P. To the west, where the Triassic and Permian sections thin onto basement highs, play fairways overstep each other. On the eastern flank of the basin, play fairways terminate against major basin bounding faults, or where fan delta facies are interpreted to occur in the Lower Rewan and Kianga.

## **Volumes**

A range of volume estimates was calculated probabilistically by applying ranges of input parameters based on wells and other available data. These volumes estimates are shown in [Table 2](#). The volumes have not been risked for chance of discovery, however the chance of discovery of gas-condensate within ATP 840P is high.

## **Play Analogues**

Excellent comparisons can be drawn between the Lower Rewan/Kianga formations of the Bowen Basin and stacked fluvial successions of the Williams Fork Formation in Piceance Basin, as well as Cretaceous targets in the Deep Basin of western Canada. Permian Tinowon sandstones compare well with the prolific Montney Formation of western Canada. Similarities are also seen with the Green River Basin in Wyoming ([Figure 7](#)).

## **Conclusions**

Recent deep drilling confirms the presence of a significant Basin Centred Gas Accumulation in the southern Taroom Trough. This resource is present across a number of stratigraphic intervals from the Late Permian to Early Triassic. Gas saturated sandstones are evidenced by high mud gas while drilling, overpressure, and gas flows to surface with little to no water production on test. Recovered fluids and basin modelling

indicate the gas is very rich in condensate. The area has potential for large resources of gas and condensate, with the immediate ATP840P study area to have 11.8 Tcf recoverable gas and 699 million barrels recoverable condensate resource (most likely estimate).

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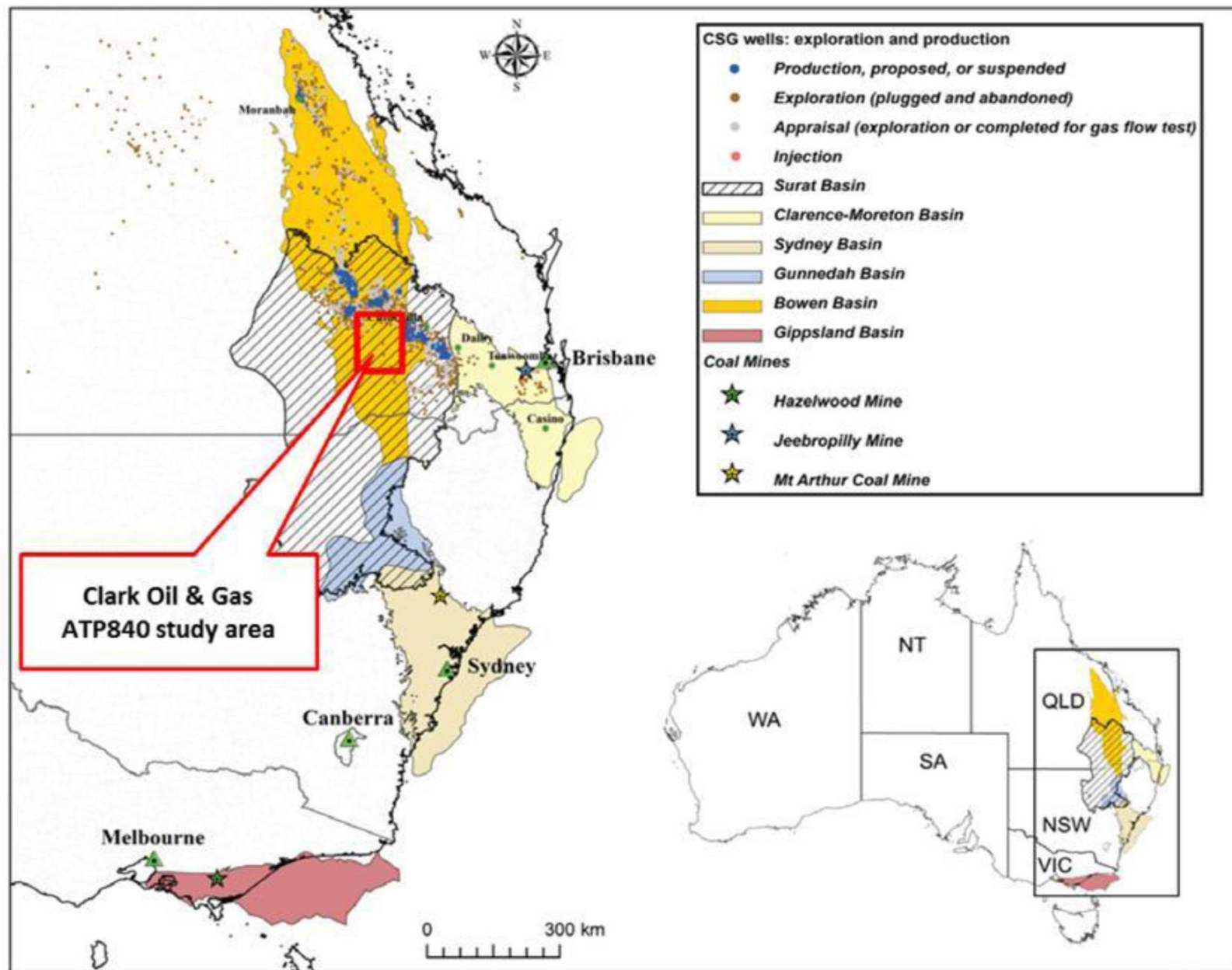


