NORTHERN TERRITORY GOVERNMENT

DEPARTMENT OF PRIMARY INDUSTRY AND RESOURCES

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File Ref: E2016/0036

The Honourable Justice
Rachel Pepper
Hydraulic Fracturing Taskforce
GPO Box 4396
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Dear Justice Pepper

Thank you for the opportunity to be able to provide you with updated geological information on the definition of the boundaries of the Beetaloo Sub-basin, which have been derived through ongoing geoscientific studies within the Department of Primary Industry and Resources (DPIR).

The Interim Report for the Inquiry released in July this year contained maps that displayed a boundary of the Beetaloo Sub-basin provided by the NT Geological Survey (NTGS) within DPIR. This was the boundary as used by the NT Government at the time, on the basis of interpretation of gravity geophysical data and limited seismic interpretation. However, ongoing work by NTGS has led the interpretation of substantial industry seismic data that has led to a better defined boundary based on consistent and scientifically defendable data.

The boundary in currently being prepared for public release in a digital form on DPIR's minerals and energy web mapping system STRIKE (strike.nt.gov.au), with release expected by the end of November. The metadata associated with the spatial boundary is in Attachment 1. A version has also been made available to the Taskforce for use in figures for the Final Report. A more detailed publication that includes all of the background data will be released by NTGS in early 2018.

Criteria for defining the Beetaloo Sub-basin

The Beetaloo Sub-basin as defined by NTGS represents a volume of thickest preserved sequences of the Mesoproterozoic (1400-1300 million years old) Roper Group, south of the Mallapunyah Fault. The Roper Group contains the Kyalla and Velkerri formations, which highly prospective for shale gas and liquids. The concealed boundary of this volume has been defined by NTGS as where the top of the Kyalla Formation is at a depth of 400m below topographic surface (see Rationale section below for further information).

The Beetaloo Sub-basin is a subset of the larger 'Roper Basin' which was previously considered to be the upper part of the McArthur Basin but is now being re-defined by NTGS as a separate basin that overlies the older McArthur Basin. The 'Roper Basin' represents the entire volume and extent of the preserved Roper Group (and its correlative Tijunna Group and Renner Group) regardless of thickness. Therefore the Beetaloo Sub-basin lies within, and forms part of, the 'Roper Basin' (which is informally named until fully defined).

This definition of the Sub-basin and its boundary is a geological interpretation of the sub-surface basin structure that is not intended to represent a physical limit to petroleum resource potential in this region. However, it does include the areas where the presence of shale gas resources has been defined with the highest degree of confidence. Shales of the Velkerri Formation locally extend beyond the sub-basin boundary and may contain hydrocarbons in these regions, although given the shallower levels of burial outside of the Sub-basin the shales in these areas would be less thermally mature and more likely be oil- rather than gas-bearing. It should also be noted that shales of the older (Palaeoproterozoic,

1800-1600 million years old) underlying McArthur Group of the McArthur Basin are also known to be a significant source of hydrocarbons, and extend over a much larger area, including the area of the Glyde gas discovery south of Borroloola.

The rationale and description of the revised boundary of the Beetaloo Sub-basin is outlined in the paragraphs below.

Background on the Beetaloo Sub-basin and the submission of a revised boundary

The Beetaloo Sub-basin is centred about 300 km south-southeast of Katherine and extends over an area of approximately 28,000 km^2. It is geologically defined as a sub-basin within the greater McArthur Basin that contains a thick preserved succession of flat-lying sedimentary rocks of the Roper Group (Figure 4). This includes the prospective Velkerri and Kyalla formations that host large shale-gas resources. The sub-basin has high gas and oil potential because the shales have been buried deeply enough, and preserved at an appropriate depth to generate and retain hydrocarbons. The margins of the sub-basin represent areas where the Roper Group has been uplifted and eroded, most commonly associated with faults, bringing the prospective shales closer to the surface, or in some areas eroded away altogether.

