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Subject: Report to NT Hydraulic Fracturing Taskforce
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Attachments: [image001.gif](#)
[Proterozoic Shale Gas-McArthur Basin Central Trough.pdf](#)

The Hon. Justice Rachel Pepper
Chair for the Hydraulic Fracturing Taskforce
Northern Territory

Dear Madam

Following a review of the recently released 'Interim Report' as part of the 'Scientific Inquiry into Hydraulic Fracturing in the Northern Territory' we have found the Interim Report has a heavy bias towards the Beetaloo sub-basin. We do not understand this focus as the McArthur sub-basin, and in particular the McArthur Basin Central Trough ("MBCT"), consisting of the Batten Fault Zone and Walker Trough have been subject to extensive research programs going back to the 1980's.

To provide the opportunity for the Hydraulic Fracturing Taskforce to take a more balance approach, Imperial has provided a detailed background and research (including drilling results) analysis of the MBCT. On review of all available research, it is clear that the MBCT has the required characteristics to potentially be the key petroleum province in the NT.

In support of this claim, the attached report provides these key characteristics, commencing from the creation of the MBCT (1.64 billion years ago) through to the rationale and support for its current day petroleum prospectivity.

We hope the report is useful and look forward to further comments and participation.

Kind Regards



Bruce McLeod
Executive Chairman & CEO
Empire Energy Group Limited



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The McArthur Basin Central Trough in Australia's Northern Territory

*An exceptional Petroleum Prospective Shale Development
Opportunity to benefit the Northern Territory*

Imperial Oil & Gas P/L

August 2017



**Why the McArthur Basin Central Trough should be
the first shale petroleum development in the
Northern Territory**



PURPOSE OF THIS REPORT

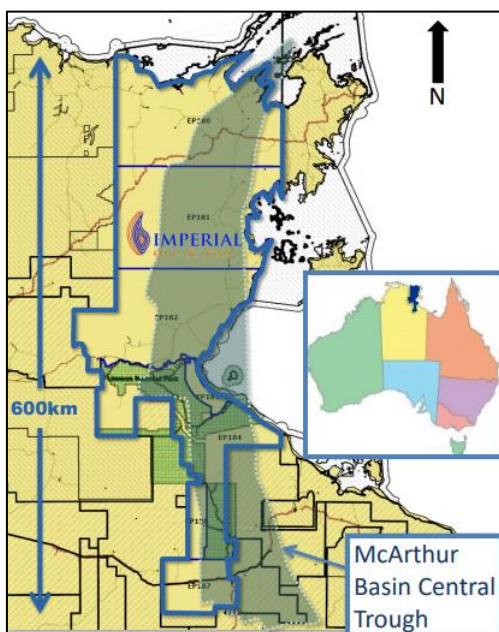
Following the release of the 'Interim Report' in July 2017 as part of the 'Scientific Inquiry into Hydraulic Fracturing in the Northern Territory', Imperial Oil & Gas Pty Ltd (a 100% owned subsidiary of Empire Energy Group Limited, both referred to in this Report as "Imperial") wishes to provide the Committee additional material highlighting the significant hydrocarbon potential of the McArthur sub-basin, with a specific focus on the potentially, petroleum prolific, **McArthur Basin Central Trough ("MBCT")**.

The report calls upon the extensive quantity of research work covering the MBCT, undertaken by many parties, over the past 40 or so years.

SUMMARY

The focus of the report is specifically on the considerable, yet underexplored, hydrocarbon potential of the MBCT. The MBCT is the extensive sedimentary trough of the Greater McArthur Basin (see dark grey area in map below). The work undertaken by Imperial and others clearly demonstrates that the MBCT is an ideal petroleum producing region within the Northern Territory.

Since Imperial's involvement in the MBCT from 2011, many of the regions Traditional Owners have expressed strong support to expedite the MBCT evaluation in order to recognise potential economic benefits. Amongst the benefits that would accrue to local indigenous communities would include royalties, job creation and economic stimulation. In addition, a portion of the benefits accruing to the Northern Territory would also flow back in many forms to the local indigenous communities.



The MBCT has many factors that emphasise the region's petroleum potential. Listed below is a summary of the key concepts supporting the MBCT as a potential world class petroleum basin:

- (1) The MBCT is one of the few global petroliferous basins to have **retained its integrity** since its formation. When the Australian Plate separated from its neighbours during the breakup of the ancient Pangaea supercontinent billions of years ago, its particular drift direction allowed it to avoid collisions with the other plates. As a result, the MBCT was

neither buried nor significantly fractured allowing the hydrocarbons to be preserved in-place and at ideal depths for petroleum development.

- (2) As a **structural basin**, the MBCT was geographically ideal for hydrocarbon development as its structure allowed the Paleoproterozoic ocean waters to become isolated when ocean levels receded. The oxygen levels of these ocean waters were low in their deepest areas. As a result, sediments, such as silts and prolific organic microorganisms, were repeatedly deposited forming layer-upon-layer of rich preserved organic carbon (the precursor to hydrocarbons).
- (3) The MBCT has a series of **impervious shale protective barriers** that have successfully sealed in the hydrocarbons ensuring little migration.
- (4) **Extensive 3D mapping** of the MBCT's formations strongly supports the region's hydrocarbon potential. Evidence suggests optimum hydrocarbon potential will be found in the Batten Fault Zone (in the South of the MBCT) and the Walker Trough (in the North of the MBCT).
- (5) The **stratigraphic hierarchy** of the MBCT region comprises multiple stacked prospective shale layers or formations. These key petroleum-bearing formations consist of the Roper Group (*Velkerri* Shale Formation) overlying the McArthur Group (*Barney Creek* Shale Formation) overlying the newly discovered, yet highly prospective, Tawallah Group (*Wollogorang* and *McDermott* Shale Formations). Since they are stacked the petroleum targets can be commercialised subject to quality and hydrocarbon content. These stacked formations allow a maximisation of economic benefits and hydrocarbon production while minimizing the surface environmental footprint.
- (6) The **hydrogeological setting** of the MBCT appears unique compared to other basins in the Northern Territory. Exploration drilling to date has not resulted in aquifer intersection which supports hydrogeology research that the majority of the potential aquifers within the MBCT are either discontinuous, local, shallow (less than 100 metres) or no longer connected to recharge points.

MBCT highlights

- Proven oil and gas petroleum system
- Paleo-Proterozoic geology ~1.6 million years old
- Total MBCT area ~70,000km²
- Imperial's tenements cover ~80% of the MBCT
- Major shale groups in the MBCT consist of the (youngest to oldest):
 - o Velkerri & Kyalla Shale Formations
 - o Barney Creek Shale Formation
 - o McDermott & Wollogorang Shale Formations
- Shale formations +1.5km thick
- Gas compositions from proximal wells consist of:
 - o C1 77%, C2 11%, C3 11%, C4 0.6%, C5 0.2%,
 - o CO₂ <1%
 - o Strong liquids potential
- MBCT mostly covered by Australian Aboriginal owned land (ALRA)

ESTIMATED RESOURCES

Put simply, estimated petroleum resources for the MBCT are expected to be extensive. Based on existing information and 3D modelling of the MBCT, in 2015 (updated 2017) an independent Prospective Resource Estimation¹ for only a portion of the MBCT was completed. On a conservative basis, the Recoverable P10 Prospective Resource (Unrisked) was calculated to be ~25 Tcfe over ~25,000km². This estimate is considered conservative for two reasons: (i) it was based on shale thickness to a maximum of 150 metres (in some areas shale thickness is expected to be 2,000+ metres), and (ii) the location's hydrocarbons were discounted by 75% due to variation in rock quality and lack of data. In addition, Imperial's tenements in the Beetaloo Basin (~2,500km²) have an Estimated Recoverable P10 Prospective Resource (Unrisked) of ~3.5 Tcfe.