Figure 1. Location of ATP840P study area (modified from Geoscience Australia).



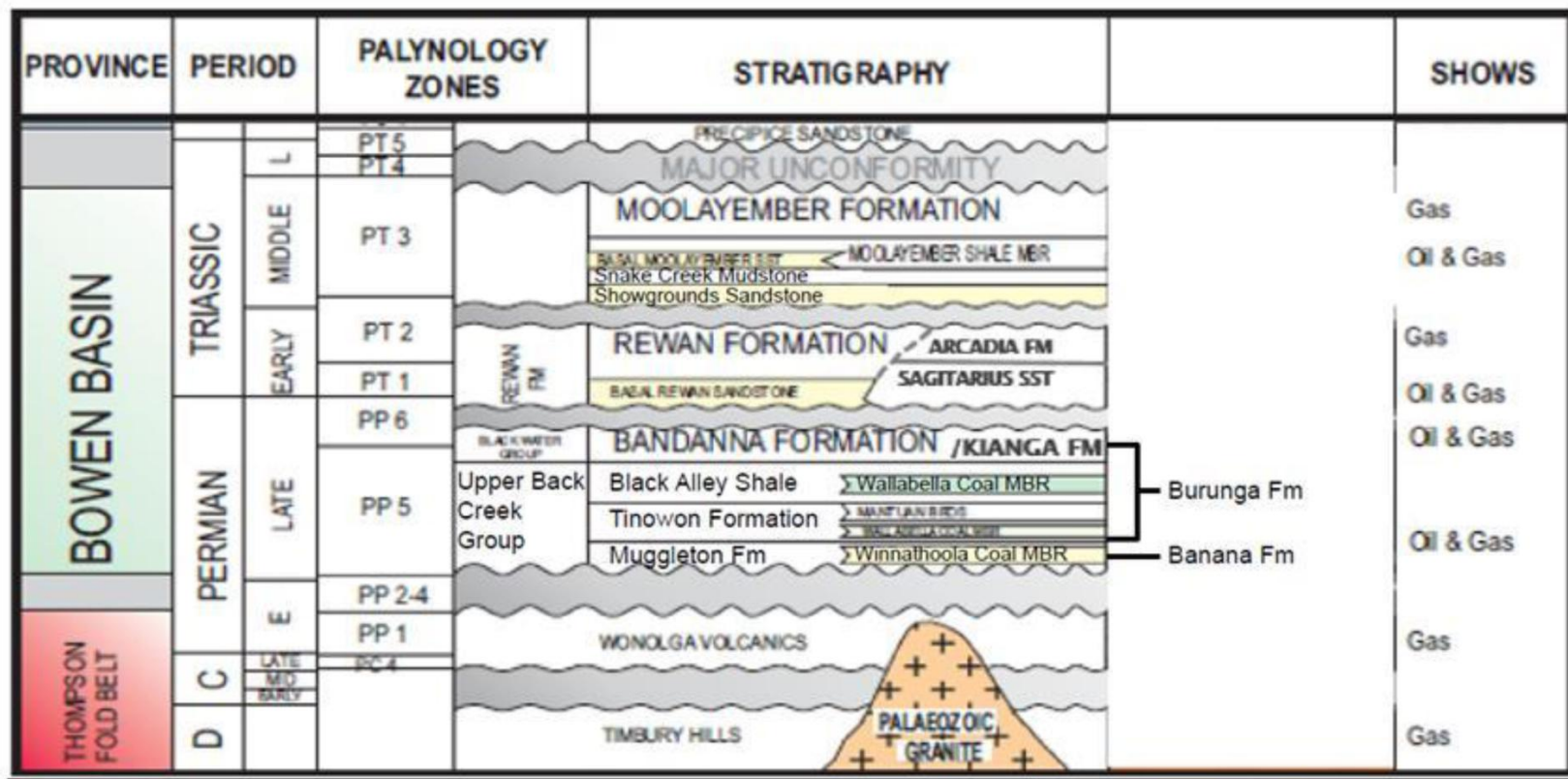


Figure 2. Stratigraphy of the Bowen Basin (modified from Origin Energy, 2004).