The geology of the Beetaloo Sub-basin is buried beneath younger basins and therefore the boundary of the sub-basin is not exposed and can only be interpreted from drilling and geophysical data (especially seismic lines and gravity surveys). As a result many interpretations of the boundary have been published by both Government and industry since the sub-basin was first defined in the late 1980's. The ongoing increased data acquisition from industry and government has led to refinements of this concealed boundary

The initial boundary of the Beetaloo Sub-basin was provided by DPIR to the Hydraulic Fracturing Inquiry for use in the Interim Report with the following caveat: "... *the boundary remains somewhat poorly defined, as it is a sub-surface transitional boundary that represents the approximate boundary where the sub-basin deepens and where it is likely to have high gas and oil potential. This is why there have been different interpretations of its shape. The prospective shales (Velkerri and Kyalla) extend beyond that boundary, but will largely be too shallow to be prospective plays outside the sub-basin. The sub-basin was originally defined only on the basis of interpretation of gravity geophysical data, although the shape of the northwestern part of the sub-basin has been modified on the basis of Pangaea's seismic data and drilling. NTGS may in future further revise the boundary of the eastern part of the sub-basin as seismic data is incorporated into our 3D model.*"

Although the initial boundary provided to the Inquiry was considered a reasonable approximation of the sub-basin extents at the time, a number of issues were identified. In particular, much of the existing boundary (with the exception of the area towards the northwest) was defined only on the basis of gravity data, and did not incorporate all recent industry seismic acquisition that would increase the confidence of the boundary location. This was particularly the case on the eastern boundary of the Sub-basin, where the NTGS interpretation was substantially different to industry interpretations that were based on depth-migrated seismic data.

The November 2017 boundary of the Beetaloo Sub-basin

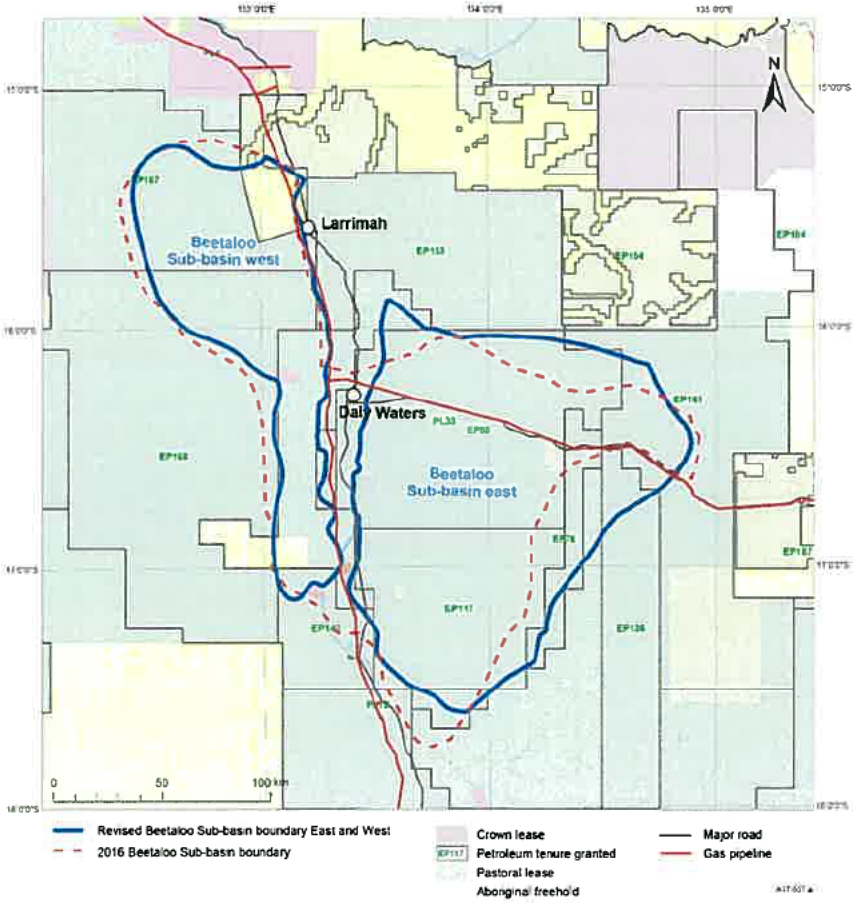

Figure 1. The revised boundary of the Beetaloo Sub-basin (blue) overlain on the 2016 boundary (dashed red line) and on petroleum leases and land tenure.