Thus, the MBCT, even when using conservative estimates, is a highly prospective region of the Northern Territory for hydrocarbon development.

IMPERIAL BACKGROUND

After securing extensive shale land positions in the North-East of the United States from 2006, Imperial directed its attention to the production potential of shale basins in the Asian Pacific. Consequently, Imperial became one of the first companies to identify the potential of live shale systems in the Northern Territory (securing exploration tenements in 2010). Imperial's activity in the Northern Territory sits alongside its operational experience in the United States (2,200 oil and gas wells).

Since obtaining exploration tenements in the Northern Territory, Imperial has worked closely with the Northern Land Council ("NLC") and Traditional Owners to facilitate an understanding of the impacts that hydrocarbon exploration and production development (both conventional and unconventional) can have on the Indigenous Australian population and the environment of the Northern Territory.

To date, in conjunction with the NLC and anthropologists, Imperial has conducted 25 on-country meetings with Traditional Owners across its tenements. At these meetings, Imperial has used practical models and clear presentations to describe in detail the design of wells, their construction, the use of water, and the potential impact on aquifers.

Imperial prides itself on the close relations it has developed with the local Australian Indigenous communities. As a result, communities have authorised Imperial to operate in significant areas. For example, in 2015 Imperial entered one of the first ARLA Petroleum Exploration Deeds (EP 187) granted by the NLC.

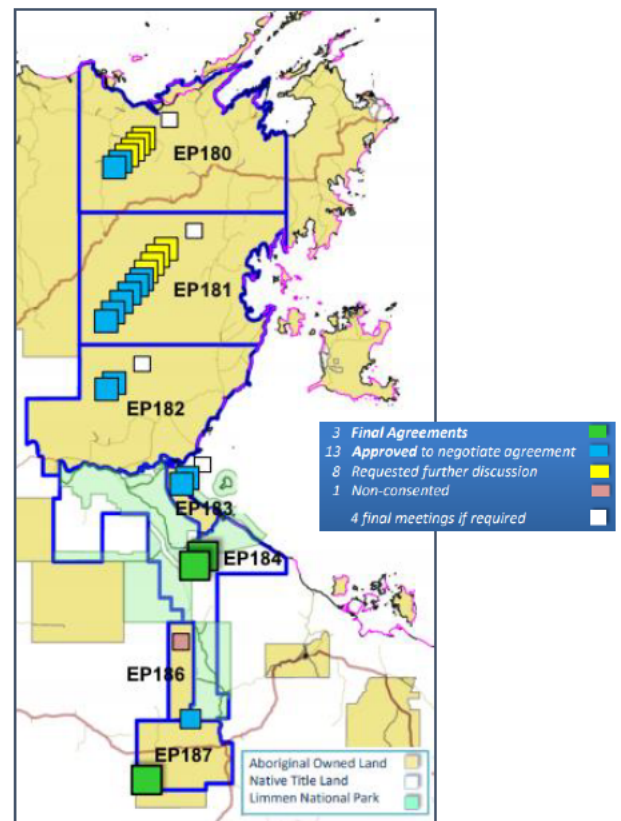


IMPERIAL'S HOLDINGS

Imperial holds a 100% working interest in:

- **EP187** – this tenement overlaps the Beetaloo Sub-Basin. This was the first ALRA Petroleum Exploration Deed granted by the NLC.
- **EP184** – this tenement makes up the central portion of the depositional area of the MBCT's Batten Fault Zone. It contains the proven hydrocarbon system of the *Barney Creek Shale Formation* and the prospective *Wollogorang and McDermott Shale Formations*.
- **EP(A) 180, 181, 182 & 183** – these deeds are in final stages of negotiation.

See map below for more information on Imperial's holdings:



¹ Muir, W, and D Barringer. *Resource Estimation – McArthur Basin Permits, Imperial Oil & Gas Pty Ltd. Muir and Associates Pty Ltd And Fluid Energy Consultants, 2015, pp. 1-40.*

In early 2015, Imperial commenced work with American Energy Partners LP (“AEP”), based in Oklahoma, USA. AEP was considered one of the world’s most experienced shale development group with key management personnel previously from the Chesapeake Energy Corp, which was the largest USA producer of natural gas.. After 12 months of geological review and negotiation, Imperial and AEP entered into a US\$75 million agreement to commence the development of the MBCT. AEP considered the MBCT to be the most prospective, yet underexplored shale basin it had identified anywhere outside the US. The joint venture was prematurely terminated after the untimely passing of AEP’s founder in early 2016.

THE POTENTIAL OF THE MBCT

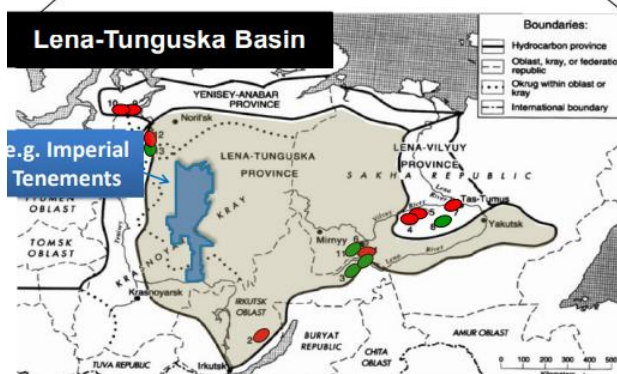
Comparing the MBCT to similar basins overseas

The potential of the MBCT can be seen when comparing it to already-producing Proterozoic petroleum basins around the world, including the following:

- Lena–Tunguska Basin, Siberia, Russia, and
- Russian Volga–Ural region, and
- Middle-Eastern, South Oman petroleum fields.

The MBCT is similar to these regions for two reasons; (i) petroleum generation, migration, and trapping were late in their geological histories; and (ii) the hydrocarbon accumulations were preserved beneath highly effective super-seals (e.g. Lena–Tunguska).

These similarities suggest that the MBCT region has; (i) a similar petroleum production capability; and (ii) a hydrocarbon system that has experienced an undisturbed geological history and the effective sealing of the entrapped hydrocarbons. [See the following map of the Lena-Tunguska Basin, Russia:]



Similar production capability to other basins

The MBCT has many similarities with the highly productive Lena-Tunguska Basin. Similarities with the MBCT are important because the Lena-Tunguska Basin has yielded over 30 conventional hydrocarbon discoveries containing a total proven 80 billion barrels of oil and 477 Tcf of gas (with the largest find hosting 200 million barrels of oil and 11 Tcf of gas). In the Lena-Tunguska Basin, the unconventional hydrocarbons are trapped in high quality Upper Proterozoic carbonate and clastic reservoirs primarily at the basin margins, while the conventional petroleum has migrated out of mature and highly carbonaceous source rocks in the basin centre.

These basin centre source rocks are direct analogues to those in the MBCT. However, unlike the Lena-Tunguska Basin, there are no high quality conventional basin margin reservoirs in the MBCT through which hydrocarbons can escape. Accordingly, all petroleum in the MBCT has remained trapped in the shales.

There are other similar Proterozoic petroleum basins in addition to the Lena-Tunguska Basin that can be examined to determine the hydrocarbon potential of the MBCT. The Sichuan and Tarim Basins, which are located in China, hold proven resources of 18 billion barrels of oil and 9 Tcf of gas. In the Oman Basin, located in the Middle East, there are proven resources of 5.5 billion barrels of oil and 30 Tcf of gas. The geological conditions of these Proterozoic basins and the highly prospective oil and gas shale source rocks are similar to those of the MBCT. Because of the close similarities, there is a genuinely high expectation of economically significant finds within the MBCT.