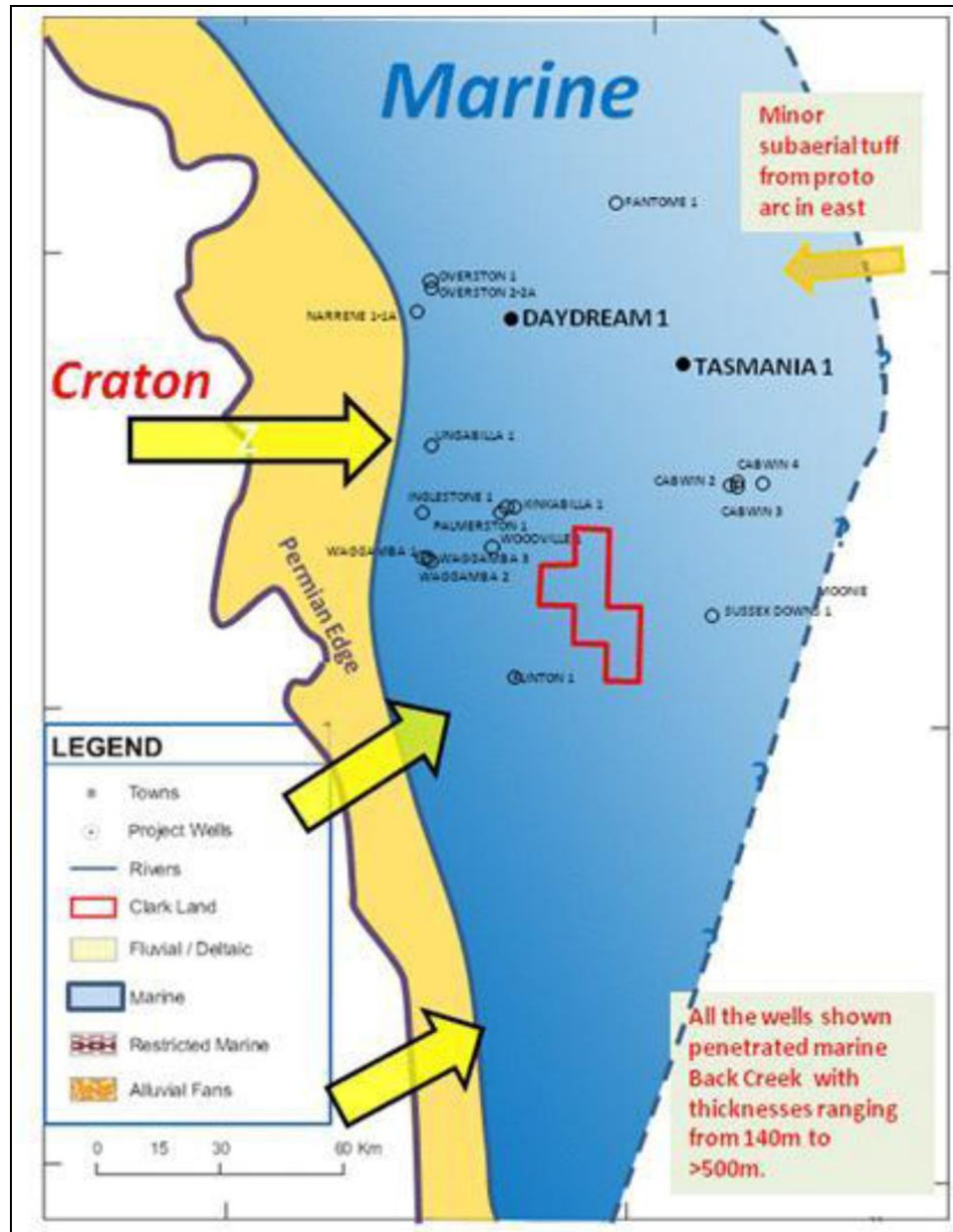


Figure 3. Upper Back Creek facies map (Ziolkowski, 2015), showing the Daydream 1 and Tasmania 1 wells with core within this interval.