As part of the ongoing project under the CORE initiative the NT Geological Survey has depth-converted and interpreted industry seismic data within the greater McArthur Basin (including the *Roper Basin*) to improve the 3 dimensional understanding of the currently preserved shapes of the Basins. Seismic lines that are interpreted to cross the boundary of the Beetaloo Sub-basin have been prioritised. The revised boundary for the Sub-basin has been defined utilising lithostratigraphic data from 26 petroleum wells tied to geological interpretations of more than 96 seismic surveys, with the margins of the basin defined by where the top of the Kyalla Formation is at a depth of 400m below surface. This has split the sub-basin into an eastern and western domain (informally known as Beetaloo Sub-basin east and Beetaloo Sub-basin west) separated by a faulted and uplifted zone between Larrimah and Elliott (Daly Waters Fault Zone, also referred to in some reports as the Daly Waters Arch or Daly Waters High). The Beetaloo Sub-basin east covers 18,940 km2, and the Beetaloo Sub-basin west covers 9,265 km2.

Figures 1 and 2 show the location of the new boundary and its comparison with the previously published boundary that was included in the Interim Report. Figure 2 also shows the location of the wells and seismic data that have been used to constrain the boundary, with pink triangles representing the locations where the top of the Kyalla Formation has been determined to be at 400m based on seismic interpretation by NTGS.