Lena–Tunguska Basin, Siberia, Russia highlights

- Paleoproterozoic petroleum basin ~1.6 billion years old
- Conventional dolomite reservoirs
- 30 hydrocarbon discoveries
- Largest field 2P ~260 million barrels of oil & 11 Tcf of gas
- Proven 80 billion barrels of oil & 477 Tcf of gas
- Oil & Gas Shales
 - o Black, bituminous, limy, silty, carbonaceous
 - o Average TOC = 0.2%, locally 5-10%

Effective sealing compared to other basins

The top-seal of the petroleum systems in the Lena-Tunguska Basin is the Lower Cambrian salt. Although salt is an excellent top seal for conventional petroleum, it is not as important for the sealing of hydrocarbons in some geological environments, such as the MBCT shales.

Due to over-pressure gradients and multiple layers of formations acting as seals along with little fracturing within the MBCT, the hydrocarbons in large volumes have become trapped within the host shales, which due to their low porosity and permeability allow little hydrocarbon migration.

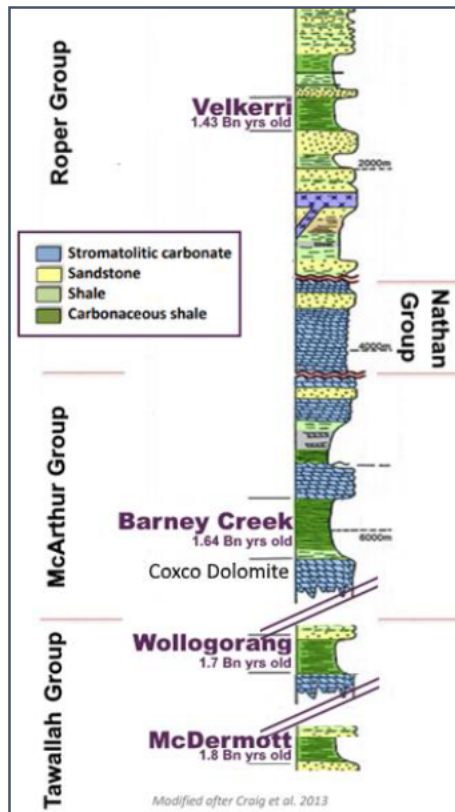
Accordingly, the presence of hydrocarbons trapped in the shales of the MBCT provides for very attractive petroleum exploration and eventual development.

EVIDENCE FOR A PROSPECTIVE PETROLEUM RESOURCE IN THE MBCT

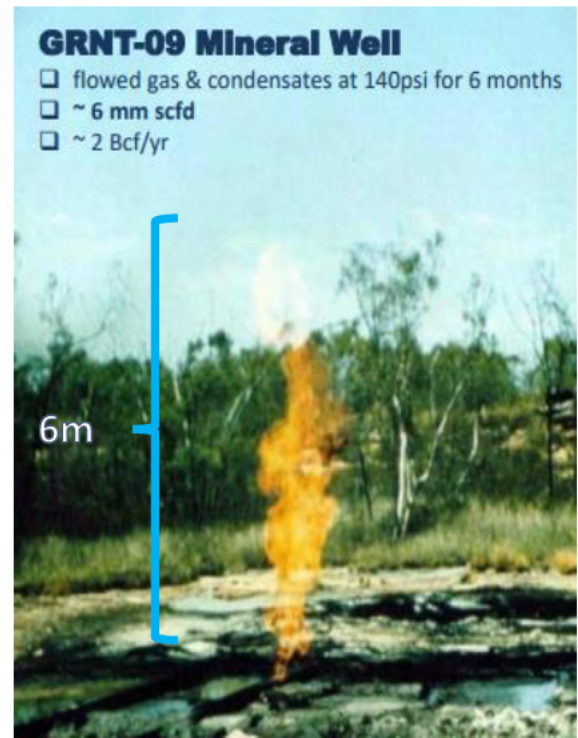
Drilling evidence

The petroleum potential of the MBCT is supported by in-depth analysis of the region, including; outcrop mapping, field results, and drilling. This analysis has added to the understanding of local reservoir, source, and seal relationships of the MBCT (for example, and described later, the widespread presence of Precambrian stromatolitic carbonate units of potential conventional reservoir facies).

The elements that constitute an attractive potential hydrocarbon producing region are all present in the stylised stratigraphic column for the MBCT (see below).

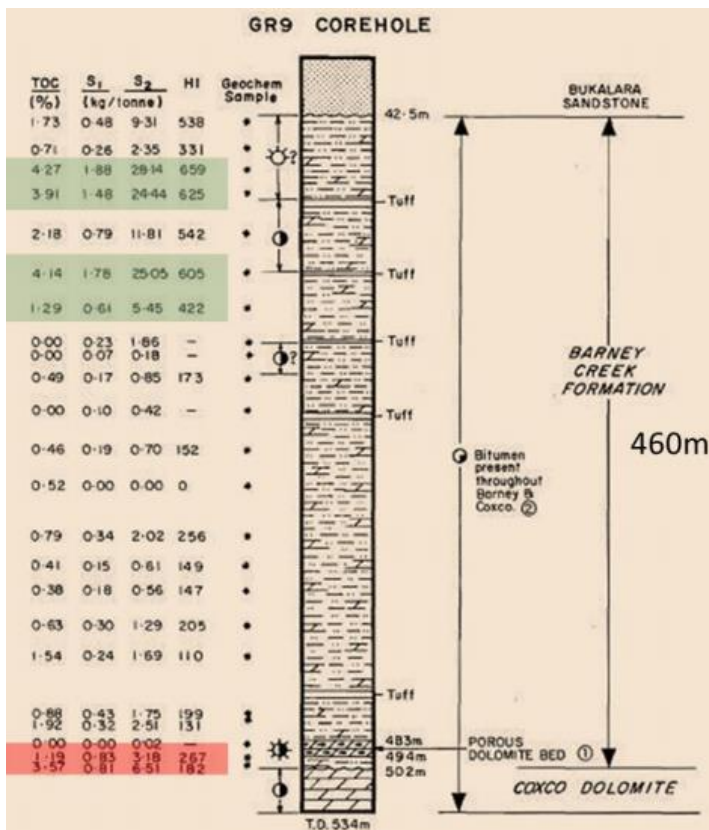


Drilling evidence clearly demonstrates the petroleum potential of the MBCT. An example of this is GRNT-09, one of the most successful producing wells in the MBCT, which flowed as a result of a drilling accident. Drilled in 1979 in the search for minerals, GRNT-09 accidentally blew-out and ignited. The mineral layers of interest were contained within the Barney Creek Shale Formation. At the time, the petroleum potential of the Barney Creek Shale Formation had not been acknowledged. An accurate measurement of gas flow was not recorded, but estimates have been made based on the colour, height, and duration of the flare for the period the well burned.



GRNT-09 sustained a 6 metre high yellow smoky gas flare for 6 months (image above). The yellow/orange smoky flame suggests petroleum liquids associated with the gas. An estimated 0.5 Bcf of gas was produced at a rate of 6mmscf/d from 1.64 billion-year-old Paleoproterozoic organic-rich black shales of the Barney Creek Shale Formation. The well continued flaring until the wet season at which time the well bore was flooded and down hole pressure was insufficient for gas to escape through the water column. Gas comprising C1 to C7 continued to bubble through the well for many months. Data, such as logs, core, and gas composition of GRNT-09, is available (see below).





“hydrocarbon yields from mature samples indicate that good to excellent source rocks are present” in these formations.⁴

The petroleum potential of the MBCT, as laid out in Crick et al. (1988), has also been supported extensively by other research. Munson (2014) in relation to the MBCT...“Marginally mature organic-rich sediments may have up to 10.4% TOC contents. The Barney Creek Formation is marginally mature to over-mature for hydrocarbon generation in proximity to the fault zones, with areas away from fault zones being less mature.”⁵

Field evidence and drilling results have further supported these significant TOC levels and justify the exploration for petroleum in the MBCT.

