Assessing Unconventional Resource Potential of the Mesoproterozoic Roper Group, Beetaloo Sub-Basin Region, Australia*

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Abstract

In the Northern Territory of Australia, the Beetaloo and associated Gorrie, Broadmere, and OT Downs Sub-basins are potential targets for unconventional hydrocarbon exploration. Nine wells within this region were investigated in this study to assess hydrocarbon prospectivity of key formations within the Mesoproterozoic Roper Group (~1.4 Ga) using source rock geochemistry. The Roper Group comprises a regionally extensive, upward-coarsening cyclic succession of mainly marine mudrocks, including laminated organic-rich shales, alternating with sandstones and other minor lithologies. Within this sequence, five intervals composed of dominant shale lithology were evaluated, including the Kyalla, upper, middle and lower Velkerri, Corcoran, and Mainoru formations. The geochemical data set includes historical data compiled by the Northern Territory Geological Survey and more recent analyses performed by Weatherford Laboratories.

The two main intervals with greatest hydrocarbon potential are the Kyalla and middle Velkerri formations. Geochemical characteristics of these shales compare favorably with producing unconventional plays in the USA. The Kyalla has an average total organic carbon (TOC) content of 1.08 wt.% and the middle Velkerri averages 3.76 wt.%. These source rocks were originally composed of oil-prone Type II marine kerogen, which has been thermally altered due to hydrocarbon generation and expulsion. Although geochemical maturity data from organic petrology (R_o) and programmed pyrolysis (T_{max}) indicate the presence of oil-mature and gas-mature rock, thermal maturity may be a limiting factor in shallower parts of the basin. The Kyalla Formation is generally within the oil-window; whereas the middle Velkerri has reached the dry-gas window in the deeper sub-basin regions. Spatial and depth-based trends in the geochemical data within the Beetaloo Sub-basin will be reviewed and compared to previously published results.

Hydrocarbon yield calculations were utilized in conjunction with other methods such as core-based shale rock properties and pyrolysis S1 yields to evaluate original oil and gas in-place contents (OIP, GIP). Comparative volumetric assessment figures for the OIP and GIP are presented that indicate a range of P50 values, from 94–722 MMbbl oil in the Kyalla Formation, to 9–83 MMbbl oil and 202–752 TCF gas in the middle Velkerri Formation. The sources of uncertainty associated with these estimations of hydrocarbons in place will also be discussed.

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ASSESSING UNCONVENTIONAL RESOURCE POTENTIAL OF THE MESOPROTEROZOIC ROPER GROUP, BEETALOO SUB-BASIN REGION, AUSTRALIA

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May 21, 2018

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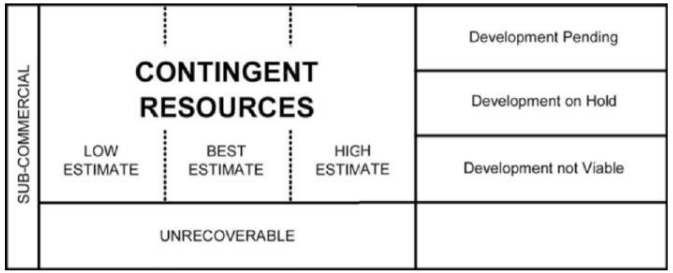
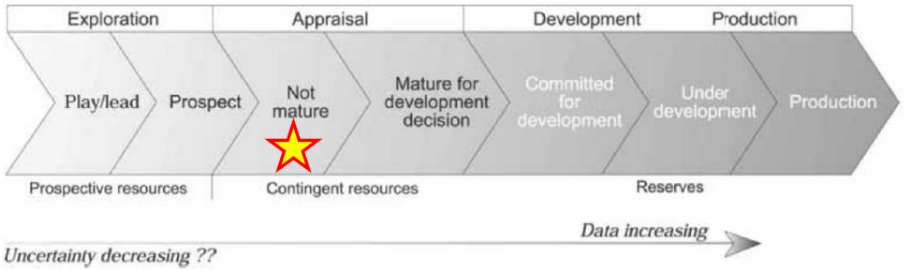
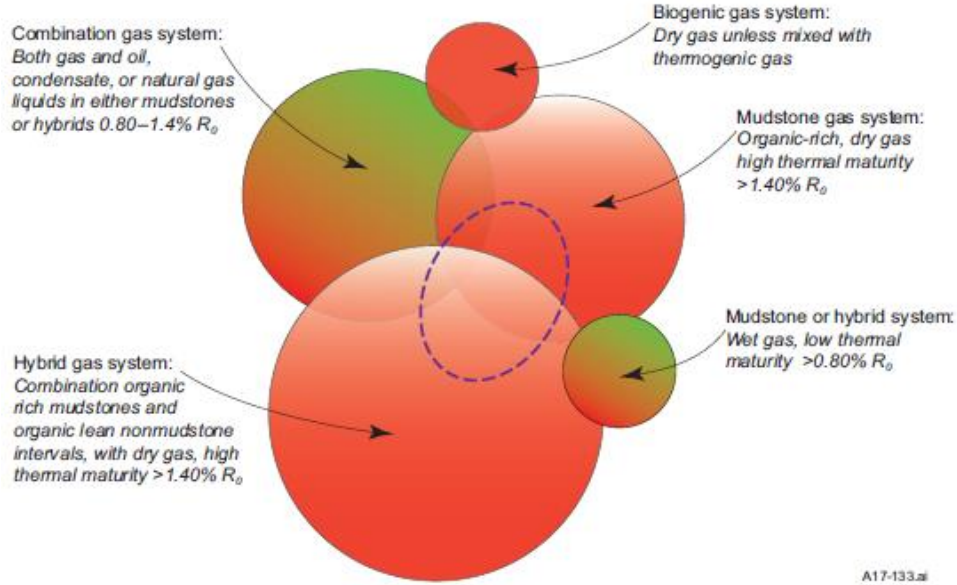
BEETALOO SUB-BASIN REGION SHALE STUDY

- Provide valuable geological and geochemical datasets to assist with mineral and hydrocarbon exploration
  - Moving from imprecision to a more robust dataset
- Estimate the resources in place; P10, P50 and P90 values for Oil in Place (**OIP**) and Gas in Place (**GIP**)
- The government can quote this resource to support science-based decision making with repeatable assessment volumes
- Resource unrestrained by tenement boundaries
- Publically available dataset — Digital Information Package 014

BEETALOO SUB-BASIN REGION SHALE STUDY







Simplified classification scheme for shale-gas resource systems

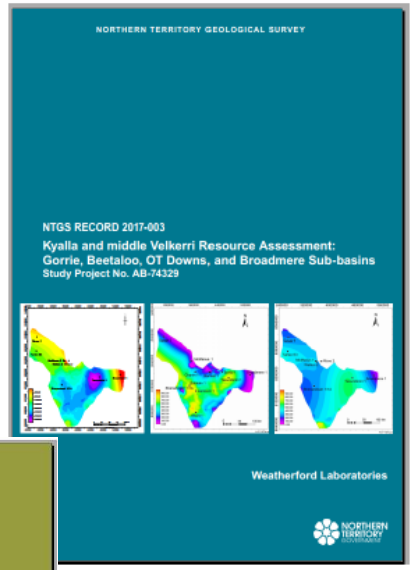
Size of circle is indication of resource potential

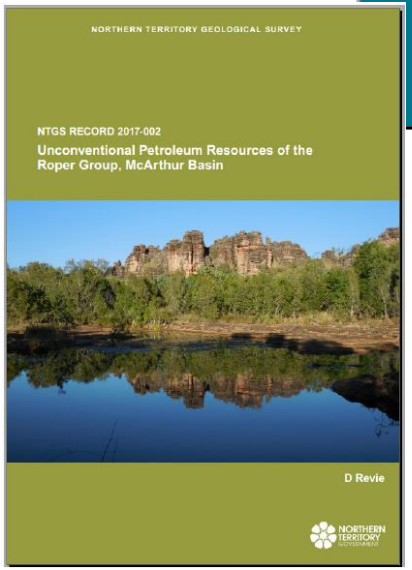
Potential Roper Group shale gas resources fall within dashed circle

Image from: Revie, D. J., 2016b, after: Jarvie 2012, Sedimentary characterization of the Wilton package, greater McArthur Basin, Northern Territory. Northern Territory Geological Survey, Record 2016-003.

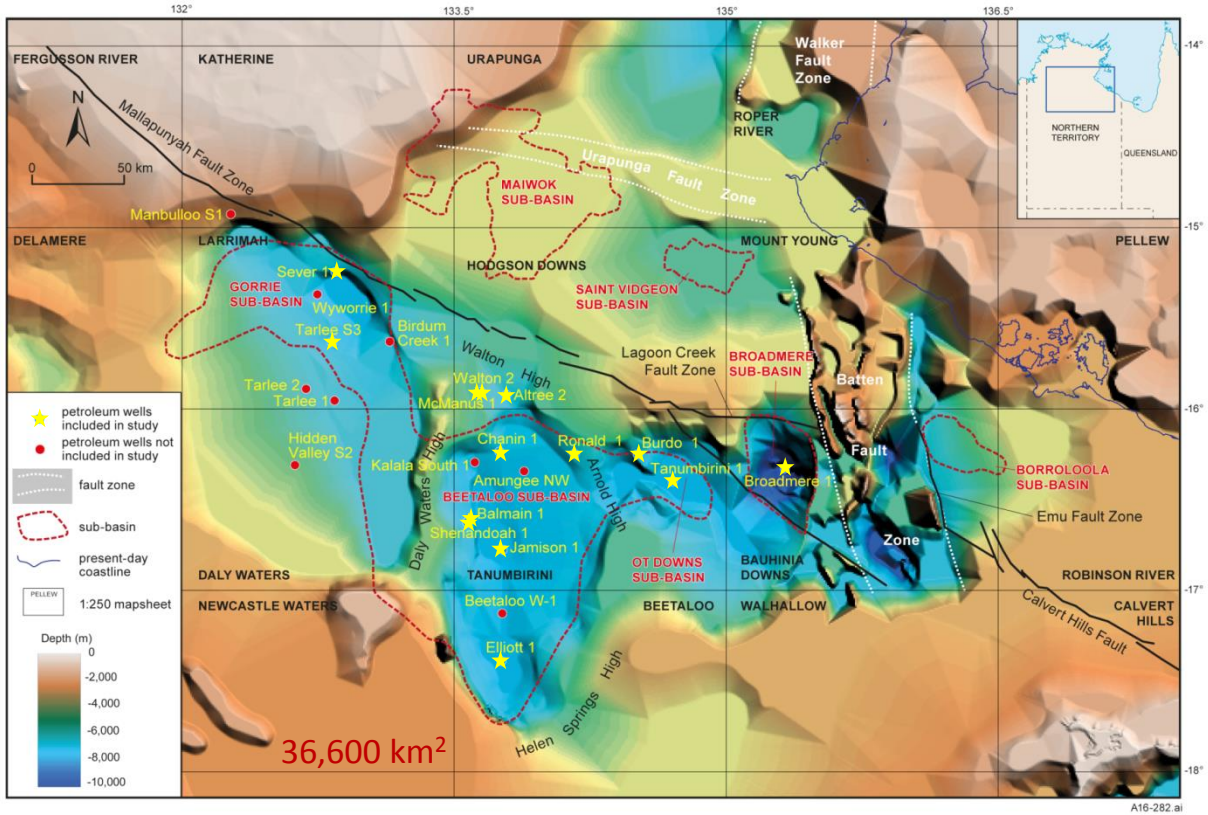
BEETALOO SUB-BASIN REGION SHALE STUDY

- **Desktop study** ≈ 6300 historical samples
- **Sampling program** ≈ 1600 new samples (13 wells)
- **Analyses:** TOC, programmed pyrolysis, elemental analyses of kerogen, organic petrology, GCMS for biomarkers, XRD for mineralogy, porosity permeability, fluid saturations.
- **Calculation** and **Interpretation**
- **Integration** of the data into the depth and formation volume models





BEETALOO SUB-BASIN REGION AUSTRALIA



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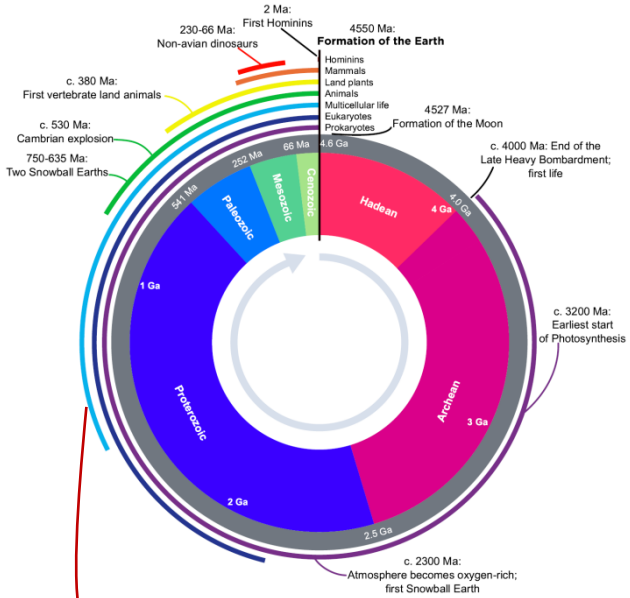
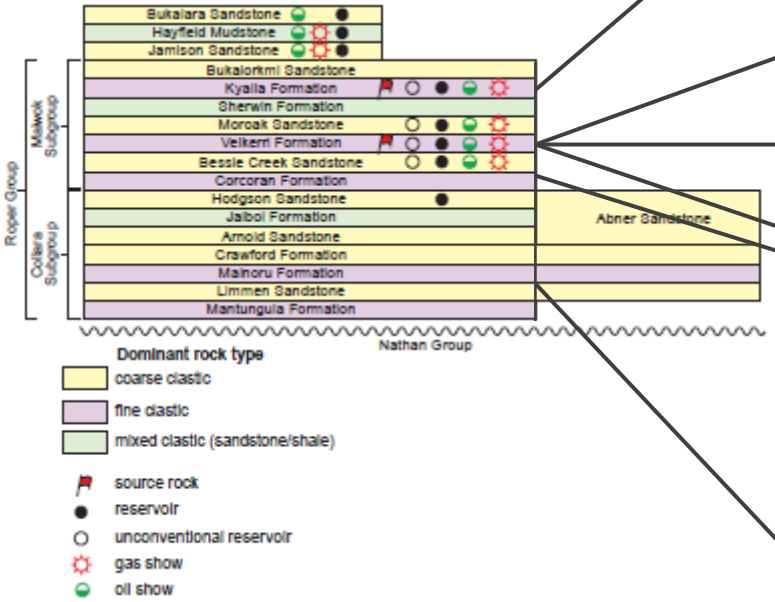


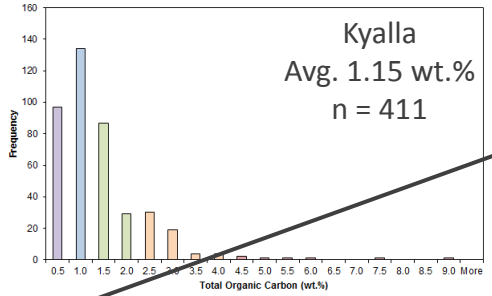
Roper Group (~1.4 Ga)

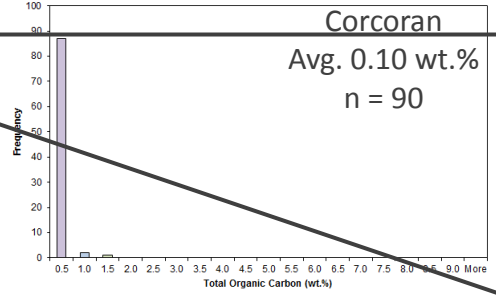
By WoudloperDerivative work: Hardwigg - File:Geologic_clock.jpg, Public Domain, https://commons.wikimedia.org/w/index.php?curid=11926892

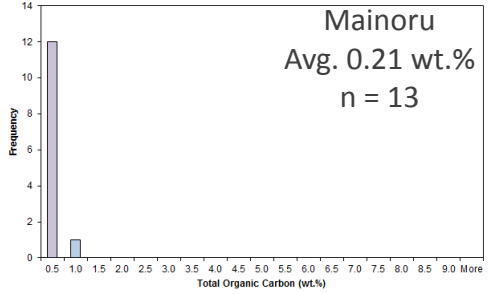
ORGANIC RICHNESS

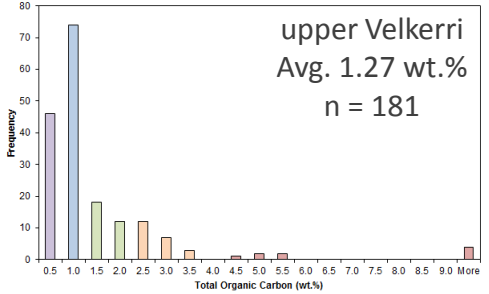
Generative Potential	TOC (weight %)
Poor	<0.5
Fair	0.5 – 1.0
Good	1.0 – 2.0
Very Good	2.0 – 4.0
Excellent	>4.0

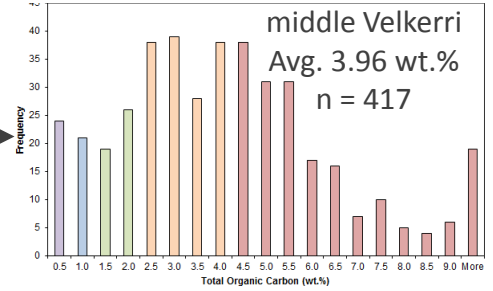












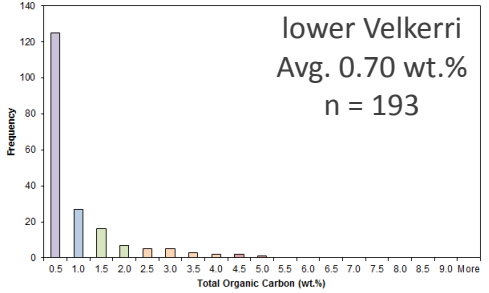
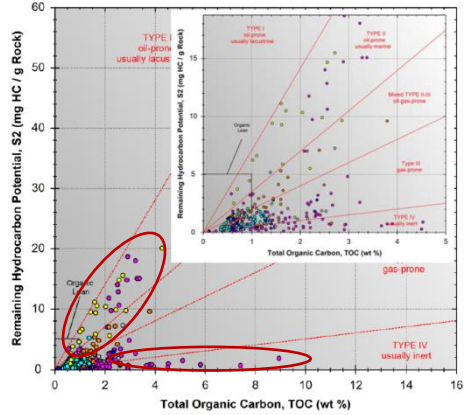


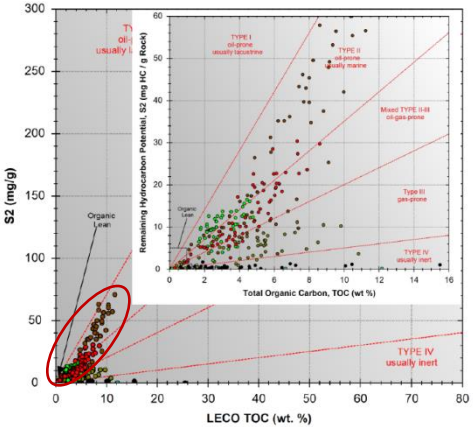
Image from: Munson, T. J., 2014, Petroleum geology and potential of the onshore Northern Territory, 2014. Northern Territory Geological Survey, Report 22 03/2014.

KEROGEN TYPE

Kyalla



middle Velkerri

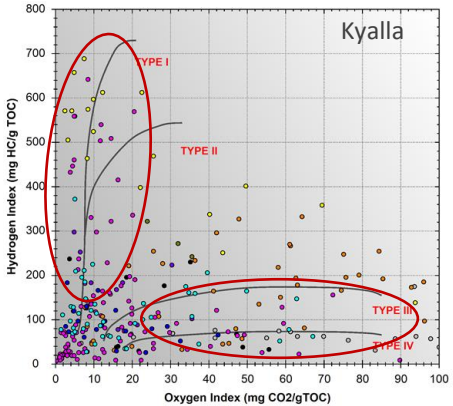


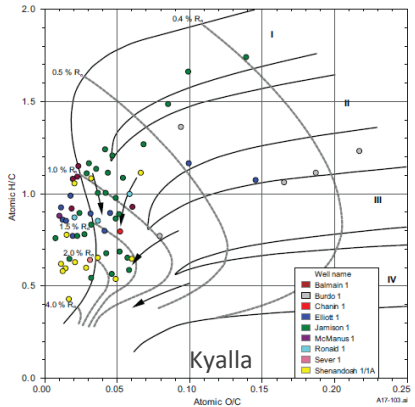
Altree 2, Balmain 1, Broadmere 1, Burdo 1, Chanin 1, Elliott 1, Jamison 1, McManus 1, Ronald 1, Sever 1, Shenandoah 1A, Tarlee S3, Walton 2

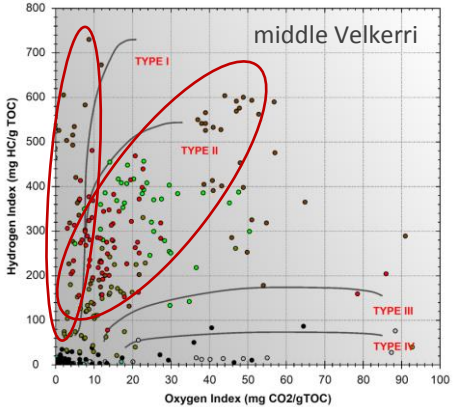
Kerogen type	Hydrogen Index (HI) mg HC/g TOC	Main product at peak maturation
I	>600	Oil
II (II-S)	300 – 600	Oil
II/III	200 – 300	Mixed oil and gas
III	50 – 200	Gas
IV	<50	None

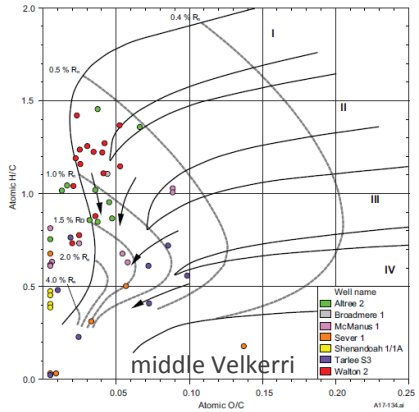
- Mesoproterozoic age limits types of organic matter that is present in these source rocks
- Primitive marine cyanobacteria are likely dominant and these are associated with Type I & Type II kerogen
- Organic petrology has identified alginite as dominant maceral along with abundant solid bitumen
- Thermal maturity has effects must be considered for interpreting data

KEROGEN TYPE





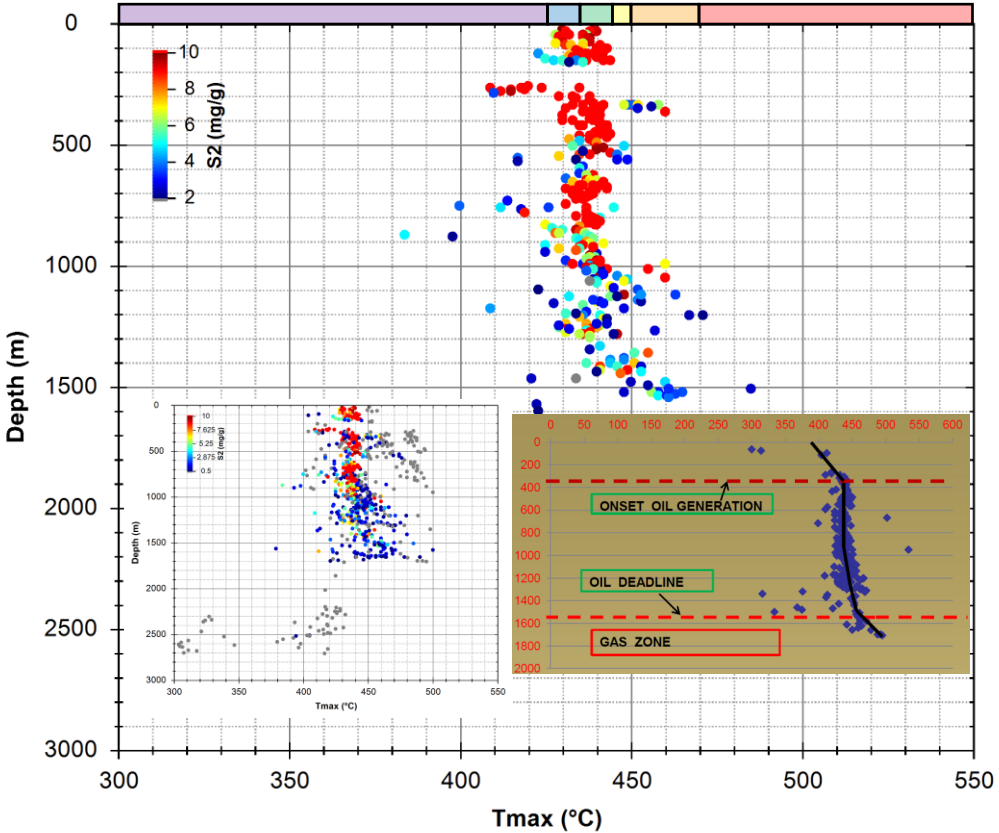




Kerogen type	Hydrogen Index (HI) mg HC/g TOC	Main product at peak maturation
I	>600	Oil
II (II-S)	300 – 600	Oil
II/III	200 – 300	Mixed oil and gas
III	50 – 200	Gas
IV	<50	None

- Programmed pyrolysis and elemental analyses of kerogen document occurrences of oil-prone Type I & Type II kerogen
- In some instances poorly preserved organic matter with elevated oxygen content (high OI) indicates the presence of inert Type IV kerogen
  - More common in Kyalla
- Thermal maturity has effects must be considered for interpreting data

THERMAL MATURITY

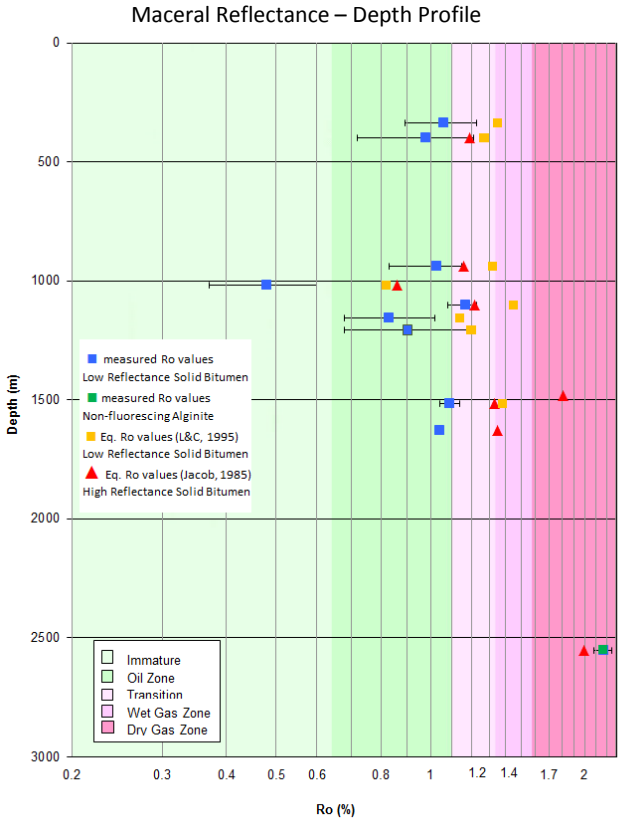


Maturity	T_{max} (°C) Type II Kerogen	T_{max} (°C) Type I Kerogen
Immature	<425	<440
Early Oil	425 – 435	440 – 442
Peak Oil	435 – 445	442 – 446
Late Oil	445 – 450	446 – 450
Condensate/Wet Gas	450 - 470	450 - 470
Dry Gas	>470	>470

- Published maturity depth profile for Beetaloo Sub-basin constructed from Tmax data (Law et al., 2010) indicates the depth range of 350 to 1500 m corresponds with the main oil window
- Tmax data from current study cover larger depth range from near surface to ~2500 m and show a similar maturity depth trend within the Roper Group source rocks
- Oil window may extend to surface
- Samples with very low S2 yields (grey symbols on insert plot) clearly fall off of the proposed maturity depth trend

Insert mage from: Law, B. E., Ahlbrandt, T. and Hoyer, D., 2010, Source and reservoir rock attributes of Mesoproterozoic shale, Beetaloo Basin, Northern Territory, Australia. Search and Discovery Article #110130 (14 June 2010).

THERMAL MATURITY



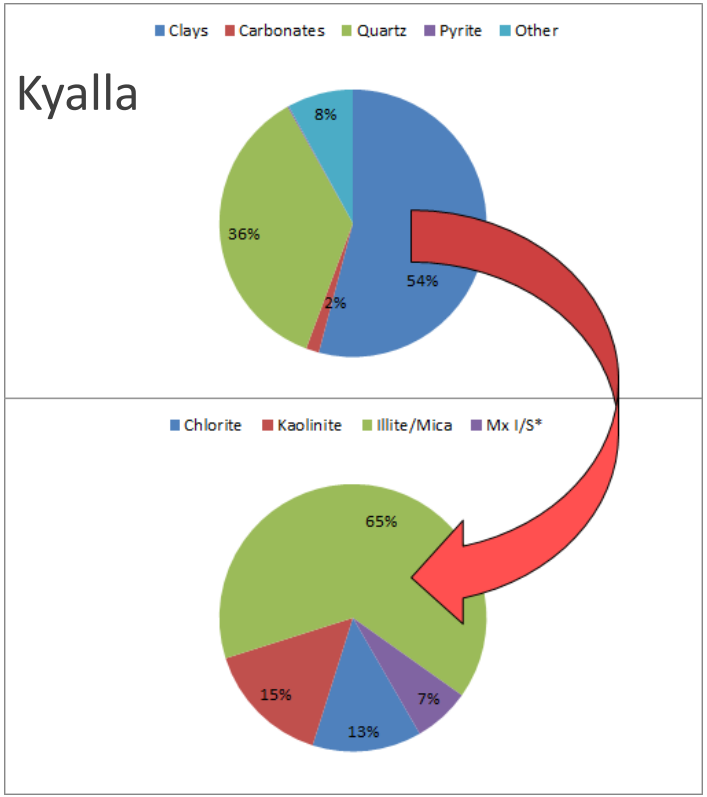
Maturity	%R_o
Immature	< 0.50
Early Oil	0.50 – 0.65
Peak Oil	0.65 – 0.90
Late Oil	0.90 – 1.1
Condensate/Wet Gas	1.1 – 1.4
Dry Gas	>1.4

- Measured maceral reflectance (% R_o) analyses were conducted on Roper Group samples from eight wells
- Macerals identified as either fluorescing alginite, non-fluorescing alginite, low reflectance solid bitumen or high reflectance solid bitumens
- Low reflectance solid bitumen and non-fluorescing alginite average from 0.48 to 2.18% R_o and are considered the most representative indigenous kerogen population for thermal maturity assessment
- The organic petrology data collected in the current investigation is considered insufficient to fully constrain a thermal maturity depth profile
- Error bars associated with min/max reflectance readings show a high degree of anisotropy in these Mesoproterozoic solid bitumens

MINERALOGY

Formation	Clays	Carbonates	Quartz	K-spar	Other	Mixed I/S*	TOC	Brittleness Index
Kyalla	54	2	36	6	2	4	1.15	41