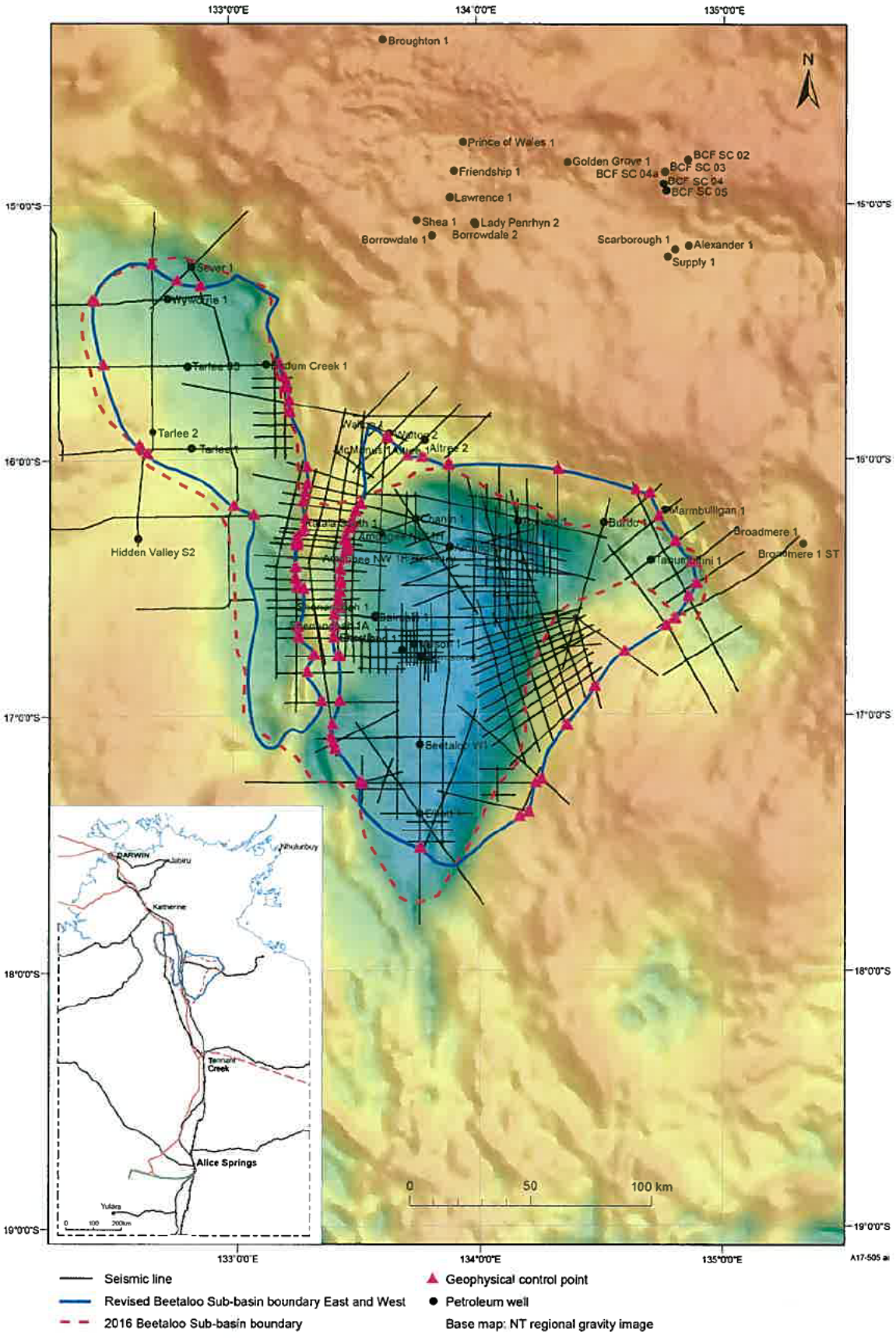

Fig. 2 The revised boundary of the Beetaloo Sub-basin (blue) overlain on the 2016 boundary (dashed red line) showing data used to constrain the boundary (wells, seismic and gravity data). Pink triangles indicate where the top of the Kyalla Formation has been fixed at 400m based on seismic data

Although the boundaries of the Sub-basin have been changed as further geological information has been incorporated, with revised versions released by NTGS in 2014, 2016 and 2017, the total surface area of the interpreted sub-basin has remained almost unchanged, as outlined in the table below. Prior to 2014, the interpreted sub-basin was smaller (within the range 15,000-20,000km^2) as it only included the Beetaloo Sub-basin east.

Year	Area	Data used to constrain boundary
2014	**28,400 km^2**	Gravity geophysics
2016	**27,480 km^2**	Gravity with limited seismic data in northwest
2017	**28,205 km^2**	Depth-converted seismic data and well control

Definition of the Beetaloo Sub-basin

The Beetaloo Sub-basin is now defined as two concealed sub-surface volumes of sedimentary rock (Beetaloo Sub-basin east and west) occurring south of the Mallapunyah Fault. The sub-basin contains a thick preserved succession of the Roper Group including both the Kyalla and Velkerri formations, which are the two shales that have known potential to host significant hydrocarbon resources. The Sub-basin is typically bounded by faults, except along its western margin, where it gradually shallows to the west. To allow a consistent boundary to be created given the presence of both faulted and transitional relationships, the basin extents have been defined as the point at which the top of the Kyalla Formation (the upper shale unit) is greater than 400m depth below present day topography.

The Beetaloo Sub-basin is now divided into eastern and western areas (Beetaloo Sub-basin east and west). The larger Beetaloo Sub-basin east is mainly bounded by fault structures that lead to rapid shallowing of the stratigraphy. This means that changing the depth contour of the Kyalla Formation in these areas has minimal impact on the boundaries of the sub-basin. Along the western margin of the Sub-basin, the basin shallows gently to the west, and therefore the boundary can be considered to be gradual and transitional.

Rationale of using the 400m depth contour of the top of the Kyalla Formation as the boundary of the Sub-basin

Given that the Sub-basin does not have a structurally controlled margin on its western edge, the only way to provide a consistent boundary was to select a stratigraphic depth contour as the boundary. Consideration was given to defining the boundary simply as the area within which the Kyalla Formation is present at depth. However, the Roper Group has been eroded and overlain by younger sedimentary rocks of variable thickness between 200-400m thick. Therefore, to provide consistency across the whole basin, a 400m depth contour for the top of the Kyalla Formation was selected, which represents where the top of the Kyalla Formation is close to unconformity with the overlying younger stratigraphy.