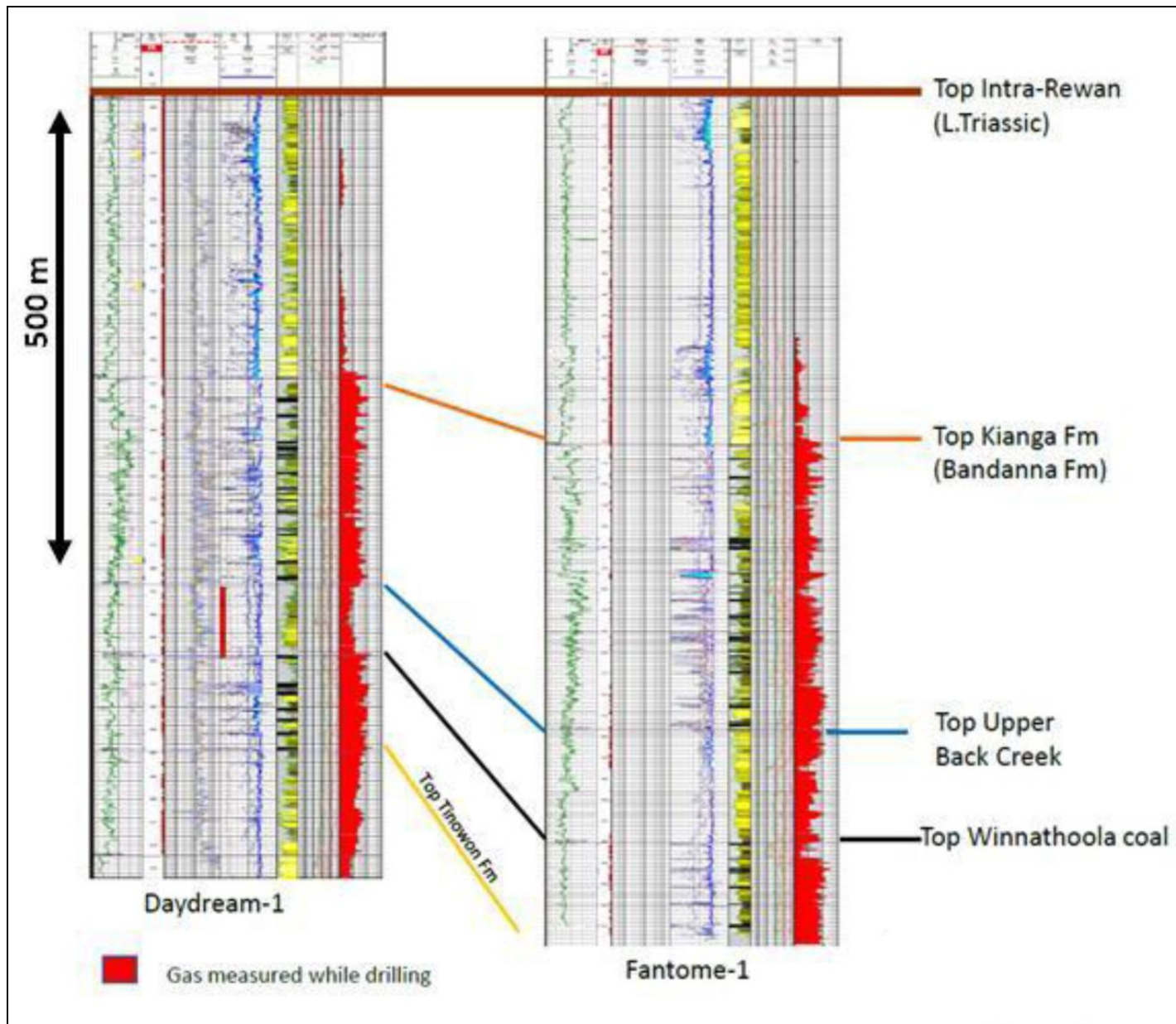


Figure 5. Correlation from Daydream 1 to Fantome 1 showing the high gas measured while drilling.