Research undertaken by Imperial

In 2011, Imperial entered into an agreement with the University of Adelaide Shale Research Group to undertake a research program to evaluate the ‘Geologic Controls on Black Shale Deposition in the Paleo-Proterozoic of the McArthur Basin’.⁶ This study laid the foundation for the current Australian Research Council (“ARC”) linkage project ‘Tectonic Geography of the World’s Oldest Petroleum Play, the McArthur Basin’ being undertaken by the University of Wollongong in collaboration with the Northern Territory Geological Survey. The earlier study by Imperial in conjunction with the Adelaide Shale Research Group also formed the foundation for the current ARC linkage study “Proterozoic Petroleum Basin Analysis: Correlation and Tectonic Evolution of the McArthur Basin, Northern Territory” being undertaken by the University of Adelaide, the NTGS, Origin Energy and Santos.

The commonly held belief, and the recent announcement of Cox and Collins (2017), is that the Velkerri Formation (Roper Group) within the Beetaloo Sub-Basin contains the oldest proven hydrocarbons in Australia at 1.4 billion years old. However, it is clear **that this is incorrect** and that the oldest proven hydrocarbon system in Australia (perhaps even globally) is the ca. 1.64 billion-year-old Barney Creek Shale Formation in the MBCT. Furthermore, recent research by Imperial (and others) indicates that the 1.8–2.0 billion-year-old Tawallah Group may yet prove to host the oldest viable petroleum systems. For example, TOC levels in the Wollgorang Formation have been shown to be up to 7%. This suggests the MBCT has a potentially greater hydrocarbon potential than previously believed.

Extensive research going back to the 1980’s along with Imperial research commencing in 2011 clearly negates the assertion of the Interim Report that most research to date has been conducted in the Beetaloo sub-basin rather than in the MBCT.

Further evidence of the proven petroleum potential of the MBCT was provided in 2012 with the drilling of the Cow Lagoon-1 and the Glyde-1 wells. These wells produced free flowing gas from the boundary of the Barney Creek Shale Formation and the Coxco Dolomite Formation without recourse to fracture stimulation. Gas analysis from these wells also revealed C1 to C7 gas and minimal carbon dioxide providing further evidence, in addition to GRNT-09, that the Barney Creek Shale Formation is a live petroleum system.

It is evident that the Barney Creek Shale Formation and the underlying Coxco Dolomite Formation offer key petroleum targets within the MBCT.

Research confirmation

Early research into the potential of the McArthur Group Formations identified that the Barney Creek Shale Formations contained total organic carbon (“TOC”) contents upwards of 7%. Crick et al. (1988) identified that “the lacustrine Barney Creek [Shale] Formation (McArthur Group) and the marine Velkerri Formation (Roper Group) compare favourably in thickness and potential with ... demonstrated source rocks in major petroleum bearing provinces in the Phanerozoic”.² The Barney Creek Shale Formations contain “up to 7% TOC” and “Type I to Type I/II kerogen”. TOC values in the Velkerri Shale Formation range “up to 6.5% TOC with Type II kerogen”.³ Crick et al. (1988) concluded that

² Crick, I. H. et al. “Petroleum Geology and Geochemistry of Middle Proterozoic McArthur Basin, Northern Australia II: Assessment of Source Rock Potential”. *AAPG Bulletin*, vol 72, 1988, p. 6.

³ Ibid.

⁴ Ibid.

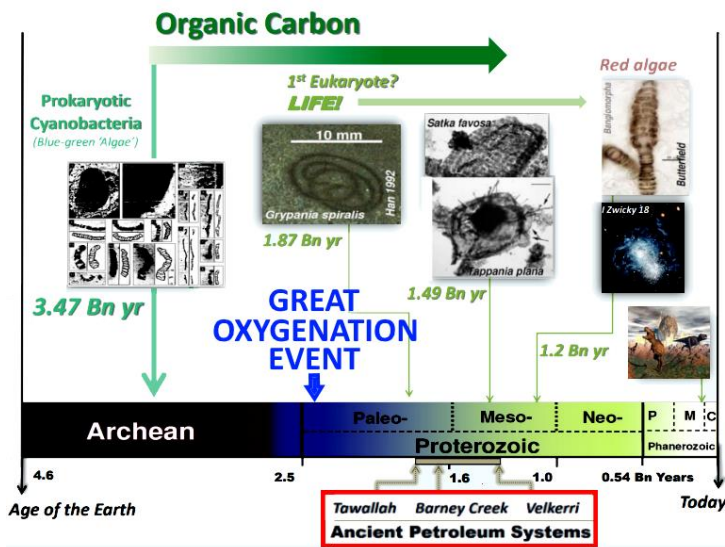
⁵ Munson, T. J., “Petroleum geology and potential of the onshore Northern Territory, 2014”, *Northern Territory Geological Survey*. Vol. 22, 2014, p. 242.

⁶ Kennedy, M., *Geologic Controls of Black Shale Deposition in the Paleo-Proterozoic of the McArthur Basin*. Australian Shale Carbon Sequestration Group, University Of Adelaide, Adelaide, 2014, pp. 1-13.

THE UNIQUENESS OF THE MBCT

Organic carbon creation

At the time the Tawallah Group and Barney Creek Shale Formation were deposited (see diagram below), the MBCT was a low-oxygen environment (anoxic) with most of the life forms being sulphur dependent. During this period, the organic carbon that later produced the hydrocarbons in the MBCT existed in the forms of algal mats that thrived in the anoxic shallow oceans. Studies undertaken by the University of Adelaide, sponsored by Imperial, confirm this.⁷ The absence of oxygen prevented the organic carbon from being oxidised and removed from the potential source rock resulting in a higher petroleum potential of the region.



Additionally, when the Tawallah Group and Barney Creek Shale Formations were deposited there was also a transition from simple cyanobacteria (blue-green photosynthetic algae) to early complex eukaryote lifeforms. Early eukaryotic organisms radiated in the Proterozoic oceans perhaps because there was a thin layer (up to 25 metres deep) of oxygenated surface water, while low-oxygen anoxic waters predominated at depth, which are required for the preservation of the crucial organic carbon.⁸ Thus, when the rich algal blooms, which proliferated in these shallow oxygenated waters fell, they were preserved in the anoxic bottom-waters of the MBCT. The vast concentration of preserved organic carbon, which resulted from the organic rich sediment that 'rained' down to the anoxic conditions below, is the reason why the MBCT shales are incredibly prospective in terms of petroleum development.⁹

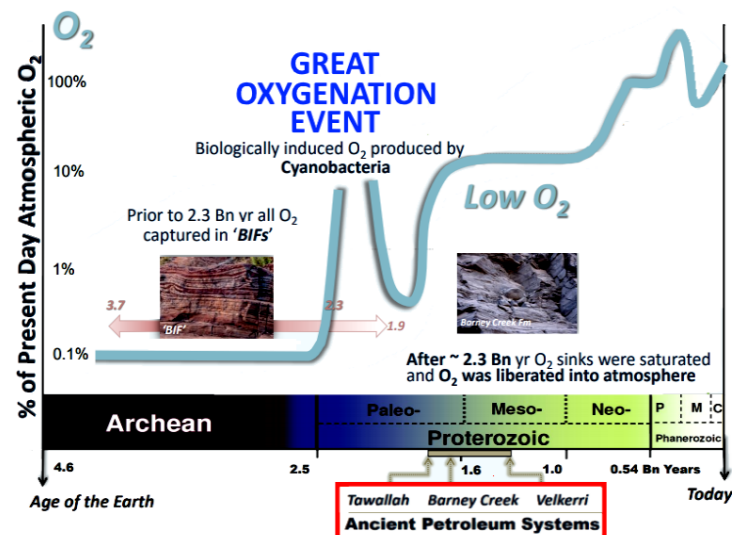
Pre-burial atmospheric conditions

The low-oxygen atmospheric conditions that prevailed during the deposition of the organic carbon precursor for the hydrocarbons generated from meso and neo Paleoproterozoic age conventional source rocks preserved the hydrocarbons before burial. It is therefore important to demonstrate that similarly low-oxygen

conditions were present when the ancient MBCT source for rock shales were deposited.

Anoxic conditions are important for organic matter preservation to prevent the reduction of the carbon by oxidation into carbon dioxide. Under anoxic conditions the complex carbon molecules are preserved, buried, and converted into hydrocarbons. It is the low water oxygen content that is important for the preservation of organic matter by precluding oxidation.

Throughout geological time there have been fluctuations in the level of oxygen in the atmosphere. The atmosphere of the earliest Earth (the Archean period) was almost certainly anoxic, containing <0.1% of the present atmospheric level ("PAL"). The evidence for this does not exclude the small oxygen oases with microbial mats near the early Earth's surface. Shortly after 2.45 billion years ago, atmospheric oxygen rose rapidly to a few percent above PAL. Due to its apparent speed, this time interval is referred to as the 'Great Oxygenation Event' (see below)



According to Sessions et al. (2009),¹⁰ the rise of atmospheric oxygen was a milestone in the history of life on Earth. At the time of the deposition of the McArthur Basin Shale Formations, from around 1.8 billion years ago, atmospheric oxygen had stabilized, (possibly in the range of ca. ~5–18% PAL) while the deep oceans and MBCT remained anoxic. This is significant as it explains why there was so much organic material available, and why it was able to be preserved in these ancient shales as a source of hydrocarbons today within the MBCT.

This lack of oxygen in the basin environment at the time of formation is what may give the MBCT its high hydrocarbon and uniquely low carbon dioxide gas content when compared to many other basins. Commercially and environmentally this is very advantageous and one of the factors that is likely to set the MBCT apart from other basins in terms of hydrocarbon production.

⁷ Ibid.

⁸ Knoll, A. H., "Paleobiological Perspectives on Early Eukaryotic Evolution." *Cold Spring Harbor Perspectives in Biology*, vol 6, no. 1, 2014.

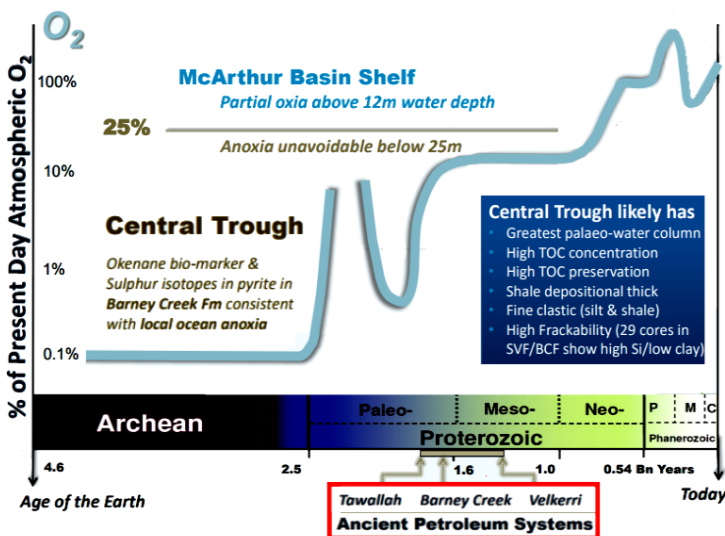
⁹ Ibid.

¹⁰ Sessions, A. L. et al., "The Continuing Puzzle of the Great Oxidation Event." *Current Biology*, vol 19, no. 14, 2009, pp. 567-574.

Post-burial preservation conditions

The distribution and preservation of organic matter in such ancient sediments is difficult to predict, but this is critical because it is the fundamental reason why a particular sedimentary basin may, or may not, be hydrocarbon productive.

According to the NTGS, during the 'Great Oxygenation Period' the production of organic carbon was prolific resulting in a sedimentary succession up to 12,000 metres thick being deposited (Pegum 1997).¹¹ These deposits were laid-down in part in the shallow water environments surrounding the prominent North-trending isolated MBCT. Quantities of live hydrocarbons have been recovered suggesting that considerable volumes of oil and gas prone shales lie within the MBCT.



Evidence comes from the 1986-to-1994 exploration program conducted by Pacific Oil and Gas Pty Ltd in the Batten Trough area (southern portion of the MBCT significantly predating the exploration by Santos and Origin in the Beetaloo). This program involved the drilling of 23 slim-hole wells, seeking conventional reservoirs. Accordingly, these wells encountered abundant organic-rich thermally immature-to-over mature source rocks showing numerous oil and gas shows. Based on the organic richness, the marine Velkerri and Barney Creek Shale Formations are considered to have the highest hydrocarbon potential of these source rocks.

To date, no drilling has targeted the deeper Tawallah Group (a basal shallow marine-to-fluvial predominantly sandstone and basic volcanic sequence) in the Greater McArthur Basin. The Tawallah Group was overlain by the McArthur and Nathan Groups (shallow water-to-intra-tidal succession of carbonates and evaporites, dolomitic siltstones, and shales), which would have preserved the vast quantities of hydrocarbons within the Tawallah Group adding to the MBCT's overall hydrocarbon potential.

¹¹ Pegum, D. M. *An Introduction to the Petroleum Geology of the Northern Territory of Australia*. Northern Territory Geological Survey, 1997.

¹² These conclusions are consistent with the work of Crick et al. (1988); and Trabucho-Alexandre et al. (2012).

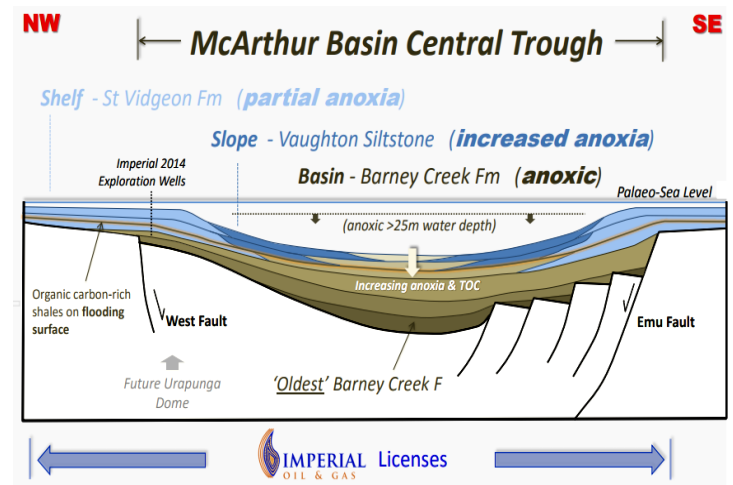
In summary, hydrocarbon preservation within the MBCT has occurred due to two factors:

- (i) the fact that the MCBT has remained largely undisturbed since its formation ~1.64 billion years ago, and
- (ii) the low oxygen content of the water column along with the concurrent anoxic conditions enhanced the probability of the necessary organic matter preservation, trapping a large portion of the organic carbon within fine grained clastic sediments which ultimately developed as shales.

THE MBCT'S ANCIENT PETROLEUM SYSTEM

It is expected that the MBCT contains several kilometres of Proterozoic petroleum prospective sediments of lacustrine and marine origin (Thomas et al., 1991). As shown by the drilling results of Pacific Oil and Gas Pty Ltd and the research conducted by Crick et al. (1988), these sediments range from thermally immature-to-over mature implying potential for petroleum liquid and gas plays

The combination of these results demonstrate that the Barney Creek Shale Formation is currently considered to be the most prospective unconventional Shale Gas plays in the Greater McArthur Basin.



The MBCT's shale depositional setting and composition

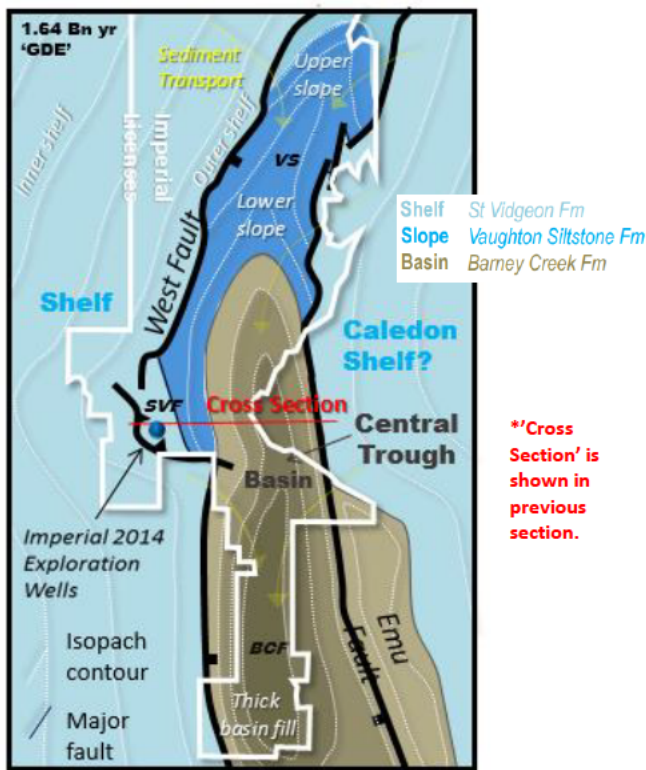
Evidence from Imperial's exploration program supports the concept that thicker carbonaceous black shale deposits are likely to be found in the deeper central trough segments of the MBCT. This is where the original organic content should have been preferentially preserved by maximum basin centre anoxia.¹²

Bitumen and hydrocarbon source rocks in the MBCT have been the subject of a number of geochemical studies.¹³ While economic

¹³ See Crick et al. (1988); Summons et al., 1988; George et al., 1994; Warren et al., 1998; and George and Ahmed, 2002.

occurrences of petroleum are only now being assessed, hydrocarbons in the basin may have been important in generating the conditions for large stratiform lead–zinc deposits, including the McArthur River zinc deposit. The role that hydrocarbons played in the formation of these ore bodies has been investigated by Logan et al. (2001) and Chen et al. (2003).¹⁴

The map below shows that the basin architecture is characterised by WNW-trending rift compartments bound by NNW-striking transfer faults during the early stages of basin evolution (ie. deposition of the Tawallah Group).



*'Cross Section' is shown in previous section.

Termination of the initial rifting stage was then followed by deposition of carbonate and evaporate dominated McArthur and Nathan Groups in a non-volcanic, sag-phase tectonic setting. This resulted in a narrow restricted fault-bounded depo-centre with the contemporaneous development of the shelf (St Vidgeon Shale Formation), slope (Vaughton Siltstone Formation) and MBCT (Barney Creek Shale Formation).

Age dating undertaken by Imperial has shown this process to be age correlative and genetically linked.

As noted previously, greatest organic carbon preservation and thickness is predicted in the restricted Barney Creek Shale Formation throughout the MBCT. However, TOC is present in shales along flooding surfaces in the shelf and so, consequently, intervening slope facies are also likely to contain significant TOC.

Further, geochemical variations between the Barney Creek Shale Formation and St. Vidgeon Shale Formation indicate some

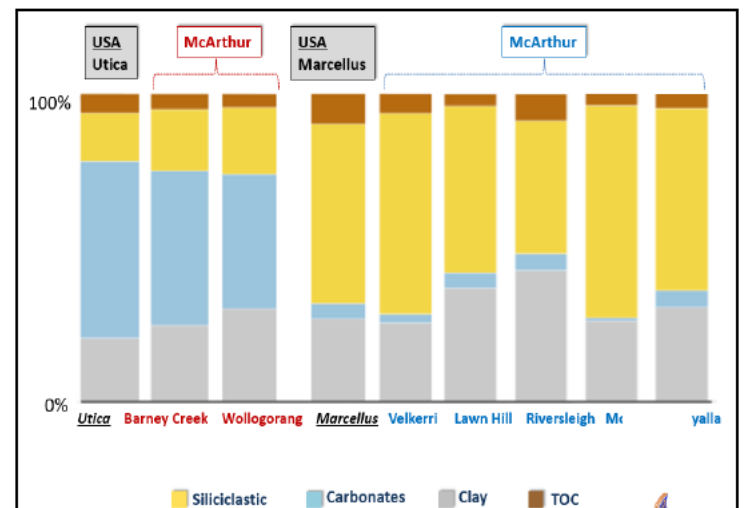
depositional compartmentalization of the Greater McArthur Basin. Imperial believes the St. Vidgeon Shale Formation was deposited in a near basin margin coastal environment characterised by shallow marine shelf environments, in contrast to the Barney Creek Shale Formation being deposited in a quiet, distal, gradually subsiding deeper water anoxic marine environment that now occupies much of the MBCT¹⁵.

Summons et al. (1988)¹⁶ carried out detailed investigations of 115 hydrocarbon extracts from source rocks in the McMinn (type II–III kerogen equivalents), Velkerri/Lansen Creek (type II), Yalco (type II), and Barney Creek Formations (type I–II). They demonstrated the chemistry of the organic matter extracted from these formations is remarkably consistent despite depositional ages spanning 250 million years and significant differences in lithology and Paleo-depositional setting.

Summons et al. (1988) demonstrated the younger levels of the Barney Creek Shale Formation are geochemically the most distinct with high abundance of isoprenoids (a distinctive group of organic compounds). The study concluded that the rapid trapping of hydrocarbons within these formations preserved the hydrocarbons in pristine and non-biodegraded form until present day. Summons et al. (1988, p.1760) also identified in their conclusion that the Barney Creek Shale Formation has the 'highest content of organic matter'.

Chemical analysis of 29 cores from the St. Vidgeon and Barney Creek Shale Formations of the MBCT indicate **high carbonate along with subordinate silica and clay contents**. The proportions of these components are very similar to the Utica Shale Formation in the Appalachian Basin, USA, (see graph below) providing an ideal shale composition for petroleum extraction.¹⁷

Studies by AEP also identified similar characteristics between the Barney Creek Shale Formation and the Utica Shale. For further detail of this study refer to Barney Creek Shale Formation versus Utica Shale, Appendix 1 and the graph below.



Source: AEP

¹⁴ Volk, Herbert et al., "Characterisation of Fluid Inclusion Oil in A Mid-Proterozoic Sandstone and Dolerite (Roper Superbasin, Australia)." *Chemical Geology*, vol 223, no. 1-3, 2005, pp. 109-135.

¹⁵ Hokin, G., *Core Sampling Report - 2014 Field Season To End-August EP184 Saint Vidgeon Shallow Core Wells*. Imperial Oil & Gas, 2014.

¹⁶ Summons, Roger E et al. "Petroleum Geology and Geochemistry of the Middle Proterozoic McArthur Basin, Northern Australia: III. Composition of Extractable Hydrocarbons." *Geochimica et Cosmochimica Acta*, vol 52, no. 7, 1988, pp. 1747-1763.

¹⁷ Hokin, G., *Geochemical characterisation and interpretation of core and outcrop samples obtained within EP184 of the McArthur Basin, NT*. Imperial Oil & Gas, 2014.

Roper River) reported that the southern portion of the MBCT could be considered a closed hydrological system except with the possibility of major faults, such as the Mallapunyah Fault, which would allow water movement from deeper aquifers, at depths below 4,600 metres, well below the level of economic extraction.

The dominant rock formations within the MBCT are Paleoproterozoic in age and are comprised of dolomite, siltstone and shales which are correspondingly considered to make poor aquifers due to their very fine grained nature and therefore low porosity and permeability. Where localised aquifers are found in these formations they are usually associated with naturally fractured rock types, mostly in zones shallower than 100 metres with bore yields less than 2 litres/second. Mostly however, aquifers in these types of rocks are either absent or occur in sparsely developed low yielding fractured rocks. Within the MBCT the only known fractured and karstic aquifer occur is in a small area of the Yalco formation where sinkholes have developed.

The contention of wider literature covering exploration drilling supports that the majority of the potential aquifers within the MBCT are either discontinuous, local, no longer connected to recharge points or have secondary mineral overgrowth which has destroyed previously existing permeability and, or porosity.

Interestingly, most of the major known aquifers within north eastern Northern Territory are not found in the MBCT. Of the potential aquifer formations identified within the Roper and McArthur Group the majority lie to the west of the Bauhinia Monocline within the Beetaloo sub basin (or to the east in proximity to and beyond the town ship of Borroloola). Further, the major aquifers of the Georgina and Daly Basins and the aquifers of the East and West Arnhem Shelf region (the Dook Creek, Tindall Limestone, Limmen Sandstone formations) also do not connect into the MBCT.

On the basis of these studies, Imperial considers that its proposed petroleum development program within the MBCT will encounter few aquifers with the exception of the shallow (above 100 metres) aquifers within the more recent Cenozoic clays and karstic fractured surface formations. Good oil field practices utilized in exploration and development programs will readily isolate these potential aquifers from exposure to risk.

ENVIRONMENTAL MANAGEMENT

As part of its development program in the MBCT, for tenements granted, Imperial:

- holds an Aboriginal Areas Protection Authority (AAPA) certificate over the granted exploration area within the MBCT. This was granted after extensive cultural and anthropological studies were conducted across the region by the NLC and AAPA anthropologists. This work was instrumental in the granting by the local Aboriginal groups of permission to explore the region and for the grant of the exploration license on ALRA land.
- has conducted an extensive study of the characteristics of the natural environment, climate, land tenure and land use within the MBCT. The studies have included aspects of existing land degradation, impact assessments of the

proposed exploration and potential future production activity. The studies have included a review of groundwater and inland drainage systems and the impacts from regional, urbanised and localised construction and operations that include land clearing for habitation and operations as well as land clearing for grazing and for the right of access ways, top soil stockpiling and trench dewatering.

- has conducted an audit of local pest species of flora and fauna and baseline studies initiated of ground water quality and land and water based flora and fauna, including rare and endangered species.
- has undertaken extensive consultation with the local Aboriginal people and other stakeholders including pastoralists to obtain permission to operate.

MOVING FORWARD

The scale and rate of petroleum development depends on many external economic considerations, such as commodity pricing, availability and cost of drilling and services, and the identification of gas markets.

Once the moratorium is lifted then full-scale development will take a number of years to achieve. Any timeline will provide for:

- undertaking prudent levels of exploration to identify sweet spots, and the discounting of un-productive ground,
- steady and progressive development of a local skilled workforce and associated infrastructure, and
- growth in a cooperative fashion with the necessary community social development thus providing long term generational secure local training, employment, and business development.

Only a portion of Imperial's McArthur Basin tenements have been formally granted and made available for exploration by the relevant Traditional Owners. Nevertheless, there is a tangible willingness amongst all groups across the region for development and job creation that is sensitive to the cultural heritage and the environment.

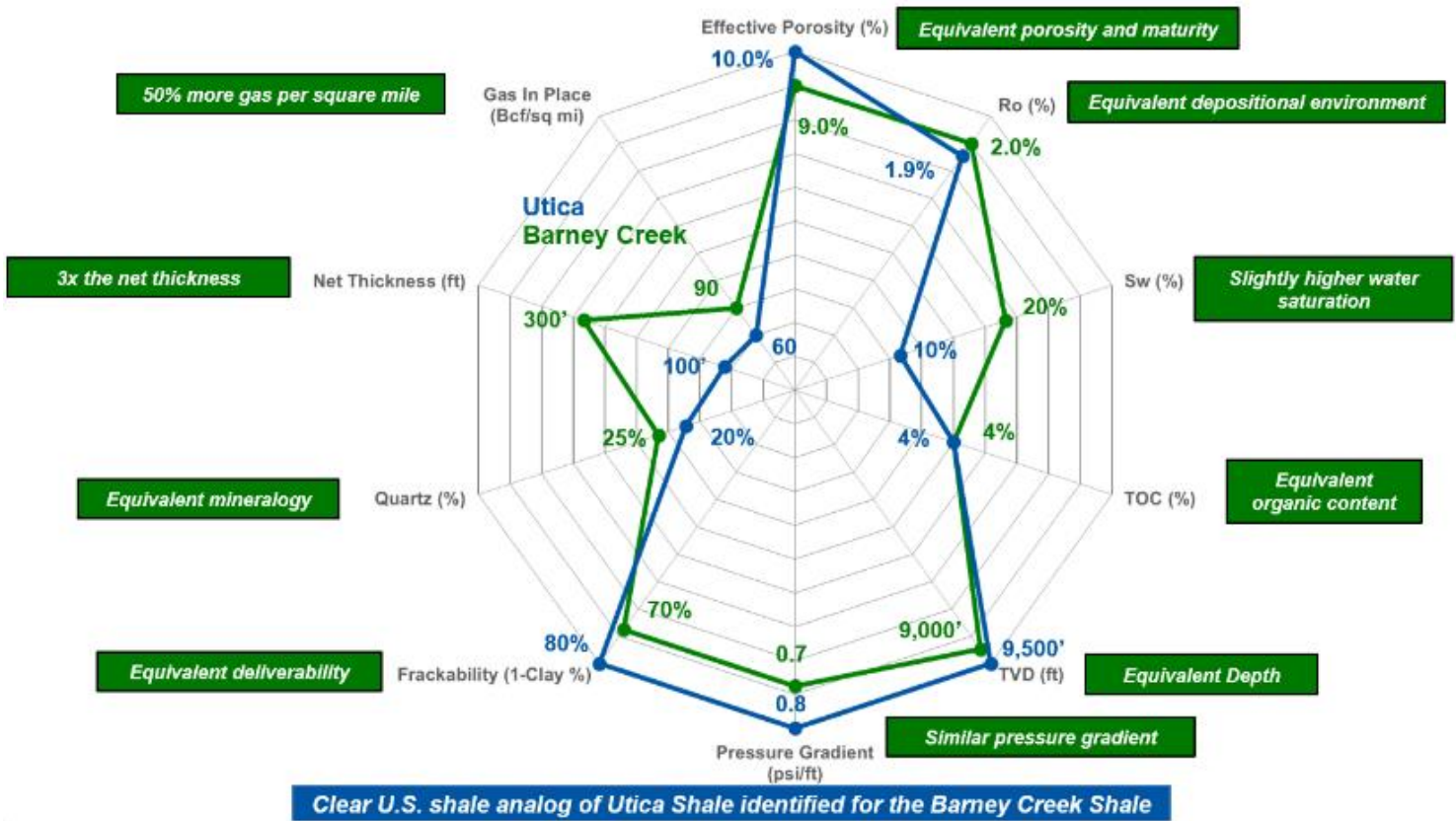
Imperial's unwavering vision for development of the region is built on these foundations.

Further, Imperial's region of operation have no pastoral stations or agriculture and few permanent communities. Imperial can draw on a workforce from surrounding communities of Ngukurr, Numbulwar, Hodgson Downs, and Borroloola and other Territory communities while providing opportunities for training and infrastructure development, and business development to the benefit of the Northern Territory, the indigenous peoples and Australia without adversely impacting the environmental, social and community values.

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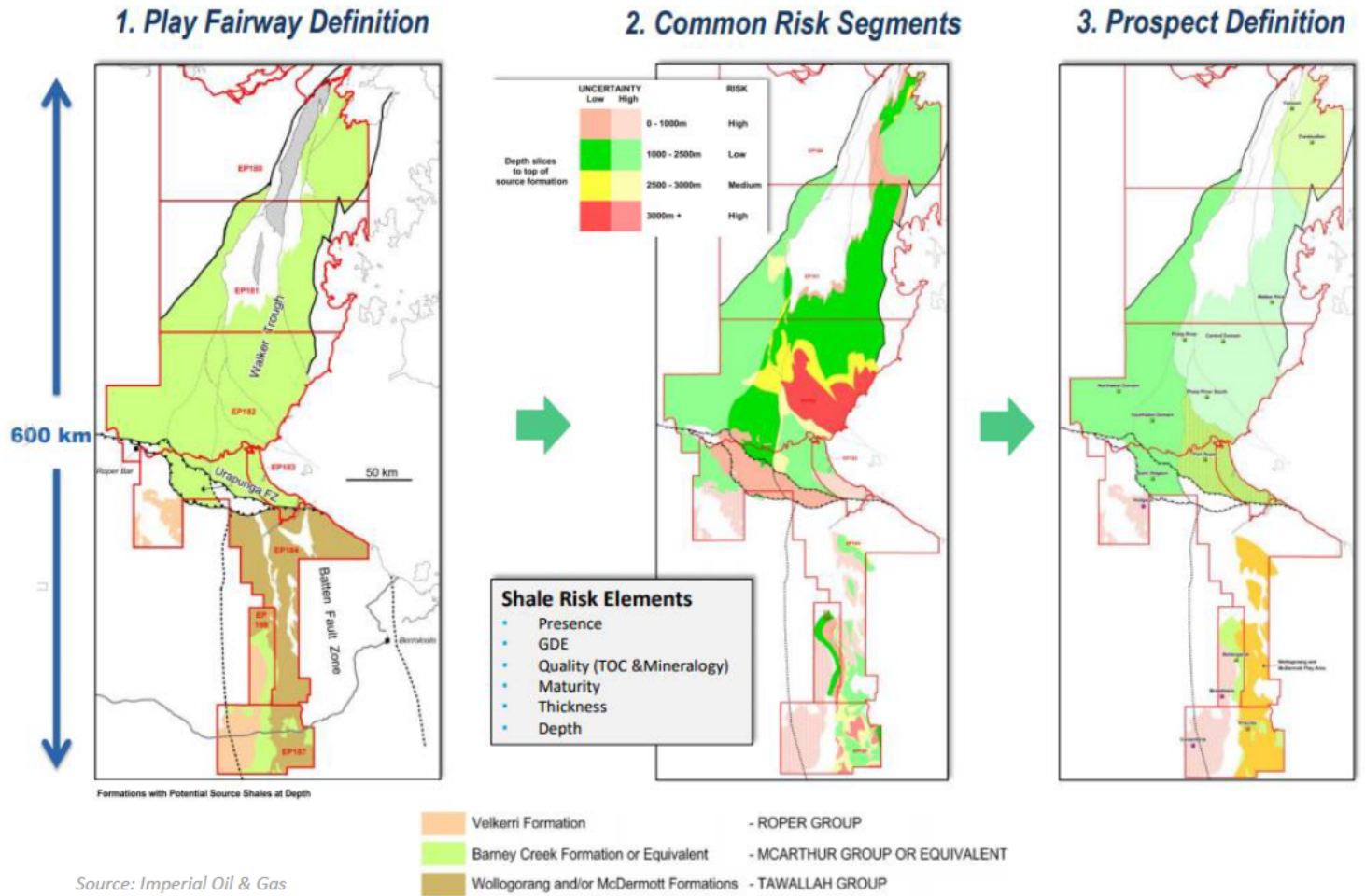
Appendix 1 – Barney Creek Shale versus Utica Shale characteristics

“A major unconventional opportunity with the Barney Creek Shale with original gas in place equivalent to 50% more than the Utica Shale play” (AEP)



Source: AEP

Appendix 2 – Prospect Evaluation Methodology



Appendix 3 – Comparison of 30 Day IP's for best 12 Marcellus and Utica Wells

Marcellus Shale Wells - 30 Day IP (average)

MMcfd	Boofd	MMcfd	Operator	Well #	County, State	Comp. Date
41.1	772	36.5	Rex Energy Corp.	2H Klever Unit	Butler, Pa.	Jan. 2017
37.0	237	35.6	Rex Energy Corp.	1H Klever Unit	Butler, Pa.	Jan. 2017
25.7			Cabot Oil & Gas Corp.	4H Makosky	Susquehanna, Pa.	Dec. 2014
22.6			Cabot Oil & Gas Corp.	2H Pijanowski J	Susquehanna, Pa.	Dec. 2012
22.2			EQT Corp.	590384 Cooper	Greene, Pa.	Oct. 2013
21.5			Cabot Oil & Gas Corp.	2H Flower T	Susquehanna, Pa.	Dec. 2012
20.7			Cabot Oil & Gas Corp.	4H King D	Susquehanna, Pa.	Aug. 2016
17.1			Magnum Hunter	1302 Stewart Winland	Tyler, W. Va.	Sept. 2014
17.0			Magnum Hunter	1301 Stewart Winland Unit	Tyler, W. Va.	Sept. 2014
16.9			Cabot Oil & Gas Corp.	1H Molnar M	Susquehanna, Pa.	Nov. 2013
16.8			Magnum Hunter	1303 Stewart Winland	Tyler, W. Va.	Sept. 2014
16.2			Cabot Oil & Gas Corp.	3H Molnar M	Susquehanna, Pa.	Nov. 2013

Utica Shale Wells - 30 Day IP (average)

MMcfd	Boofd	MMcfd	Operator	Well #	County, State	Comp. Date
72.9			EQT Resources Inc.	591340 Scotts Run	Greene, Pa.	Jul. 2015
61.9			Consol Energy Inc.	9GHAHSU Consol	Greene, Pa.	Oct. 2015
61.4			Consol Energy Inc.	4HHSU Gaut	Westmoreland, Pa.	Oct. 2015
59.0			Range Resources Corp.	11H Claysville Sportsman's	Belmont, Ohio	Dec. 2014
46.5			Magnum Hunter	1300 Stewart Winland	Tyler, W. Va.	Oct. 2014
43.7	131	42.9	Antero Resources Corp.	1H Kurtz Unit	Monroe, Ohio	Aug. 2016
41.7			Rice Energy Inc.	9H Bigfoot	Belmont, Ohio	Jun. 2014
36.8			Gastar Exploration Inc.	7H-U Blake Unit	Marshall, W. Va.	May. 2015
34.4			Rice Energy Inc.	10H Mohawk Warrior	Belmont, Ohio	Jun. 2015
33.9			Rice Energy Inc.	12H Mohawk Warrior	Belmont, Ohio	Jun. 2015
32.5			Magnum Hunter	3UH Stalder	Monroe, Ohio	May. 2015
32.3			EQT Corp.	513926 WV	Wetzel, W. Va.	Feb. 2016

Tables: Hart Energy. Data Source: IHS Inc.