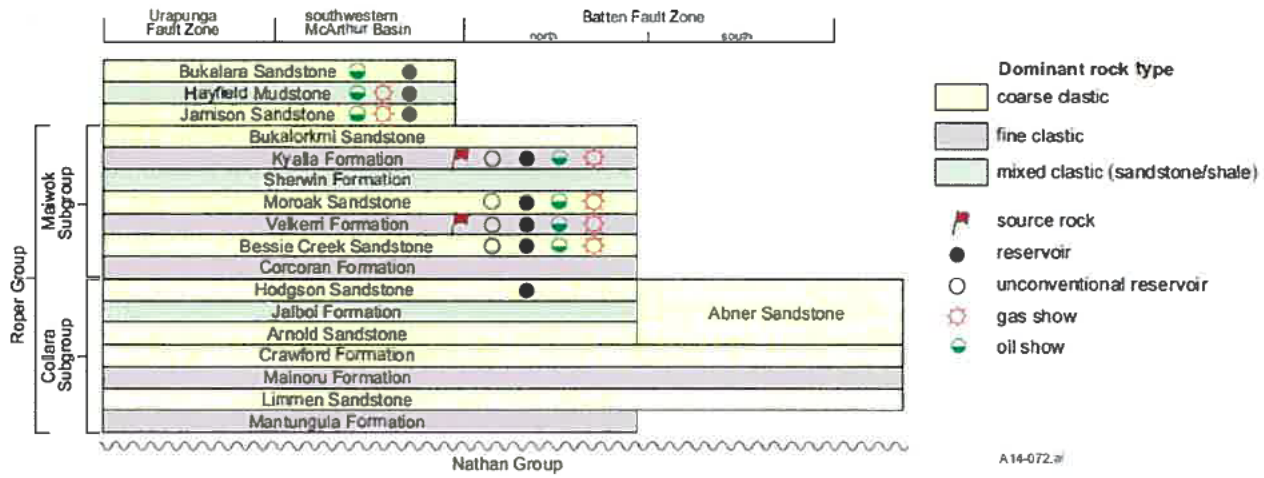

Fig. 3 Stratigraphy of the Roper Group in the Beetaloo Sub-basin (Munson 2016).

Consideration was also given to using a depth contour of the stratigraphically lower Velkerri Formation (for example at 1000 or 1500m depth). However, significantly fewer wells intersect the Velkerri Formation compared to the Kyalla Formation, and there is considerably high ambiguity regarding the depth of the Velkerri Formation. The Kyalla Formation provides the best well controls to constrain the seismic interpretation and therefore there is less uncertainty about its depth.

The 400m depth contour of the Kyalla Formation effectively encompasses the area in which gas resources have been identified in the Velkerri Formation with a high degree of confidence, including the discoveries reported to DPIR by Origin Energy and Pangaea Resources.

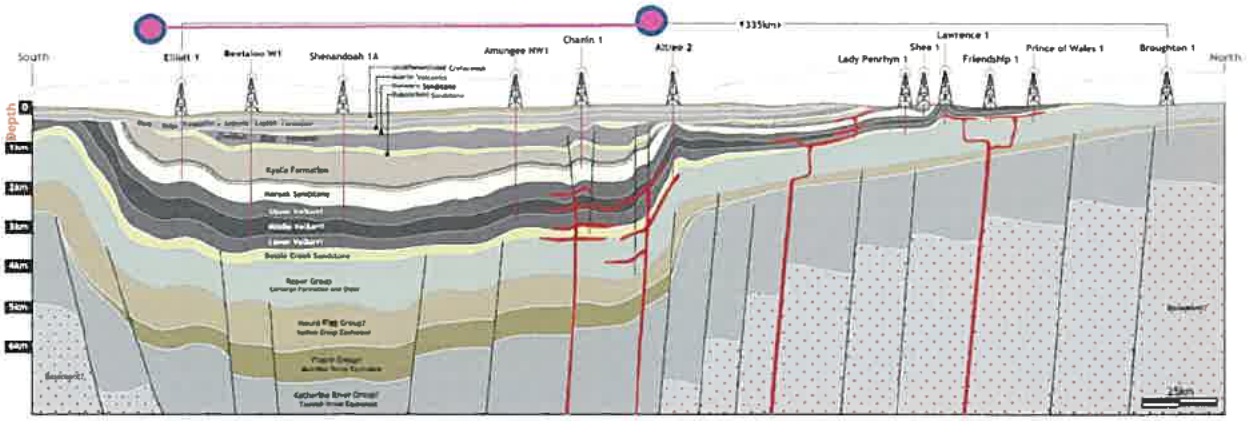

Fig. 4 Schematic south-north cross-section across the Beetaloo Sub-basin. The Beetaloo Sub-basin is the thickest part of the succession, between the two pink dots (adapted from Close et al 2017).