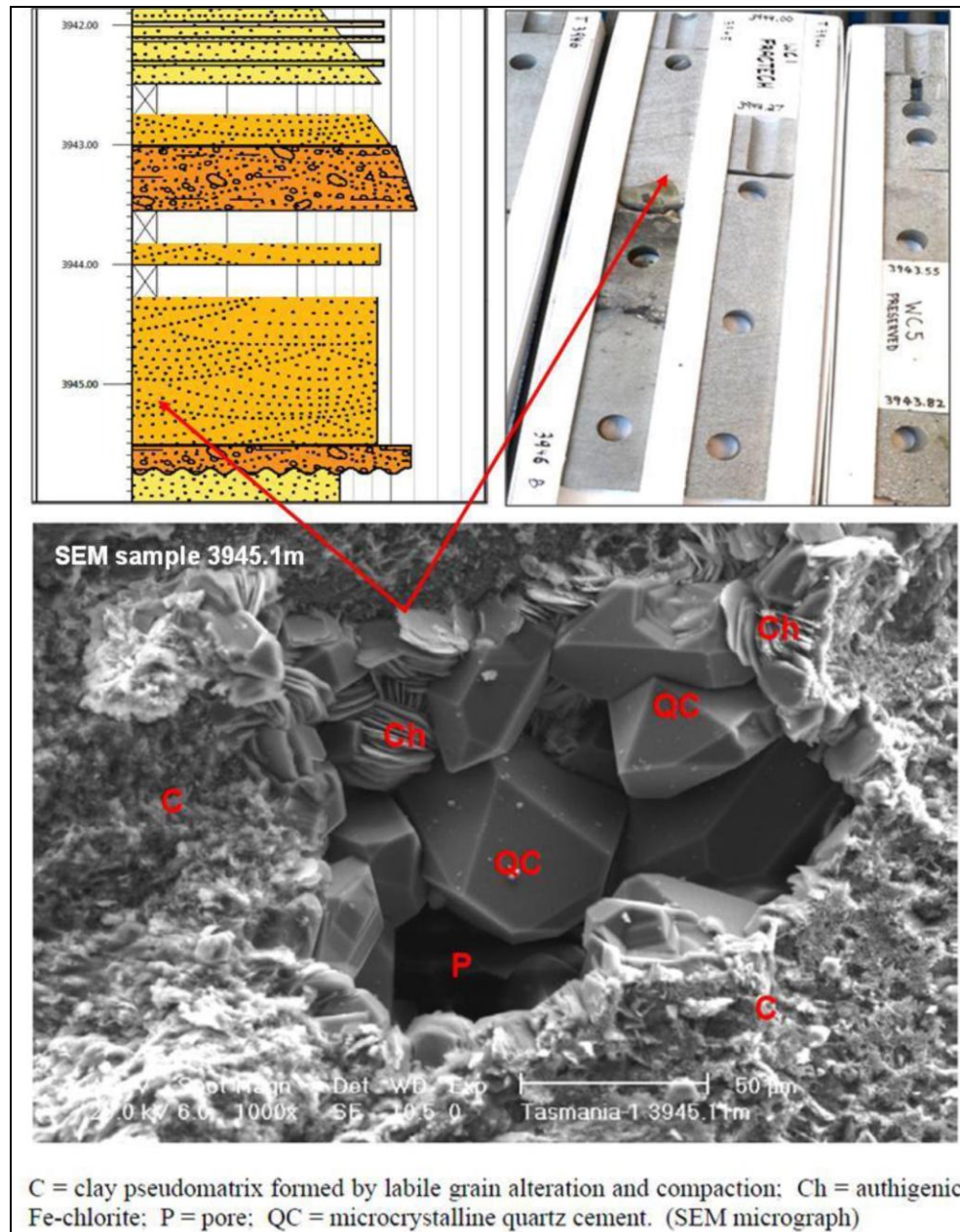


Figure 6. Core description and SEM photographs from the Upper Back Creek in Daydream 1 (Ziolkowski, 2015).

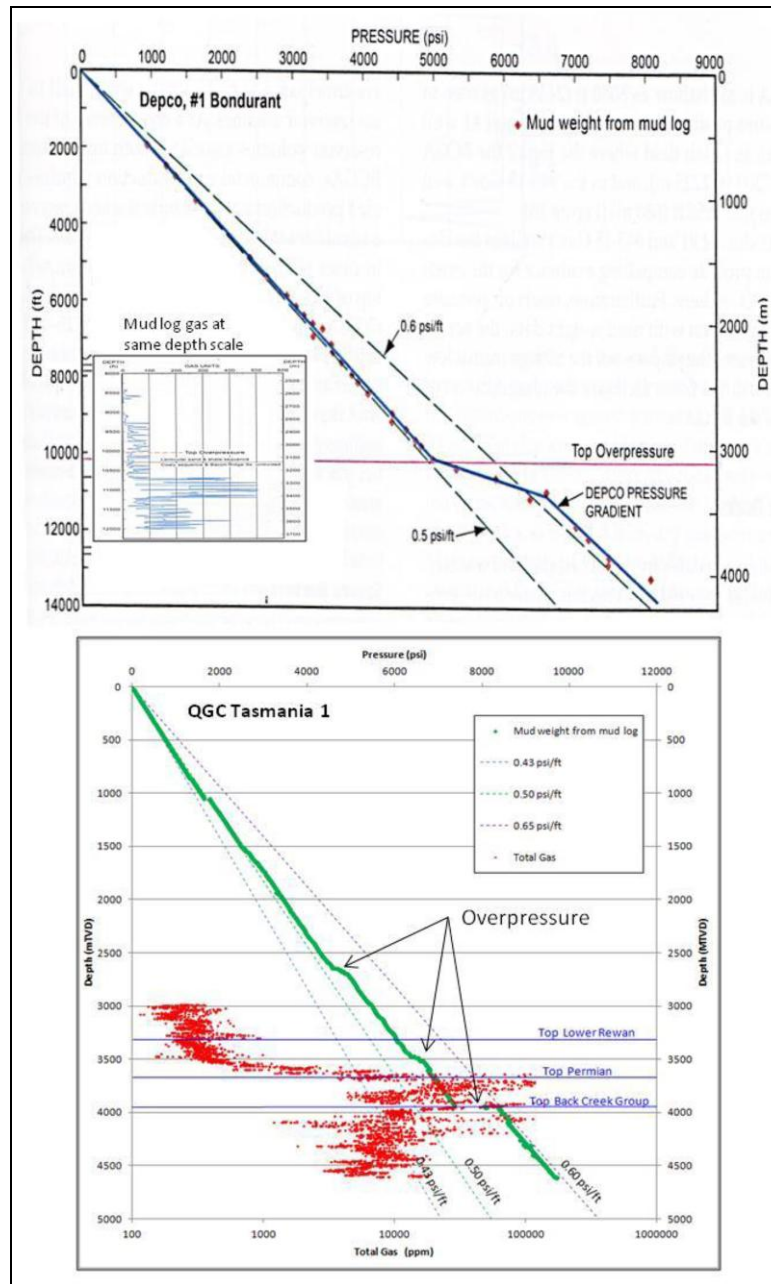


Figure 7. Comparison of (a) Bondurant 1, Green River Basin, Wyoming (from Law and Spencer 2014), with Tasmania 1 in the Surat/Bown Basin. Note the relationship between mudlog gas concentration and overpressure.

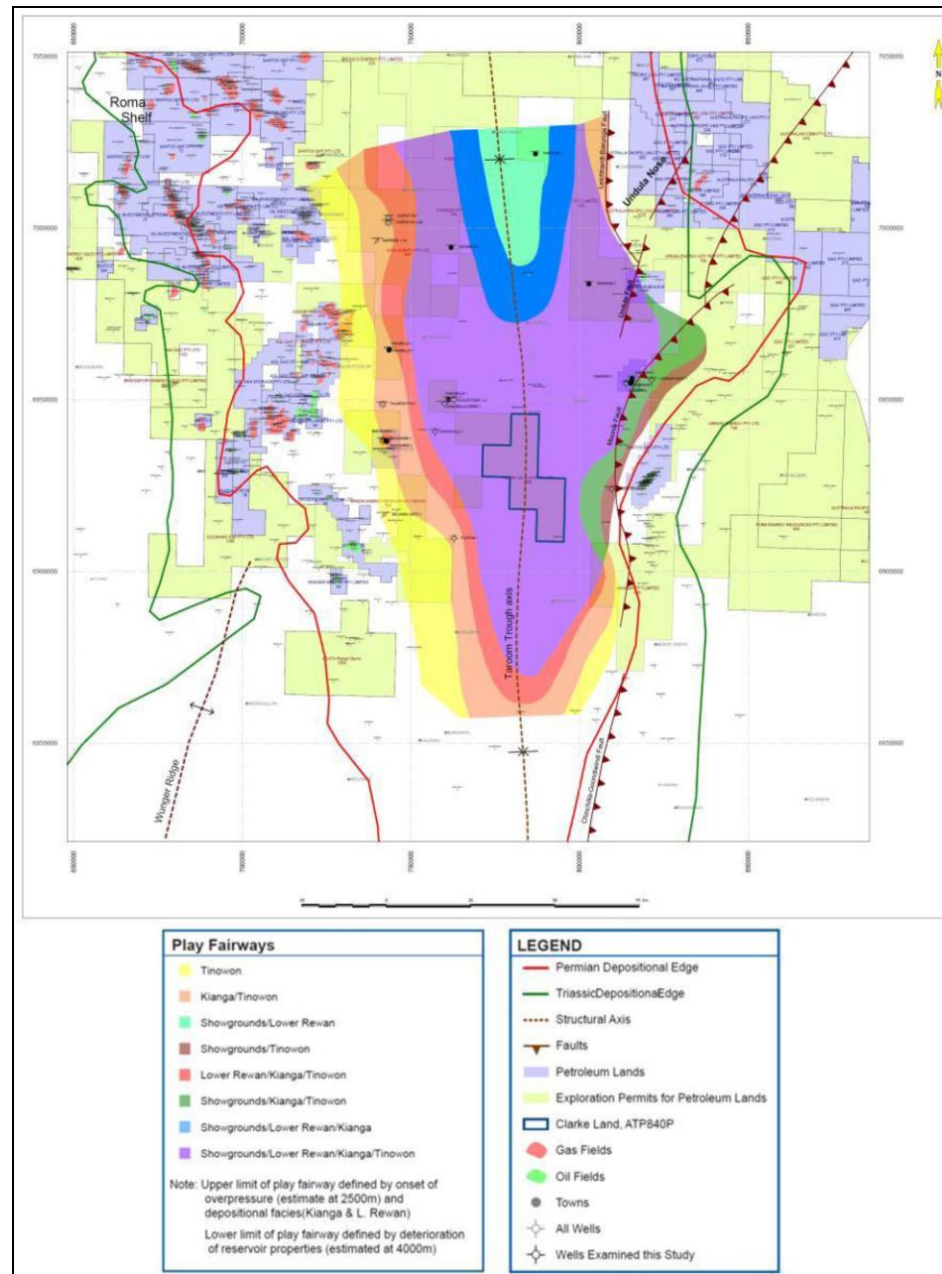


Figure 8. Play fairway map for the Southern Taroom Trough.



Well	Formation	Top	Thickness	(3% cutoff)	
				Net SS	Av Porosity
Daydream 1	Showgrounds	2882.5	158.9	128.0	8%
	Intra-Rewan	3291.6	300.8	244.1	8%
	Permian	3816.5	554.5	214.2	6%
Fantome 1	Showgrounds	3215.3	336.7	258.7	6%
	Intra-Rewan	4102.3	504.3	262.7	7%
	Permian	4441.0	596.0	93.2	7%
Inglestone 1	Showgrounds	2748.7	77.6	35.8	5%
	Intra-Rewan	2948.0	216.8	126.8	7%
	Permian	3164.8	709.0	370.4	11%

Table 1. The net sand and average porosities of the Triassic Moolayember Formation.

ATP840P Estimates of Recoverable Hydrocarbons			
Gas	Low	Mid	High
	Bscf	Bscf	Bscf
Showgrounds	2	957	3,298
Lower Rewan	854	2,768	8,389
Permian	2,164	10	2,845
<b>Total (Arith Sum)</b>	<b>3,300</b>	<b>11,829</b>	<b>40,172</b>
Condensate	mmstd	mmstb	mmstb
Showgrounds	5	21	83
Lower Rewan	46	175	586
Permian	117	503	1,974
<b>Total (Arith Sum)</b>	<b>138</b>	<b>699</b>	<b>2,643</b>

Table 2. ATP840P Estimates of Recoverable Hydrocarbons