*ordered interstratified mixed-layer illite/smectite



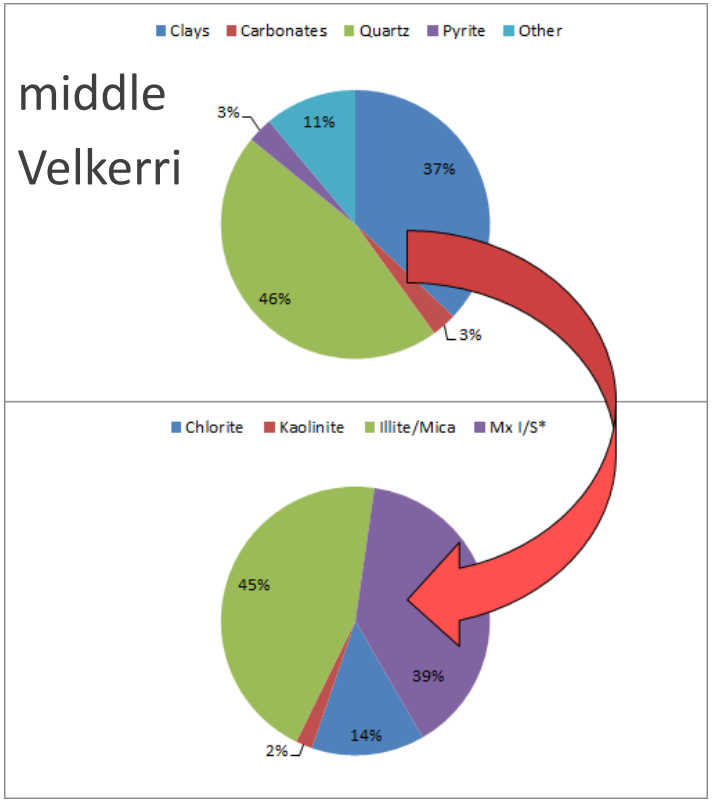
- XRD data in the Kyalla Formation shows that clays are the most abundant minerals present and total clay content averages 54%
  - This is a potential risk factor for fracture stimulation
- Clay types found are dominated by illite/mica and quartz is the dominant non-clay species
- Clays contain only minor amounts of mixed-layer illite/smectite (avg. 4% and comprising 7% of total clays)
  - Successful shale plays tend to have < 10% total mixed-layer illite/smectite
- The range of Brittleness Index (BI) values vary from 23–69 and average 41, with higher values supposedly indicating more brittle rock

$$BI = \frac{1.3(Qtz) + (Kspar) + (Plag) + 1.2(Carb)}{Numerator + 2(Mixed) + 1.5(Chlor + Kaol + Ill) + (Pyr) + (Apa) + (Bar)}$$

MINERALOGY

Formation	Clays	Carbonates	Quartz	K-spar	Other	Mixed I/S*	TOC	Brittleness Index
middle Velkerri	37	3	46	2	12	15	3.96	52

*ordered interstratified mixed-layer illite/smectite

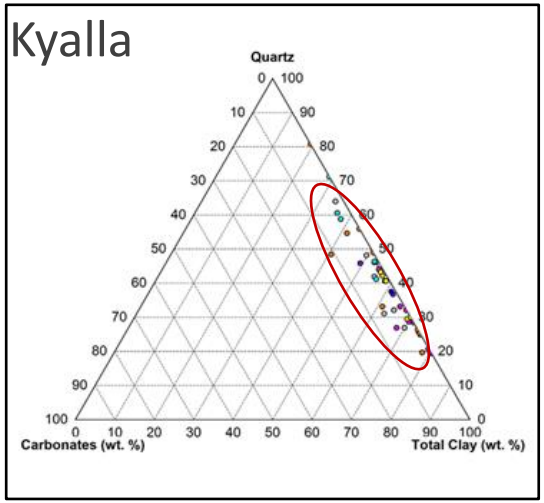


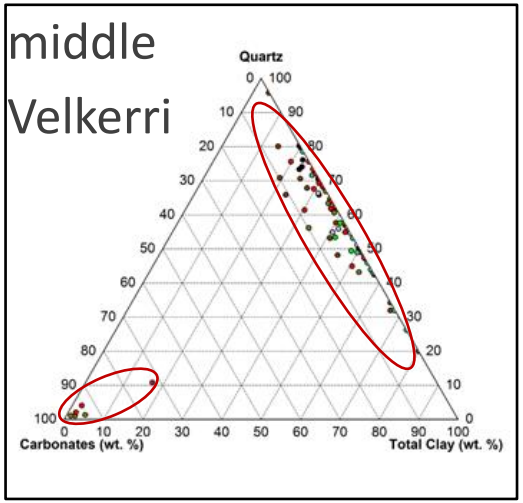
- XRD data in the middle Velkerri Formation shows that quartz is the most abundant mineral present and total clay content averages 37%
  - This is a encouraging for fracture stimulation
- Clay types found are dominated by illite/mica
- Clays contain significant amounts of mixed-layer illite/smectite (avg. 15% and comprising 39% of total clays)
  - Successful shale plays tend to have < 10% total mixed-layer illite/smectite
- The range of Brittleness Index (BI) values vary from 24−76 and average 52, with higher values supposedly indicating more brittle rock

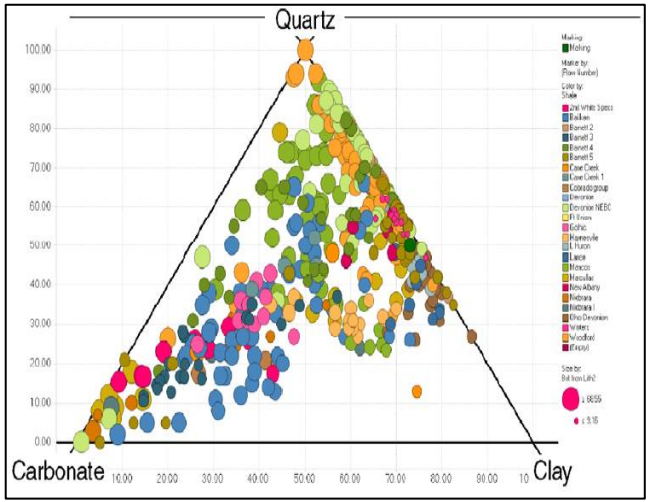
$$BI = \frac{1.3(Qtz) + (Kspar) + (Plag) + 1.2(Carb)}{Numerator + 2(Mixed) + 1.5(Chlor + Kaol + Ill) + (Pyr) + (Apa) + (Bar)}$$

MINERALOGY

- Kyalla has high clay content and is outside region of most shale plays
- middle Velkerri has higher quartz and some carbonate-rich samples







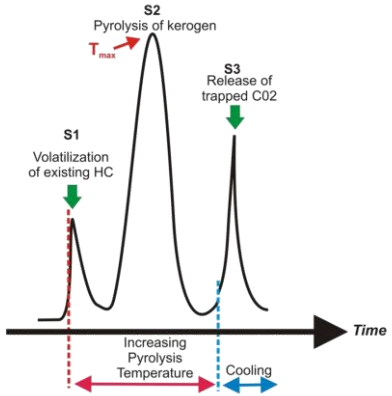
Comparison of XRD mineralogy of Kyalla & middle Velkerri and North American Shale Plays

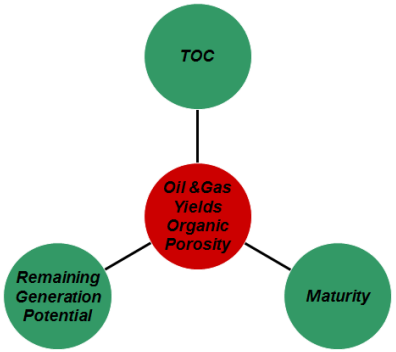
Image from: Rickman, R., Mullen, M., Petre, E., Grieser, B., and Kundert, D., 2008, A practical use of shale petrophysics for stimulation design optimization: all shale plays are not closed of the Barnett Shale, SPE 115258, 11 p.

RESOURCE ASSESSMENTS

- Laboratory measurements allow determination of original Oil in Place (OIP) and Gas in Place (GIP) by multiple independent methods

1. Programmed Pyrolysis S1 yields
2. Hydrocarbon Yield calculations corrected for expulsion
3. Shale Rock Properties (SRP) analysis of core samples via Dean-Stark solvent extraction

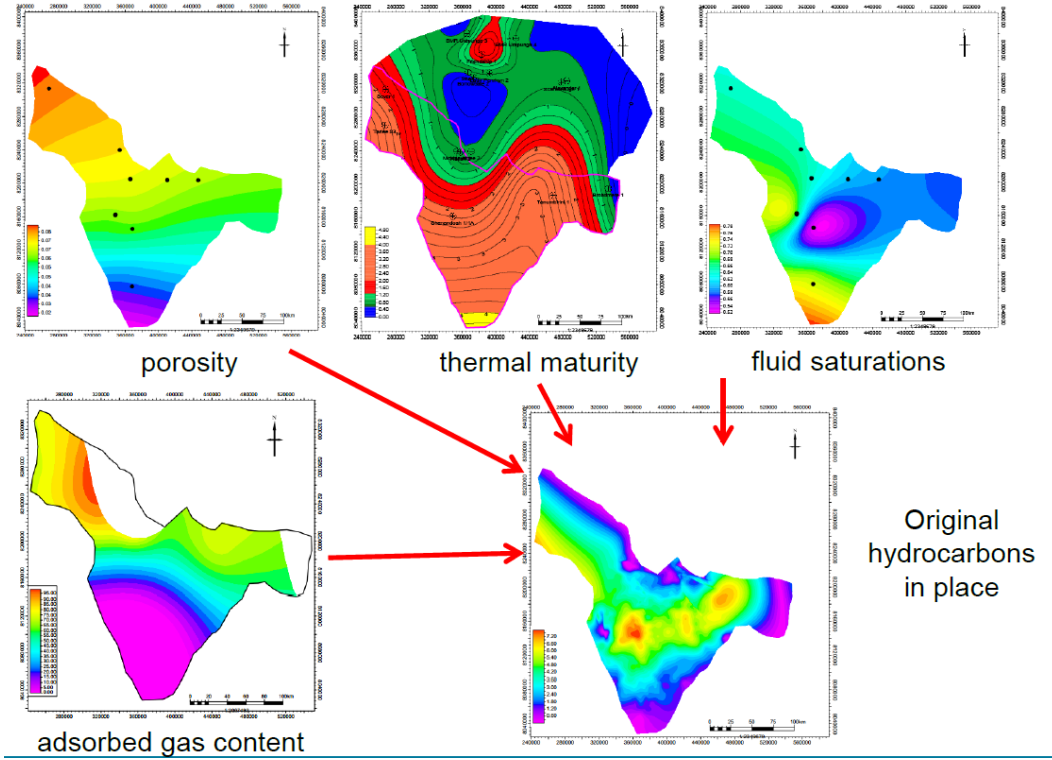




Jarvie et al. (2007) AAPG Bulletin, v. 91, no. 4, p. 497
Chen and Jian (2017) AAPG Bulletin, v. 100, no. 3, p. 405-422

RESOURCE ASSESSMENTS

- A “Map-Based Volume Calculation” approach was used to calculate original Oil in Place (OIP) and Gas in Place (GIP) for both the Kyalla and middle Velkerri intervals.
- This approach utilizes regional geology and property maps (depth structure, isopach, porosity, water saturation, adsorbed gas and net-to-gross maps) to estimate original hydrocarbons in place.



RESOURCE ASSESSMENTS

	P10	P50	P90
Kyalla Formation	**Oil (MMbbl)**		
Map Based Volumetric	1164	772	414
SRP Based Volumetric		143	
S1 Based Volumetric		94	
HC Yield Based Volumetric		293	
middle Velkerri Formation	**Oil (MMbbl)**		
Map Based Volumetric	128	96	72
SRP Based Volumetric		10	
S1 Based Volumetric		14	
HC Yield Based Volumetric		26	
middle Velkerri Formation	**Gas (TCF)**		
Map Based Volumetric	293	202	118
HC Yield Based Volumetric		752	

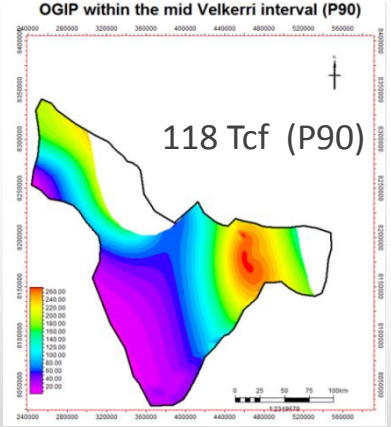
- Australia consumed 1.3 TCF in 2014-15
- Around 13.5 TCF produced from USA shale reservoirs in 2015

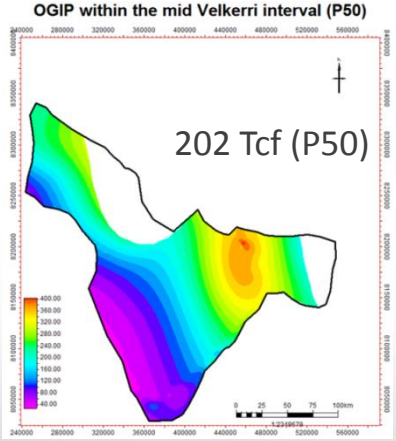
- OHIP estimates using conventional modeling were compared with estimates using SRP data, S1 data, and hydrocarbon yield calculations
- The assessment is comprehensive across the Beetaloo sub-basins and uses all available open file data across multiple tenements
- Estimates that there is a risked recoverable GIP resource in the range 118–293 TCF within the middle Velkerri Formation
- This is highly dependent on future recovery efficiencies (shale oil ≈ 4-5%, shale gas ≈15-25%)
- The P10–P90 forecasts will change with time, as forecasting is dependent on information beyond reservoir characterization, engineering and management

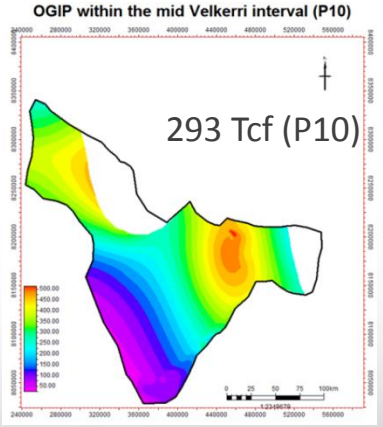
RESOURCE ASSESSMENT

Formation	Basin Area (m^2)	GIP (Tcf)
Marcellus	160000	225-248
Antrim	122000	35-76
New Albany	53000	86-160
Barnett	4200	3-30
Lewis	1100	96.8
middle Velkerri	11914	118-293

Comparison of Gas in Place values between middle Velkerri and North American Shale Plays







North America data from: Jarvie, D. M., 2012, Shale resource systems for oil and gas: Part 1 – shale-gas resource systems, in Breyer, J.A., ed., Shale reservoirs—giant resources for the 21st century: AAPG Memoir 97, CD-ROM Material, p. 69-87.

UNCERTAINTY AND RISKS

- Some samples were analyzed from old drill core that was not preserved
  - Change of the fluid saturations compared with the in-situ state
- The map-based volumetric is limited due to lack of data for such a large region
  - When more data become available model output can become more refined
- Rock properties measured in limited core data were used to generate maps
  - Possible inaccurate and biased results, especially where the cores were preferentially targeted for the best rock types
- Individual facies (eg. middle Velkerri) were grouped into one volume
  - Homogeneity assumed for heterogeneous source rocks
- Hydrocarbon yield calculations assumed 37% retention efficiency
  - Based on Barnett Shale so may not be applicable to Mesoproterozoic source rocks
  - Carbon mass balance calculations are a less constrained figure and are likely to be overestimations

SUMMARY

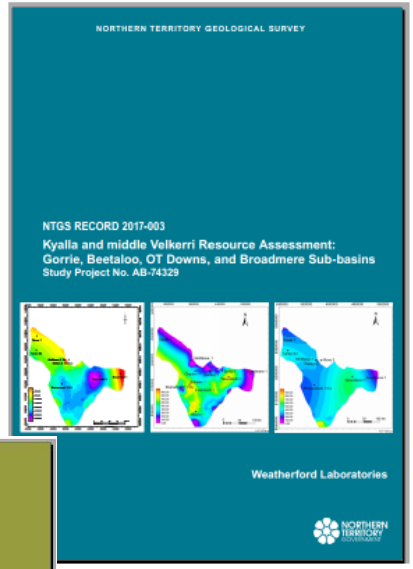
- Kyalla and middle Velkerri Formations are the most prospective and lowest-risk Roper Group targets within the Beetaloo Sub-basin region
- Kyalla Formation is in the early to late oil window and contains ‘fair’ to ‘very-good’ geochemical parameters as a productive source rock. The formation is assessed as generally having a moderate to high shale oil production risk and has high clay content. It was originally composed of oil-prone Type II marine kerogen, although oxidized Type IV kerogen dominates in some samples.
- The Velkerri Formation is comprised of three lithofacies (upper, middle and lower), with the middle being the most prospective containing organic-rich facies with ‘very-good’ to ‘excellent’ geochemical parameters and mineralogical composition. The middle Velkerri Formation was originally composed of oil-prone Type I and Type II marine kerogen, which has thermally matured and undergone petroleum generation and expulsion. The middle Velkerri Formation is within the dry-gas window in the deeper sub-basin regions and in the oil window along the basin margins.

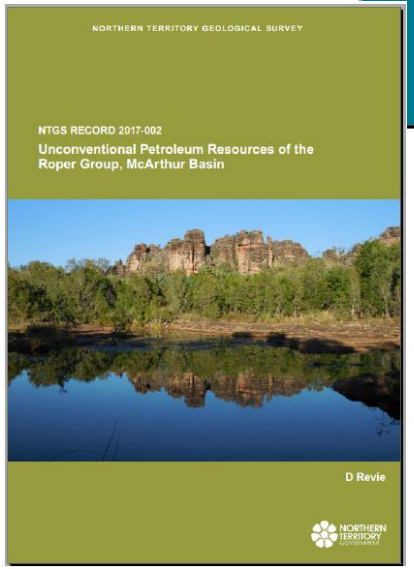
SUMMARY

- The Beetaloo Sub-basin region has an enormous shale gas resource equivalent to 50% of Australia's total estimated shale gas potential
- Resource assessments using multiple data sets and various methods have produced Gas in Place estimates in the range of 118–293 Tcf
- This resource is still in appraisal and the estimates will change with increases in knowledge and release of closed file data sets
- Coincident with this study, the Northern Territory Government has recently (April 2018) determined that hydraulic fracturing of onshore unconventional shale gas reservoirs may proceed under very strict conditions and in tightly prescribed areas
- Drilling is set to resume in 2019

QUESTIONS?

- **The complete dataset of results is available in NTGS Digital Information Package 014**
- **Interpretation report is available now as NTGS Record 2017-002**





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