Implications for hydrocarbon potential

As discussed above, the redefined boundary of the Beetaloo Sub-basin is a geological boundary that is not intended to provide a definitive boundary for hydrocarbon potential. However, it does encompass the area within there is strong geological evidence for the presence of shale gas and liquids within the Kyalla and/or Velkerri formations, and where the most advanced exploration for shale-hosted resources has taken place. Potential for other shale plays occurs outside of this area, and at depth beneath the Roper Group, including in areas to the west where the Barney Creek formation of the McArthur Group is known to be gas- and oil-bearing. There is also potential for hydrocarbons to be hosted in the Roper

Group outside of the Beetaloo Sub-basin, such as the Broadmere Sub-basin and in areas north of the Mallapunyah Fault, although the Roper Group succession is typically thinner in these areas than in the Beetaloo Sub-basin, and the shales are likely to be less thermally mature.

I trust that you will find the information provided comprehensive and useful. Should you require any further information or clarification, please do not hesitate to contact the department through Deputy Chief Executive, Mr Rod Applegate.

Yours sincerely

Alister Trier
Chief Executive

23 November 2017

Attachment 1: Metadata for the spatial layer of the Beetaloo Sub-basin boundary to be updated to the SPIR STRIKE web-mapping system

ANZLIC Identifier:	
Title:	Beetaloo Sub-basin boundary
Custodian:	Northern Territory Geological Survey (NTGS) Department of Primary Industry and Resources
Abstract:	The Mesoproterozoic Beetaloo Sub-basin is a fully concealed sub-basin located approximately 300 km southeast of Katherine. It comprises thick successions of the Roper Group within the McArthur Basin. The boundary defining the spatial extents of the Beetaloo Sub-basin represents the top Kyalla Formation at a depth of approximately 400 m below topographic surface. The depth to top Kyalla Formation is calculated from interpretation of 96 seismic lines constrained by 26 wells. The spatial extent of the boundary is further constrained by potential field geophysics.
Search Word(s):	Beetaloo Sub-basin, Kyalla Formation, Roper Group, Wilton package, McArthur Basin, geoscientific information, geological interpretation
Bounding Coordinates (GDA94):	North bounding coordinate: -15.21 South bounding coordinate: -17.61 East bounding coordinate: 134.91 West bounding coordinate: 132.39
Reference System Information:	The dataset is supplied in Geocentric Datum of Australia (GDA94), latitude and longitude [EPSG: 4283]
Data Currency Start Date:	01/09/2017
Data Currency End Date:	01/11/2017
Progress:	Complete
Maintenance and Update Frequency:	As required

Access Constraint:

Lineage:

Top Kyalla Formation was interpreted on seismic lines from the following surveys:

- McArthur Basin 2D SS 1989
- McArthur Basin 2D SS 1990
- McArthur 2D SS 1991
- McArthur Basin 2D SS 1991
- McArthur River Ph I 2D SS 1992
- McArthur River Ph II 2D SS 1992
- Beetaloo Basin 2D SS 2006
- Beetaloo 2D SS 2011
- Beetaloo 2D SS 2012
- Hidden Valley 2D SS 2013
- McArthur 2D SS 2013

Interpretations were constrained using well data and potential field geophysics.

Positional Accuracy:

Data are interpretative and positional accuracy is influenced by both input datasets and interpretation uncertainty. The quality of the input datasets is considered highly variable. Seismic two-way time to depth conversion accuracy is estimated at 150 m.

Attribute Accuracy:

Attribution accuracy is high, accurately reflecting the interpretation.

Logical Consistency:

Data is logically consistent for the purposes of the geological interpretation of the spatial extent of the Beetaloo Sub-basin.

Completeness:

The data is complete within the scope of the project and is limited by the quality of geological and geophysical input data available at the time.

Contact Organisation:

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Contact Person:

Manager Geophysics and Remote Sensing

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Metadata Date: