What lies beneath –
A review of frontier exploration for deep plays in the Bowen Basin

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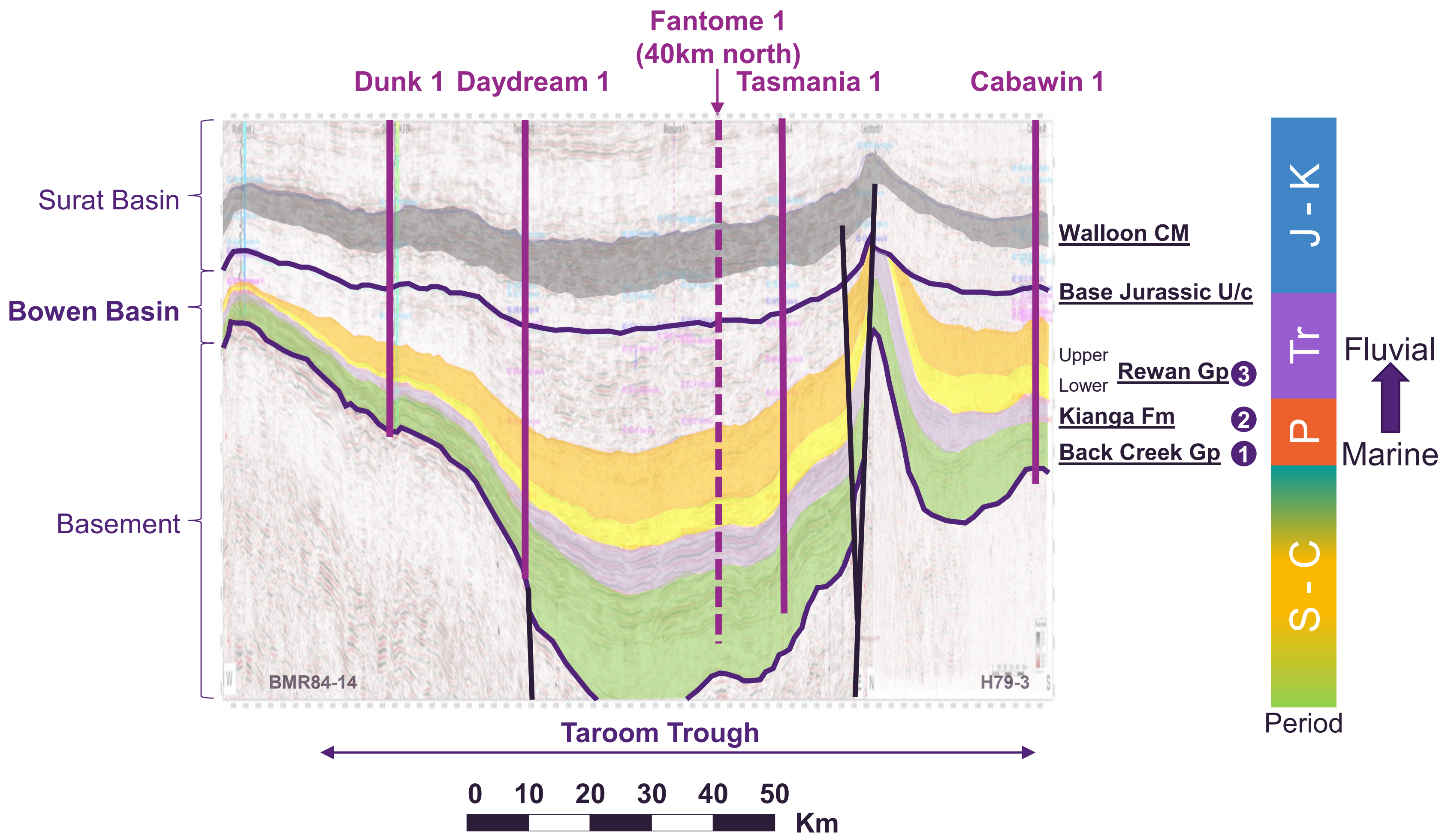
What lies beneath…

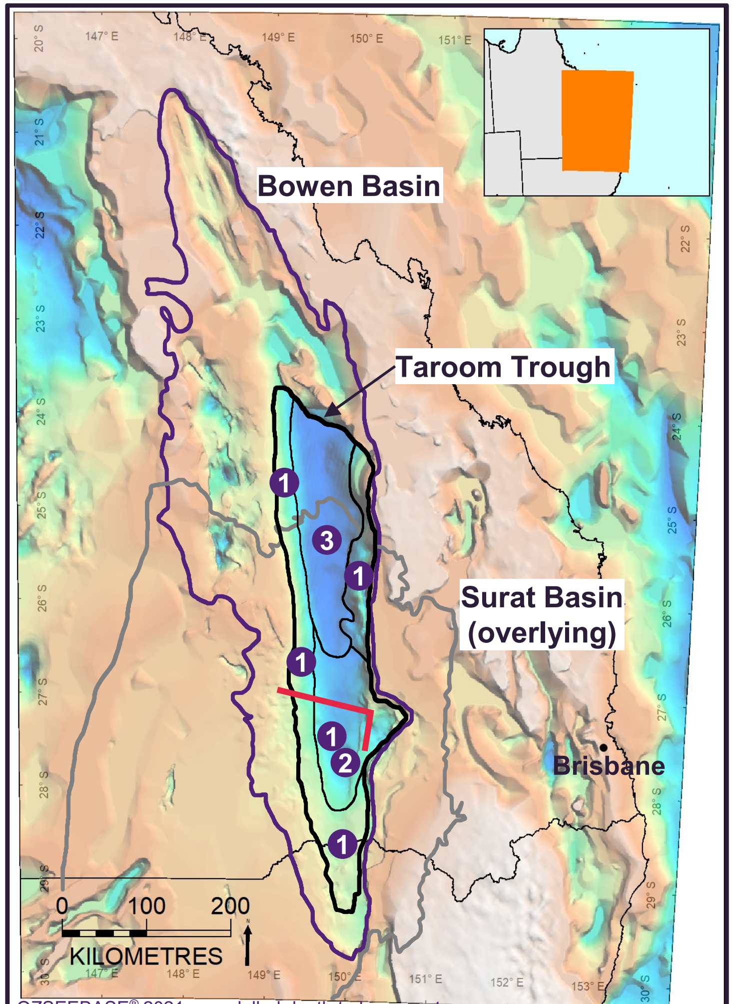
- Bowen and Surat Basins = Coal Seam Gas to LNG projects
- What is next to sustain export and domestic market supply at scale?
- Material OGIP potential in deep tight gas plays in basin with existing CSG development
- Initial tests encouraging but it is clear that challenges still exist to achieve commerciality

- What we'll cover:
  - Review key well outcomes from dedicated tight gas sand drilling campaigns from 2011-2015
  - Analysis of fracture stimulation effectiveness
  - Challenges and implications for future work

- Comprehensive but sparsely (geographically & stratigraphically) distributed open-file data

Deep plays in the Bowen Basin





OZSEEBASE® 2021 – modelled depth to basement

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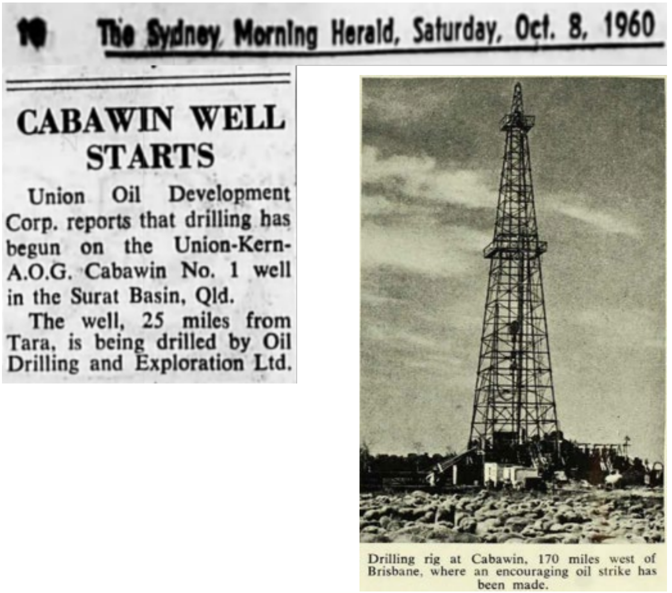
Exploration history

Only 0.3% of wells have drilled below 3000m in over 120 years exploring the Bowen & Surat Basins



10 The Sydney Morning Herald, Saturday, Oct. 8, 1960

CABAWIN WELL STARTS

Union Oil Development Corp. reports that drilling has begun on the Union-Kern-A.O.G. Cabawin No. 1 well in the Surat Basin, Qld.

The well, 25 miles from Tara, is being drilled by Oil Drilling and Exploration Ltd.

Drilling rig at Cabawin, 170 miles west of Brisbane, where an encouraging oil strike has been made.

Early days

Period: 1900 - 1960

Wells drilled to 1960: 57

Wells > 3000m: 0

Conventional oil (then gas) focus

Period: 1960 - 2000

Wells drilled to 2000: 1,826

Wells > 3000m: 24

CSG era

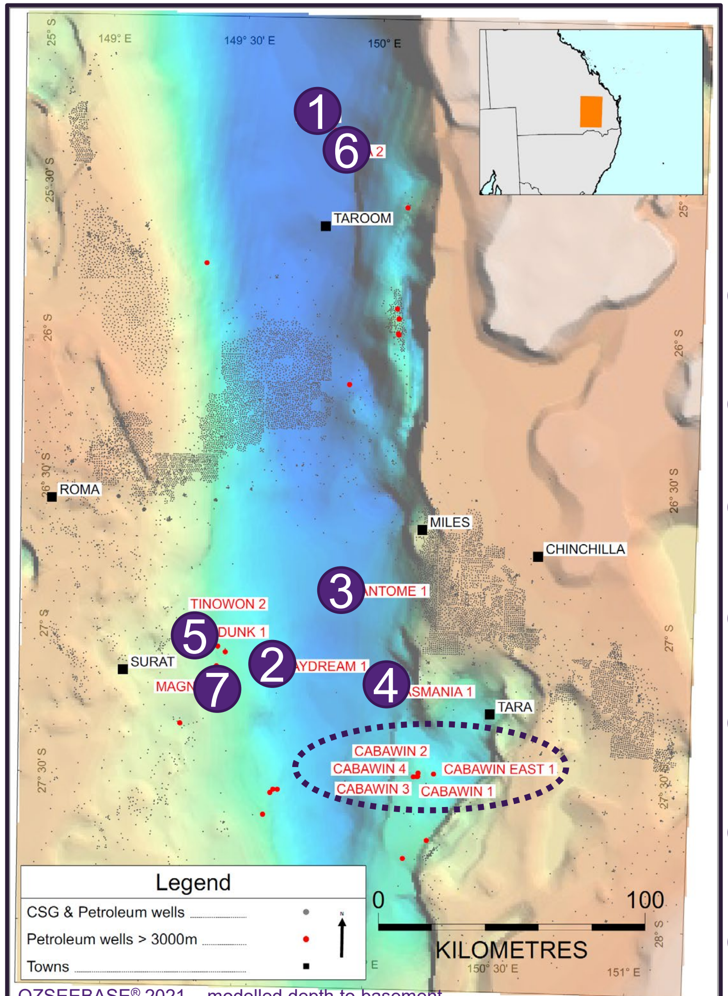
Period: 2000 - Present

Total wells drilled: 14,545

Wells > 3000m: 38

An ambitious deep tight gas program…

Focus on the seven wells drilled by QGC into the deepest part of the Taroom Trough from 2011-15

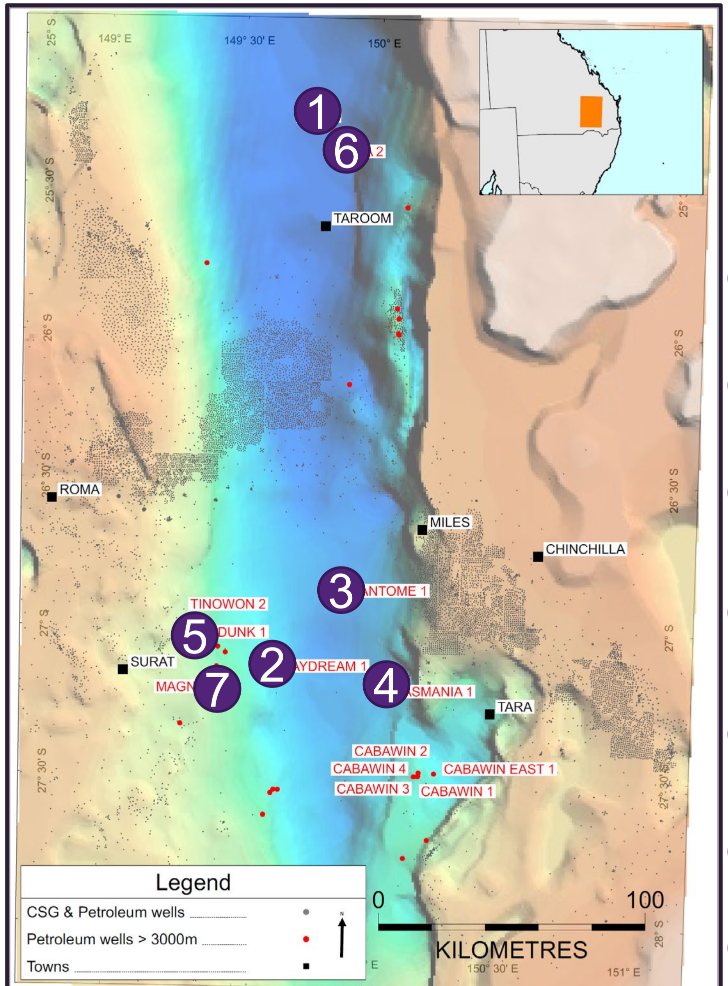


OZSEEBASE® 2021 – modelled depth to basement

	Well	Drilled	Objective	Depth (m)
1	Moa 1	2011	Rewan	3750
2	Daydream 1	2011	Kianga / Back Creek	4140
3	Fantome 1	2012	Rewan / Kianga	4694
4	Tasmania 1	2012	Kianga / Back Creek	4623
5	Dunk 1	2014	Back Creek	3180
6	Moa 2	2015	Rewan	4400
7	Magnetic 1	2015	Back Creek	3095

…with technical success, but…

Key play elements proven and sustained gas flows to surface from completed wells



OZSEEBASE® 2021 – modelled depth to basement

	Well	Test interval	Test duration (days)	Cum. test volume (MMscf)
1	Moa 1	Rewan	n/a	n/a
2	Daydream 1	Back Creek	30	0.106
3	Fantome 1	Kianga / Back Creek	70	5.014
4	Tasmania 1	Kianga / Back Creek	84	0.212
5	Dunk 1	Kianga / Back Creek	30	17.06
6	Moa 2	n/a	n/a	n/a
7	Magnetic 1	n/a	n/a	n/a

…challenges remain to achieving commerciality

From the rocks to how they were treated

Subsurface

- Low permeability
- Petrology
- Coals…not just a source?
- Moderately over-pressured

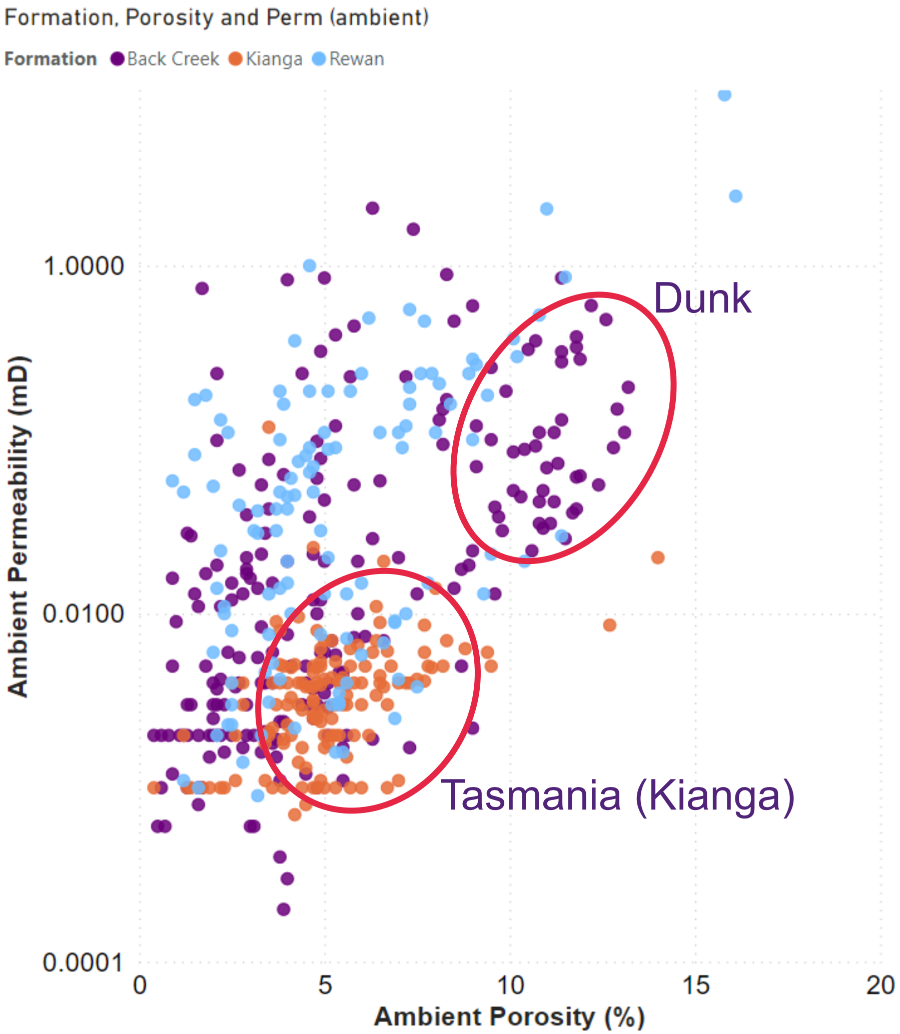
Accessing the best resource…

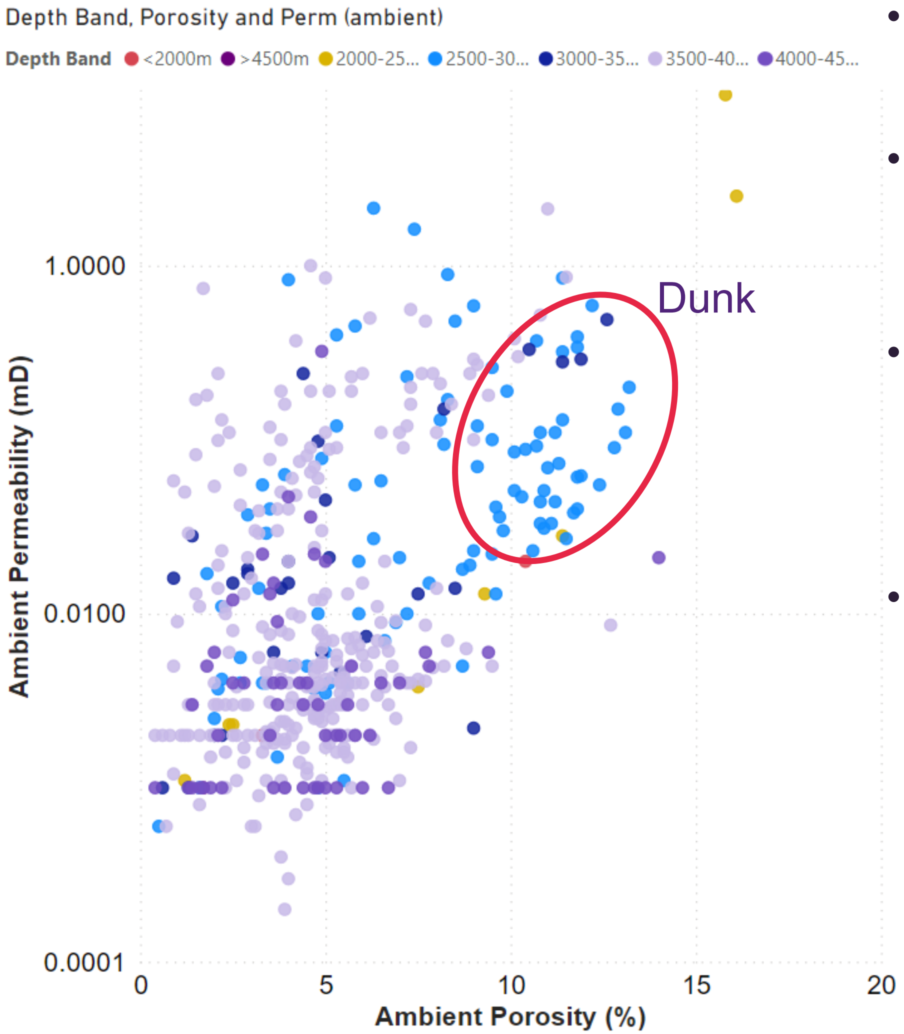
Fracture stimulation

- Stress regime
- Zone selection
- Stimulation design
- Effective use of diagnostics

…in the best possible way

Deep Bowen reservoirs are tight…

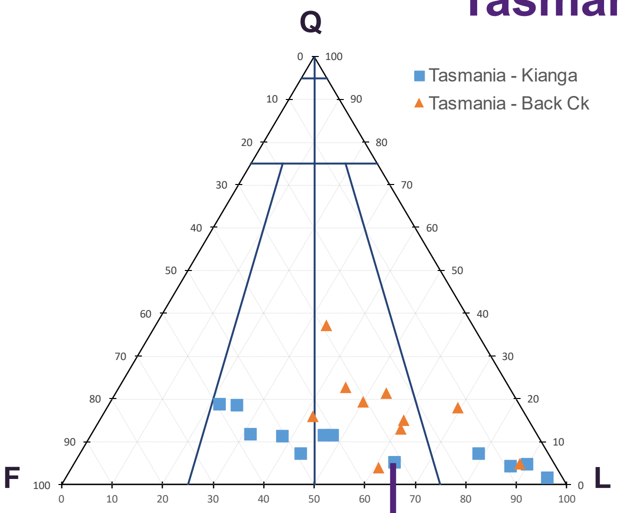


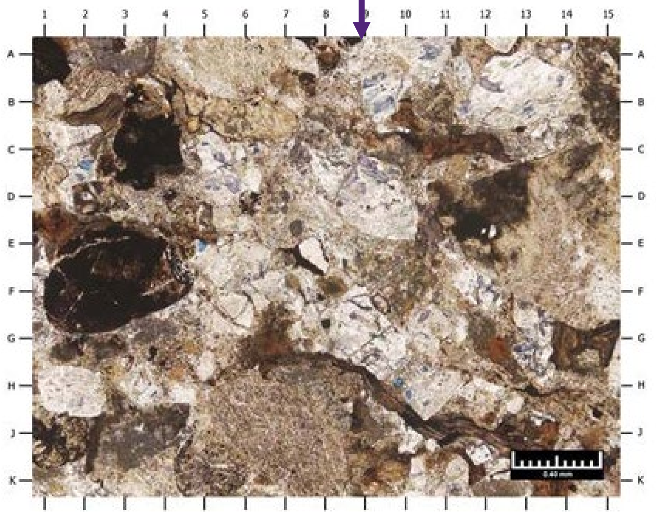


- Very few samples > 1mD ambient
- General decreasing reservoir quality with depth
- Kianga at lower end of perm distribution (mostly sampled in Tasmania)
- Dunk at upper end of poro-perm distribution (best test result to date)

…and petrologically complex

Tasmania 1



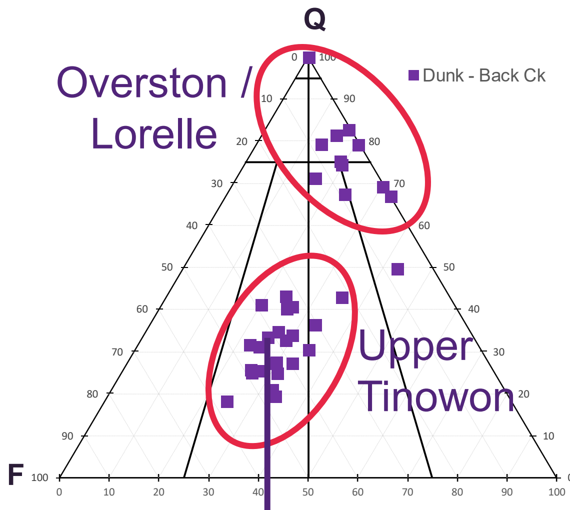


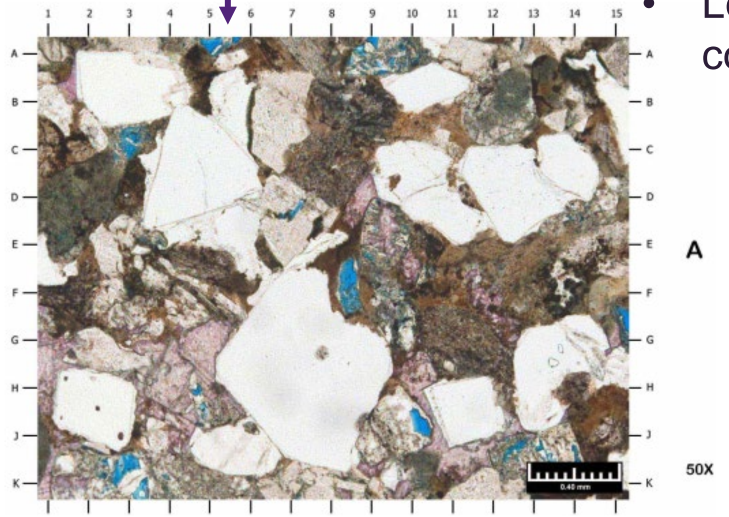
- Lithic Arkose - Litharenite
- Volcanolithic rich
- Micro-porosity
- Low swelling clay content

3733.40m (Kianga)
ϕ_{amb} 3.9%
K_{amb} 0.005mD

50X

Dunk 1



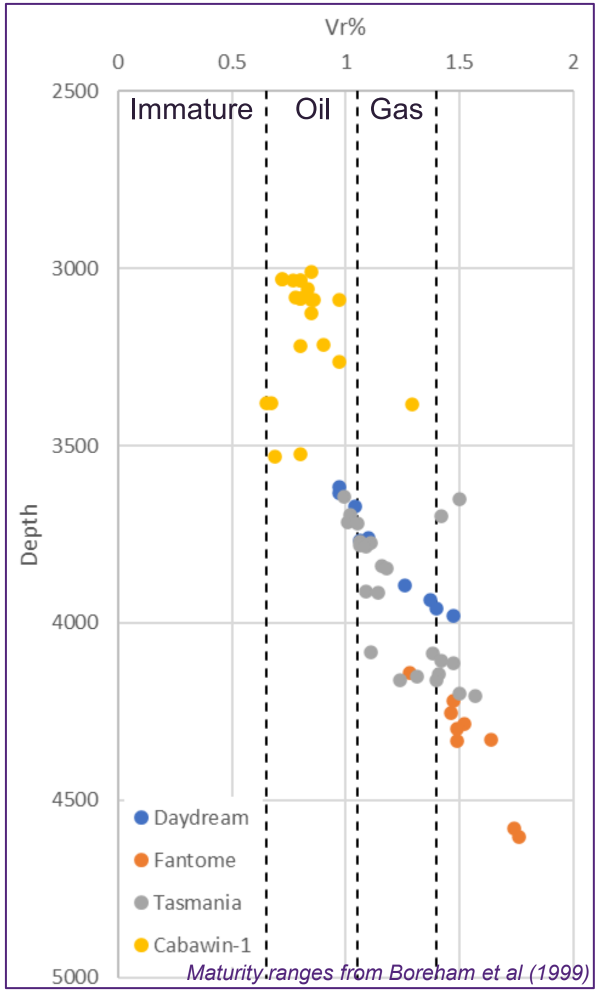


- Lithic Arkose - Sublitharenite
- Higher Q & F
- Secondary intragranular pores dominant
- Low swelling clay content

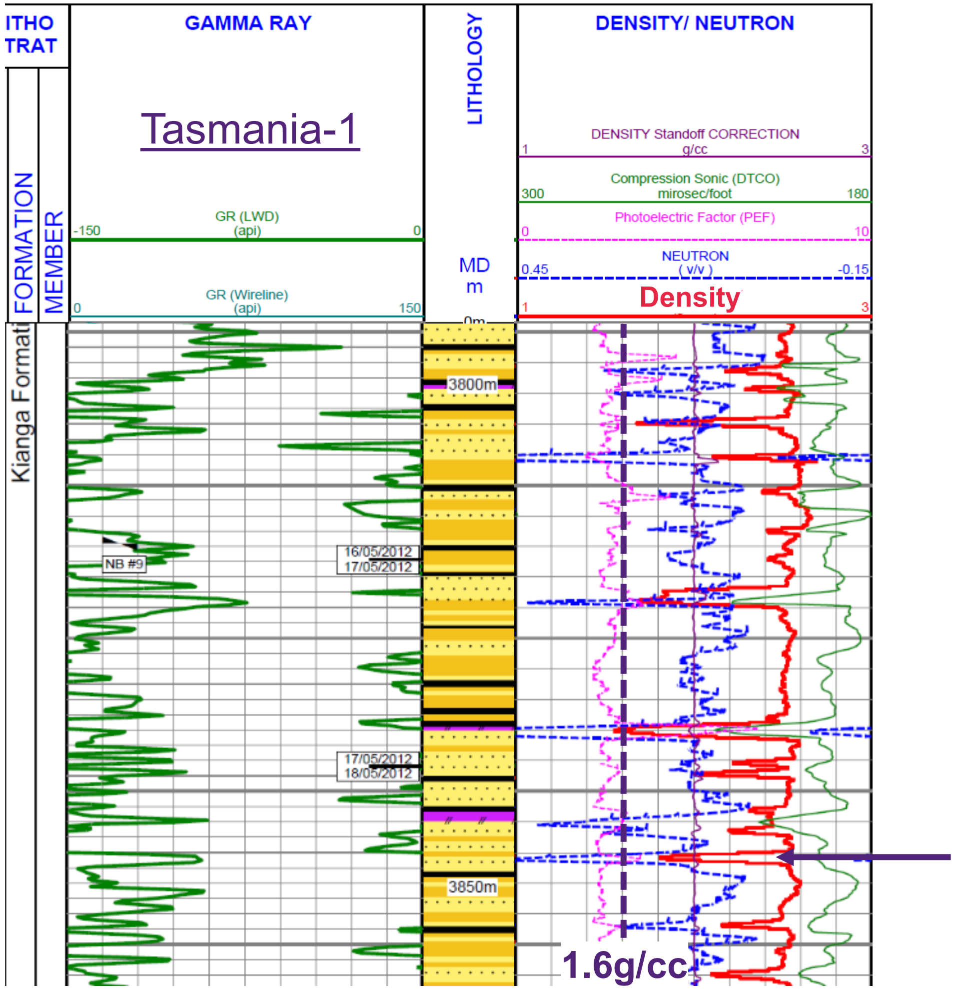
2924.21m (Back Creek)
ϕ_{amb} 10.9%
K_{amb} 0.051mD

Could coals be an additional resource?

Gas mature in basin centre



Coals or carbonaceous shales?



- Seam thickness generally less than 2m
- Dominated by vitrinite, inertinite up to 30%, minor liptinite
- >50% ash (up to 95%) from proximate analysis (Tasmania)
- Limited coal samples and log responses indicate variable quality
- Remain untested in deep basin centre

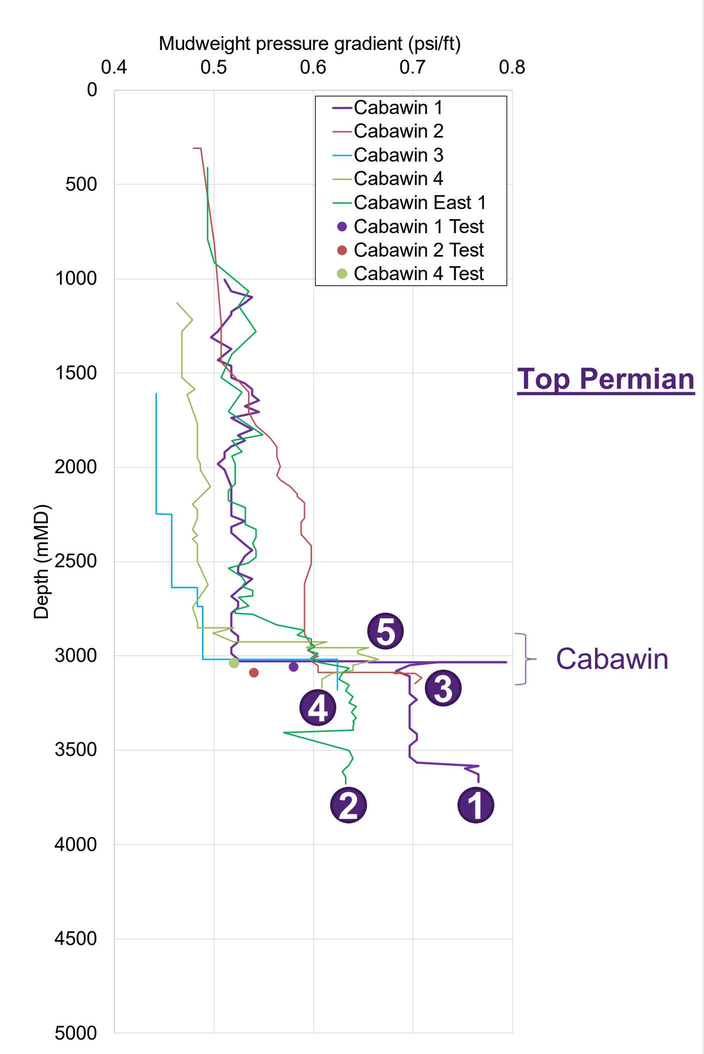
Basin is not highly over-pressured

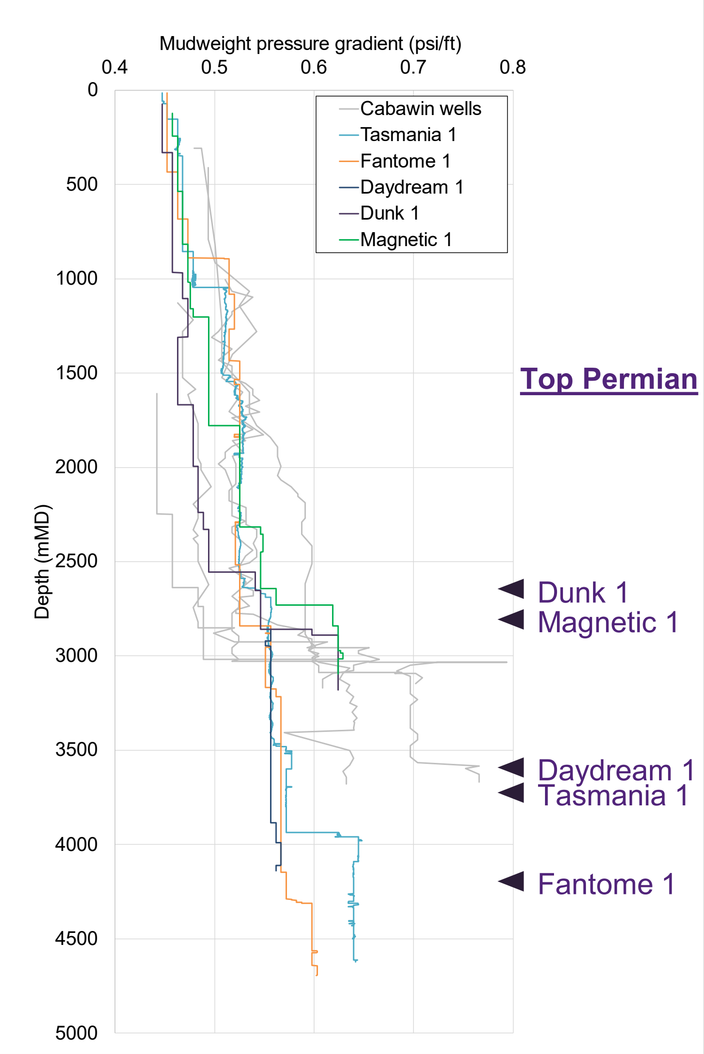
Cabawin 1 blowout took 3 weeks to control…with up to 0.8psi/ft mud weight

NO. TOURS	DATE	DEPTHS FROM	DEPTHS TO
	1960.		
	8 Dec.	9877'	9938'

to cutting core. After circulating 40 minutes noticed that the mud volume was increasing in the mud tanks. At this time had a strong blow of gas and mud, blowing the Kelly bushing, and table bushings out of the rotary table. Closed Hydril on Kelly and started bleeding off well through kill line. Pulled

Cabawin-1 WCR





- Pressure causing blowout in Cabawin 1 isolated
- Onset of overpressure at top Permian in southern Taroom (c. 2,500m in Northern Taroom)
- No evidence of underbalanced drilling in QGC wells
- Data suggests regional pressure gradient <0.60 psi/ft

1D stress profiles consistent with Pp < 0.6psi/ft

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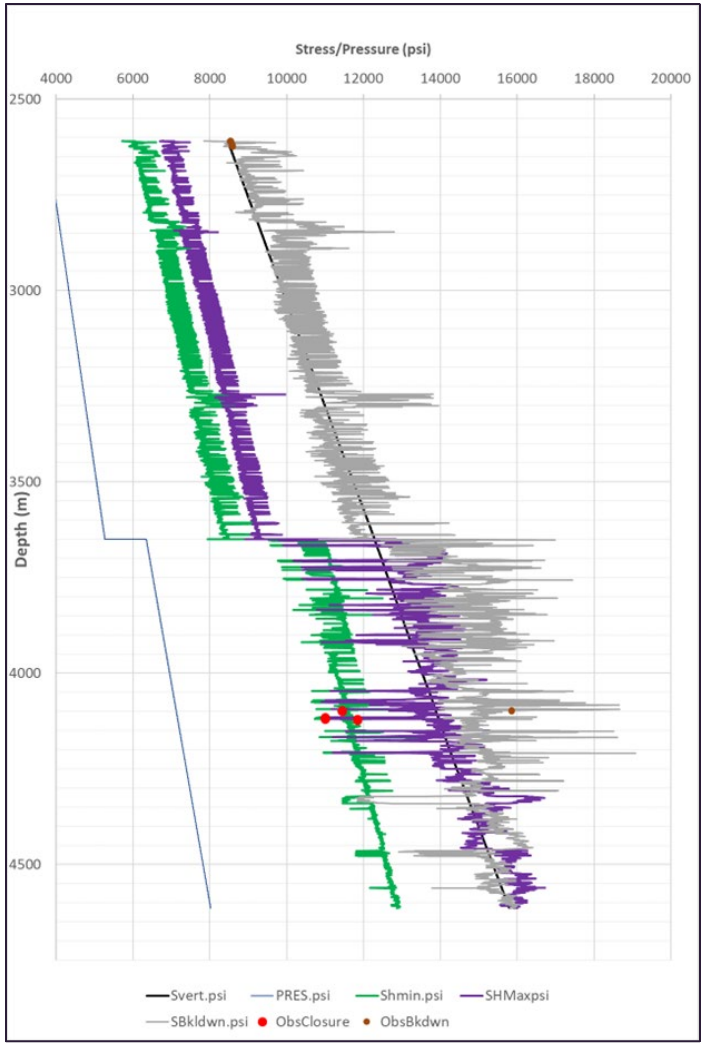
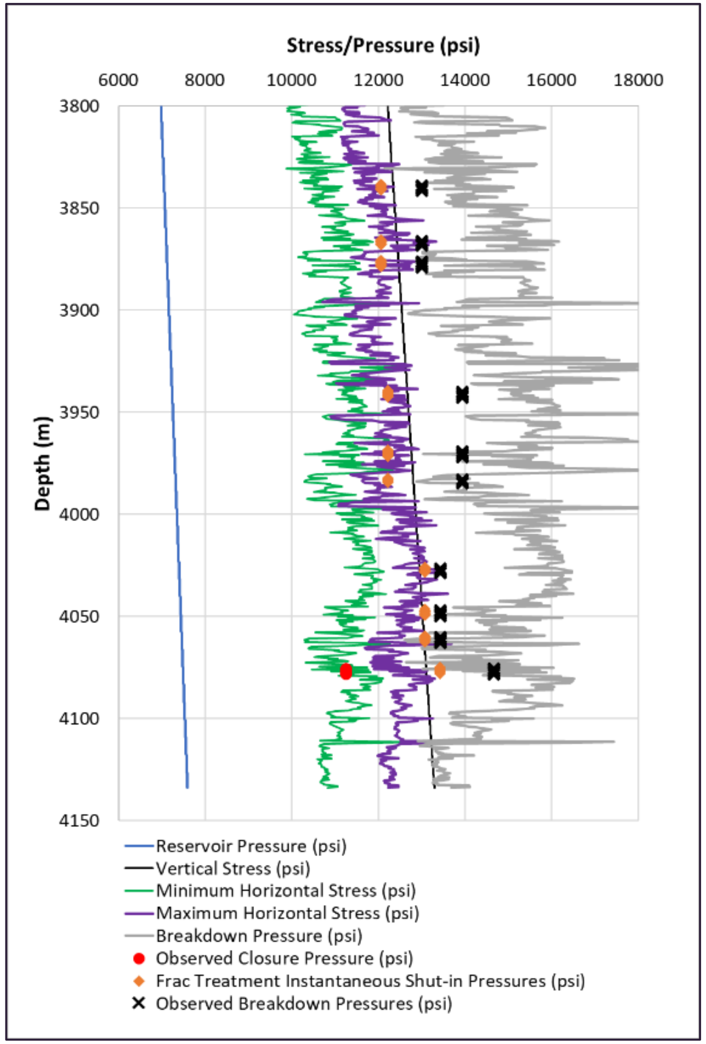
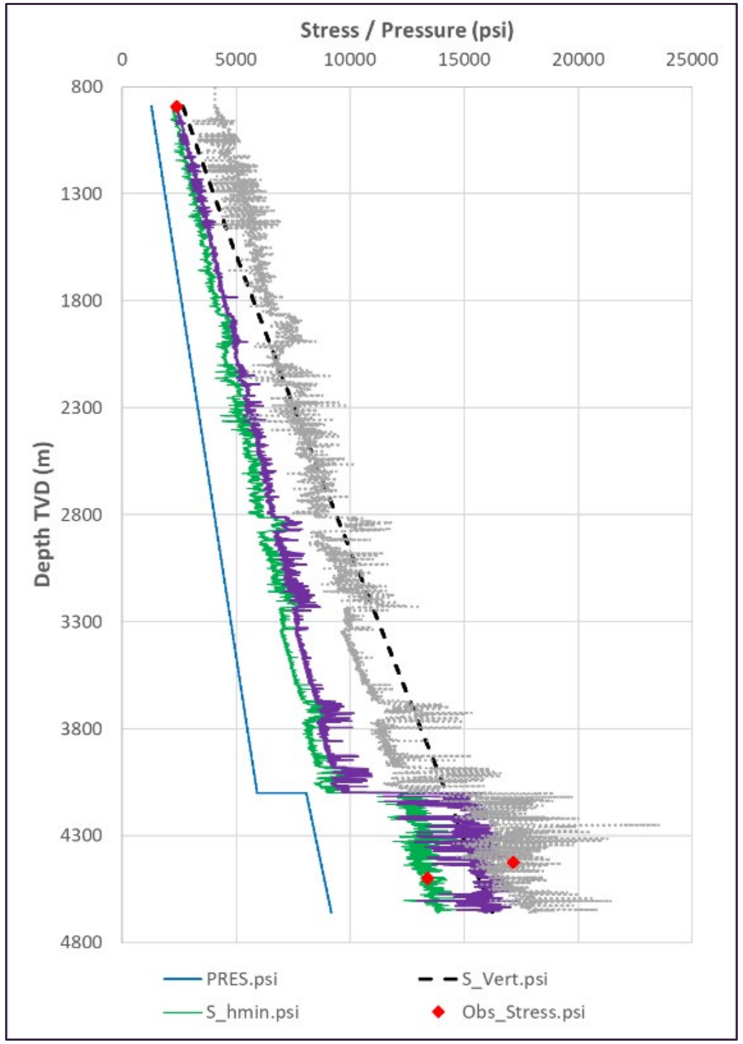
Tasmania 1 matches 0.53 psi/ft



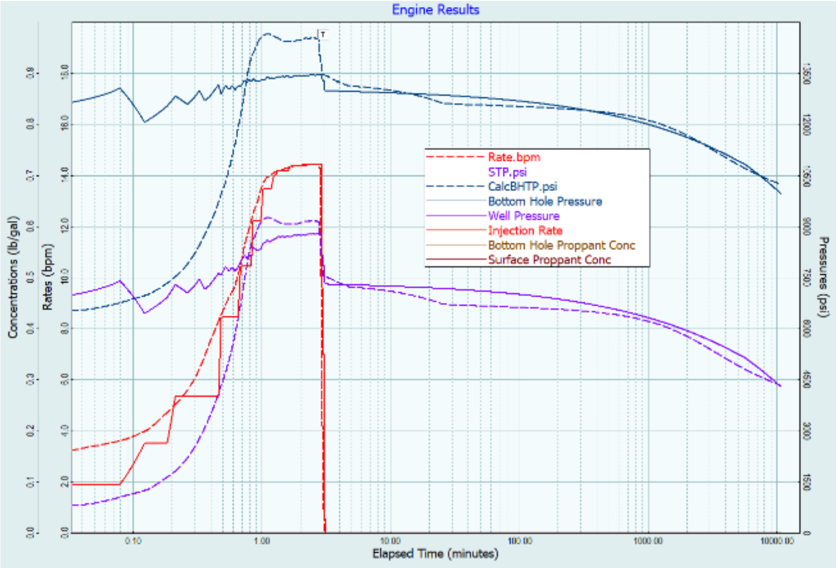
Daydream 1 matches 0.56 psi/ft



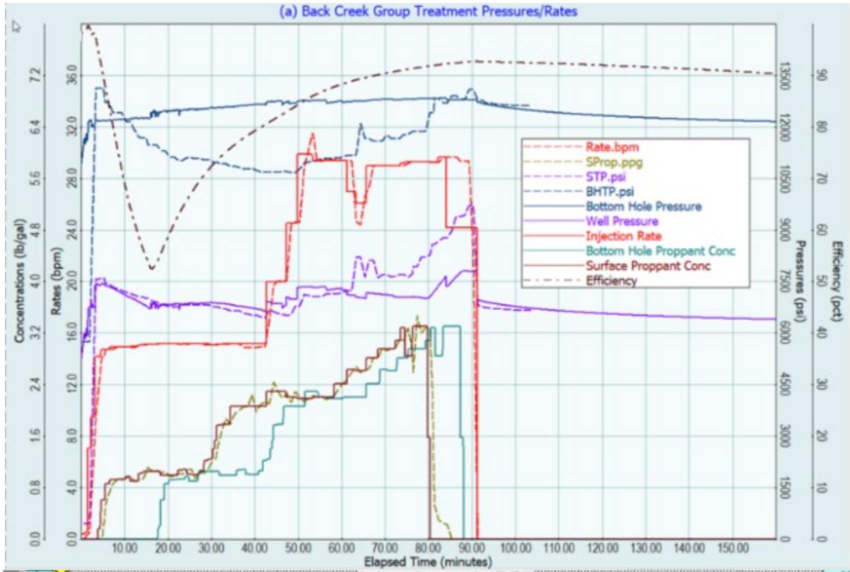
Fantome 1 matches <0.60 psi/ft



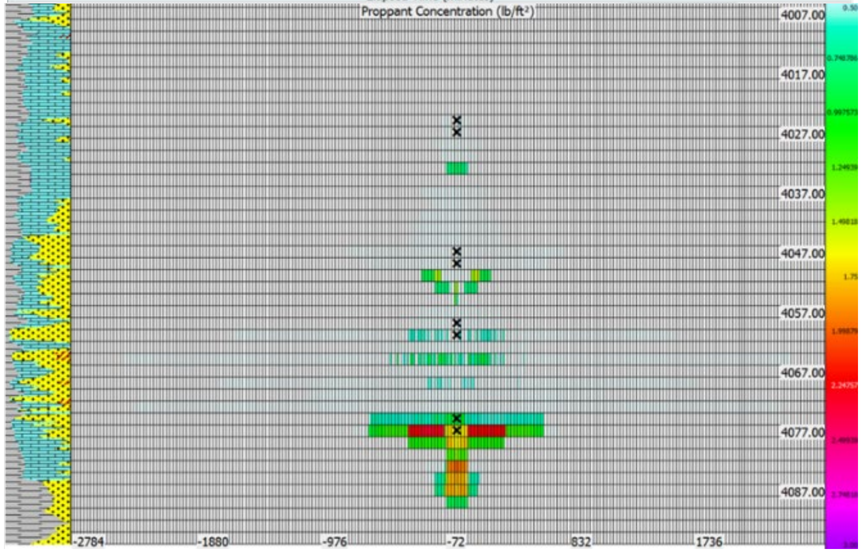
Back Creek Group : Daydream-1



- DFIT
- Good early and long time STP and BHTP history-match
- Fracture tortuosity of 125 psi/bpm^2
- Long time match, with 0.56 psi/ft reservoir pressure,
- Matched calc log perm model (~25-50 nD)
- PhiE matched log calc model (PhiE < 4%)

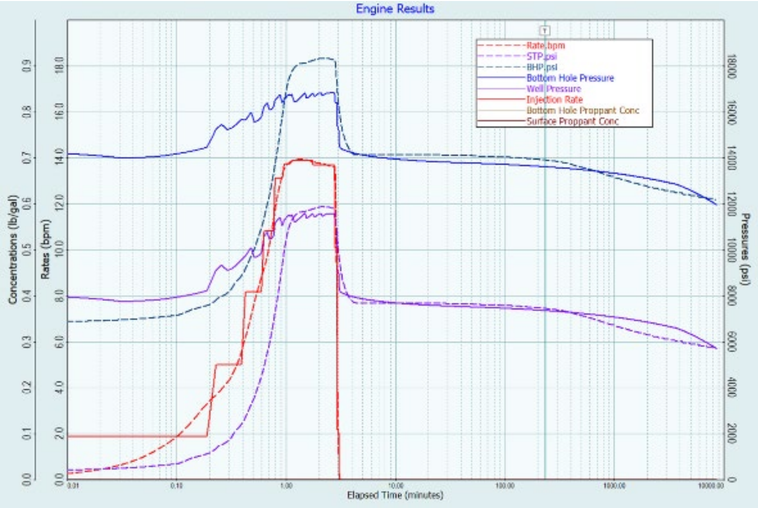


Treatment rates, proppant concentrations, STP and BHTP history-match

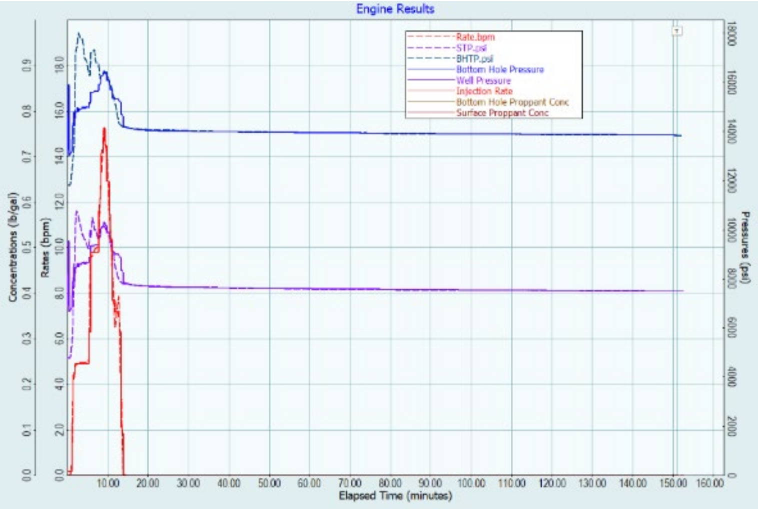


Post-frac proppant profile with 0.5 lb/ft^2 proppant cut-off with closure >3 day shut-in

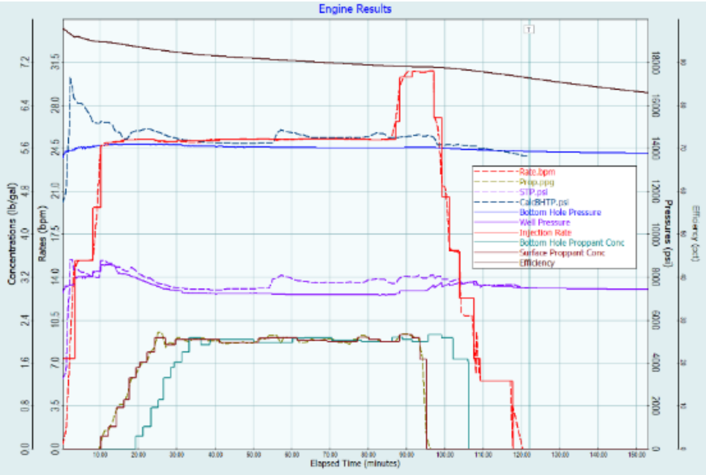
Lower Kianga Fm : Fantome-1

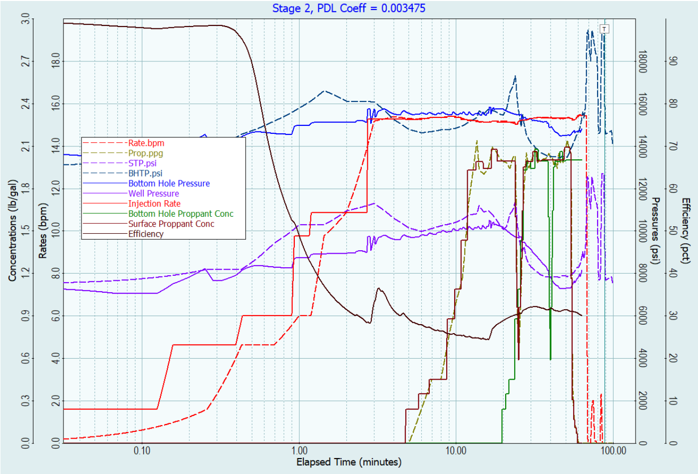


DFIT: Early and long time match with 0.6 psi/ft reservoir pressure, and 0.9% of calc log perm model (~60 nD)



Stage 2: 2m perforated interval, high fracture tortuosity 0.6 psi/ft reservoir pressure, and 3.5% of calc log perm model (~90 nD)





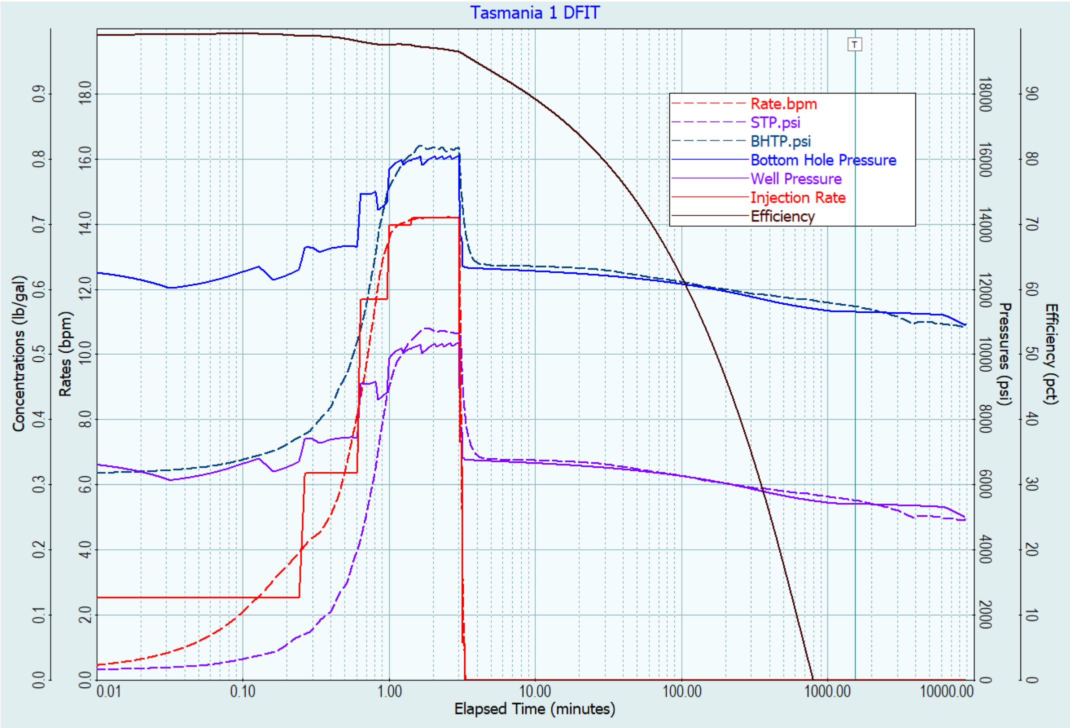
Stage 1:

- Very good match, at 100% of calc log perm model, ~1-10 µD
- Requires PDL Coeff 0.0034 psi^{-1} to match final decline

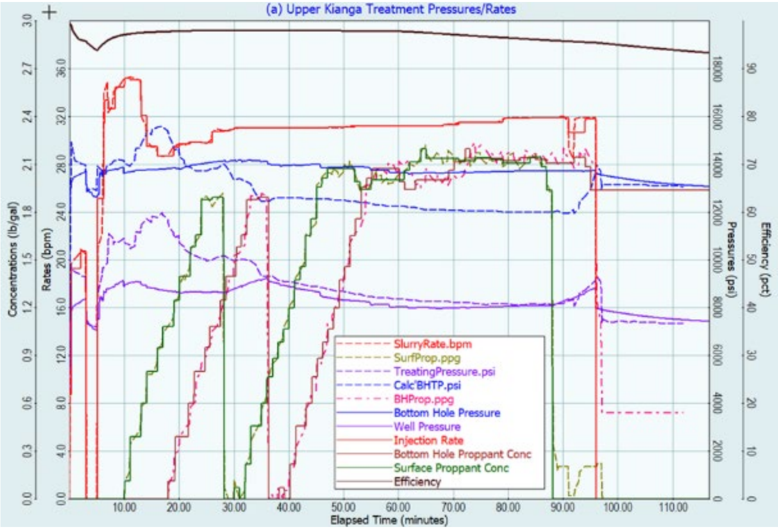
Stage 2:

- Can only match screen out (shown) with PDL coefficient ≥0.003475
- Perm at 100% of log perm model, ~3 µD
- **If PDL Coeff = 0.0033 psi^{-1}, job completes with extended closure time (>34 days)**

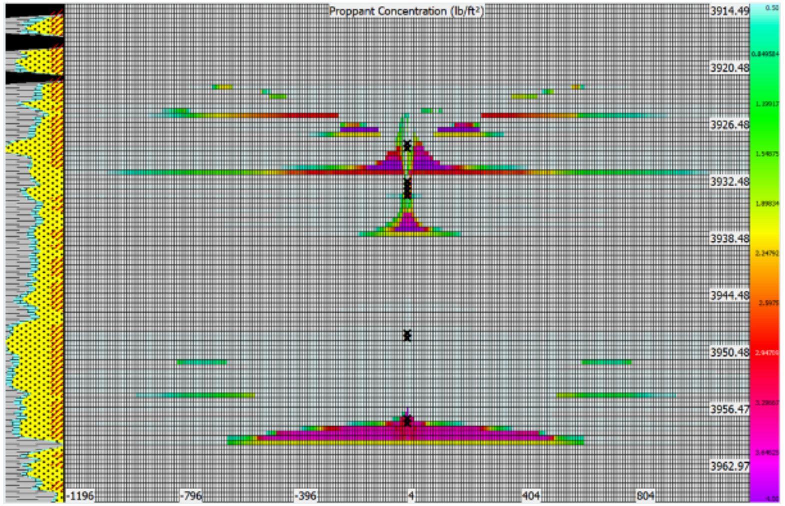
Kianga Fm : Tasmania-1



- Early time history-match indicated high fracture tortuosity
- Long time match, 0.53 psi/ft reservoir pressure,
- 15x calc log perm model (0.12 mD)
- 2.2x log calc PhiE model (avg PhiE = 0.11)



Treatment rates, proppant concentrations, STP and BHTP history-match

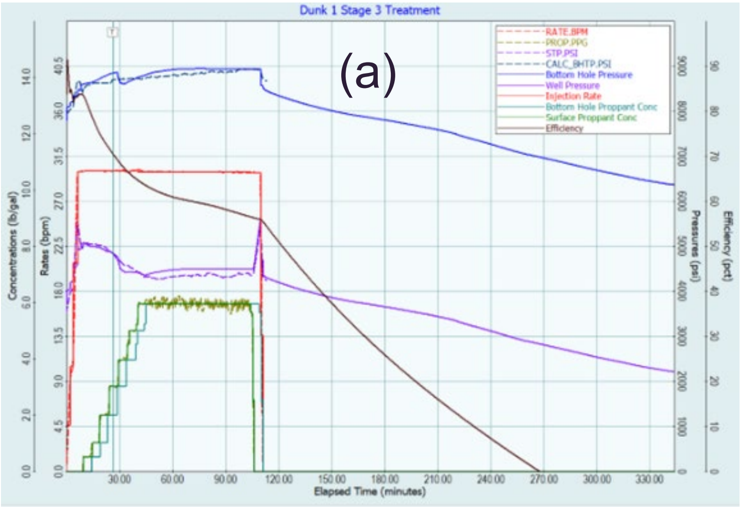


Post-frac proppant profile with 0.5 lb/ft^2 proppant cut-off

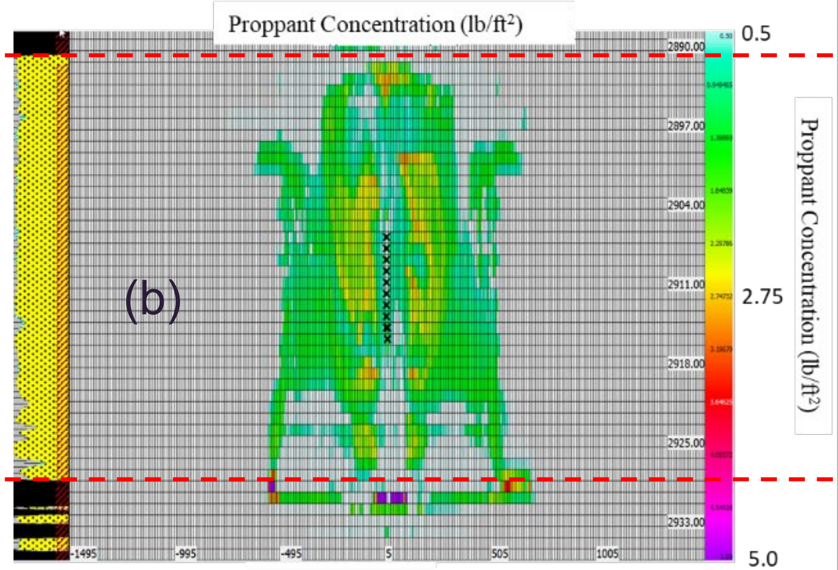
Back Creek Gp (Upper Tinowon) : Dunk-1

- Dunk 1 Stage 3 history-matched pressures (a) using a stress profile based on 0.54 psi/ft reservoir pressure gradient and lower tectonic strains than other QGC Taroom Trough wells
- Modelled dimensions (b) versus post-frac log (c) correlated on coals
  - NRT indicated height (2nd to last yellow track) match main body of frac
  - Stress anisotropy height (last green track) indicates coal growth

(a)

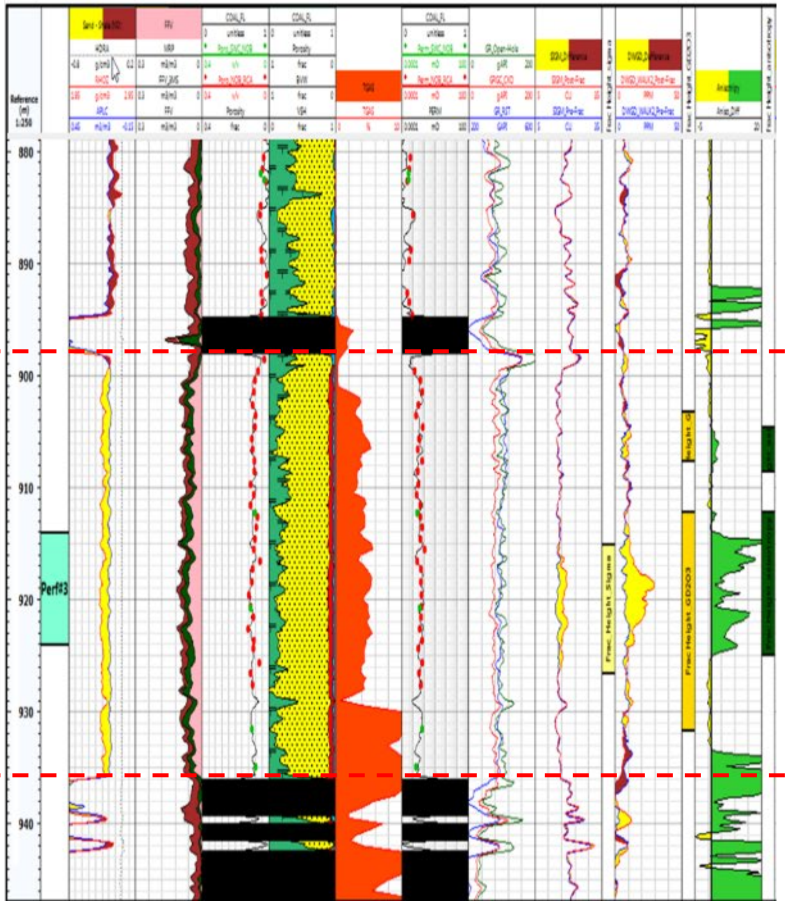


(b)



(c)

After Oliveira Neto and Yakovlev (2018)



Conclusions

Technical success with key play elements for pervasive tight-gas sand plays demonstrated, however, no commercial success to date due to challenges posed by reservoir quality and lack of an effective extractive technology.

To realise full potential of deep plays in the Bowen Basin, will need to:

Overcome reservoir quality challenges.

- Extremely low permeability.
- Need to maximise stimulated rock volume (SRV).
- Step change in understanding of basin fill history of deep Taroom Trough…BUT
- Sparsity of data precludes development of detailed geological models to identify and map highest potential zones.

Develop an effective extractive technology.

- Extremely low permeability.
- Moderate to high near wellbore pressure loss (NWBPL).
- Careful selection of fracture stimulation fluid to minimise formation damage.
- DFITs in existing wells ineffective at resolving key stress and pressure profile uncertainties.

Recommendations

Selection of highest potential completion intervals and optimisation of DFITs and fracture stimulation design will be critical to unlock deep plays in the Taroom Trough.

- **Establish a robust chronostratigraphic framework** to characterise and predict distribution of best reservoir.
- **Target deep coals** with coal properties conducive to stimulation to increase volume of resource through mixed pay completion of interbedded coals and sandstones.
  - Micro-proppants to potentially aid de-stressing and increase permeability due to degassing and shrinkage
  - Dynamic diversion to increase number of fractures and SRV without increasing size of fracs to achieve continuous conductivity across coals and sandstones
- **Optimise DFIT designs** to maximise value of information obtained in low-permeability reservoirs.
  - Small intervals, injection volume selected based on expected permeability rather than ‘rule of thumb’
  - Pay and non-pay intervals with focus on intervals with contrasting Young’s Modulus – develop stress profile <u>and</u> test for permeability
- **Optimise stimulation designs** with small frac stages in zones with sufficient stand off from stress boundaries, use of fluids with sufficient viscosity to transport proppant through near wellbore and if NWBPL is problematic then wellbore orientation aligned to direction of σ_{HMax} and oriented perforations (low and high side 180° phase)

Acknowledgements

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