Neoproterozoic stratigraphic revisions to key drillholes in the Amadeus Basin – implications for basin palaeogeography and petroleum and minerals potential

Verity J Normington[1,2] and Christine J Edgoose[1]

Introduction

The Neoproterozoic to Palaeozoic Amadeus Basin is a large (ca 170 000 km^2) elongate intracratonic basin in central Australia, predominantly in the Northern Territory but extending into Western Australia (**Figure 1**). The basin has an extensive depositional history, from sedimentation of the Heavitree Formation and Dean Quartzite in the early Cryogenian (> 820 Ma) to molasse deposition in response to the latter part of the 450–300 Ma Alice Springs Orogeny. Up to 14 km of succession is preserved locally (Edgoose 2013). The depositional history is punctuated by a number of significant epeirogenic, orogenic and erosional episodes, including a number of unconformities and time breaks of local and regional significance.

A stratigraphic characterisation study of the Neoproterozoic succession along the structurally controlled northeast margin of the basin (**Figure 1**) has enabled significant improvements in the understanding of this period of basin history. This work also resulted in changes to the stratigraphic nomenclature (**Figure 2**) that have been reported previously at AGES (Normington *et al* 2015, Donnellan and Normington 2017); and in Normington and Donnellan (in review). In summary, the new nomenclature:

- renames the Heavitree Quartzite as Heavitree Formation.
- upgrades the Bitter Springs Formation to Bitter Springs Group
- re-assigns the Gillen and Loves Creek members to formations of the Bitter Springs Group
- formalises Johnnys Creek 'beds' to Johnnys Creek Formation of the Bitter Springs Group
- formalises the 'finke beds' to the Wallara Formation

That study took a field-based approach to systematically describing, characterising and correlating the lithostratigraphic units. Herein we apply the updated nomenclature to, and produce revised drill logs for, some key drillholes in the basin. The revised drill logs were compiled from a combination of relogging, correlating hyperspectral data sets (HyLogger), reviewing published logs and existing lithological descriptions, and incorporating recent biostratigraphic studies. The results are being released through a number of NTGS publications including Normington and Edgoose (2015), Normington (2018), and Normington *et al* (in prep).

To date six drillholes have been assessed and logs updated in accordance with the revised stratigraphy. Drillholes inspected are shown in **Figure 1** and comprise: mineral exploration holes CPDD001–003 (Pipeline Prospect) and stratigraphic drillhole BMR Alice Springs 27 in the northeast of the basin; and stratigraphic drillholes LA05DD01 and BR05DD01 drilled by NTGS in the western-central Amadeus Basin.

1 Northern Territory Geological Survey, PO Box 8760, Alice Springs NT 0871, Australia
2 Email: verity.normington@nt.gov.au

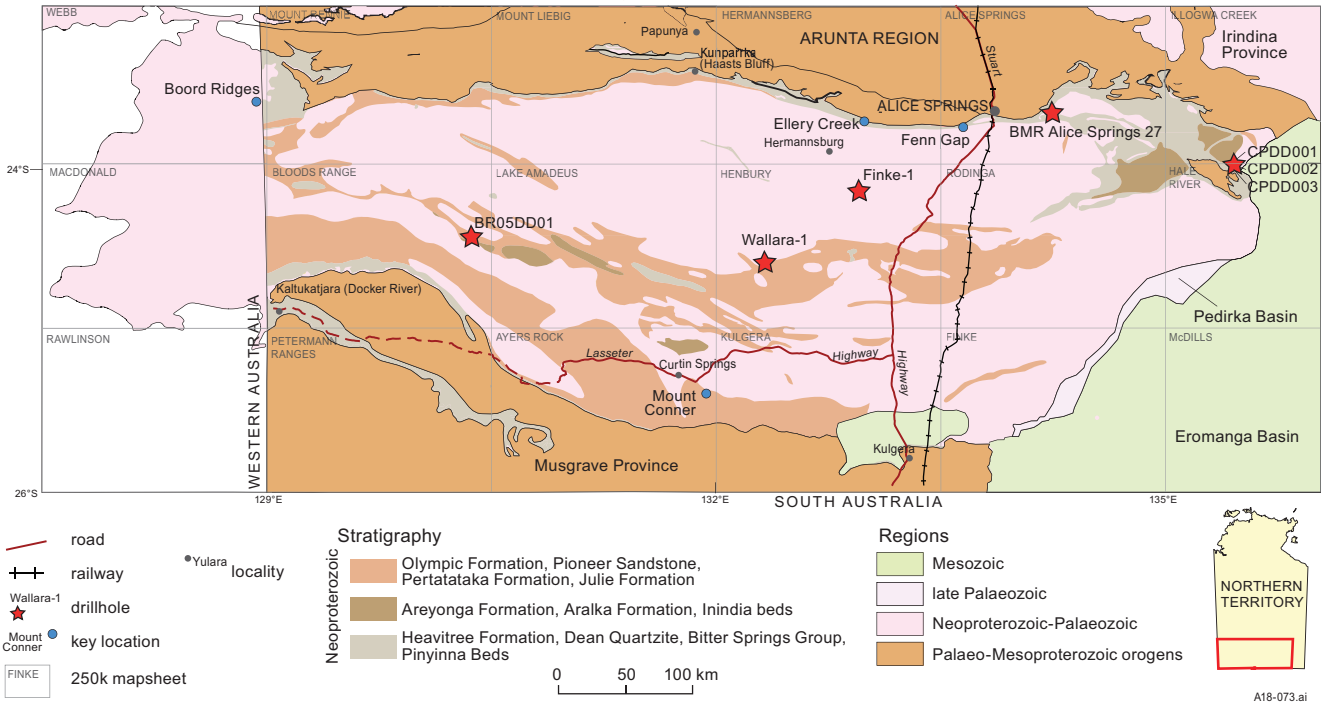

Figure 1. Regional geological setting of the Amadeus Basin in the Northern Territory. The surface distribution of the Neoproterozoic units across the basin is shown, as well as the drillholes studied. Outcrop geology is derived from NTGS 1:2.5M geological regions GIS dataset.

Starting with the oldest unit intersected in the drillholes, the distinctive cycles of red mudstone (**Figure 3**) and buff carbonate of the Johnnys Creek Formation (**Figure 2**) have been recognised in BMR Alice Springs 27, CPDD002 and CPDD003 and BR05DD01. Original logging of drillholes CPDD002 and CPDD003 by Nowland (2008) and McKinnon-Matthews (2009) also recorded numerous basalt flows characteristic of the upper Johnnys Creek Formation. Basalt was not observed in BMR Alice Springs 27 or BR05DD01 (Normington and Edgoose 2015, Normington *et al* in prep).

The Wallara Formation (formerly 'finke beds'; **Figure 2**) was not previously recorded in any of the drillholes investigated (eg Chopra 1987, McKinnon-Matthews 2009, Ambrose *et al* 2010). The type section for the Wallara Formation is in Wallara-1 (Normington *et al* 2015, Normington and Donnellan in review). The Wallara Formation has now been identified in CPDD003 (Normington 2018) and BR05DD01 (Normington *et al* in prep).

The Aralka Formation (**Figure 2**) was also not previously recorded in any of the drillholes investigated (eg Chopra 1987, McKinnon-Matthews 2009, Ambrose *et al* 2010). The Aralka Formation has now been recognised in drillholes CPDD001 (**Figure 3**), CPDD002 and CPDD003 (**Figure 4**; Normington 2018) and BR05DD01 (Normington *et al* in prep) on the basis of stratigraphic position and the presence of its characteristic organic rich and pyritic black shales (**Figures 3 and 4**). It had previously been logged as the younger Pertatataka Formation (**Figure 2**) in CPDD001 (McKinnon-Matthews 2009) and BR05DD01 (Ambrose *et al* 2010), and was not separated from the Johnnys Creek Formation (described as unit 3 of the Loves Creek Member by McKinnon-Matthews 2009) in drillhole CPDD002. The revision in BR05DD01 is confirmed by the identification of the Ringwood Member of the Aralka Formation (**Figure 2**; Allen *et al* in prep, Normington *et al* in prep) on the basis of its unique biostratigraphy (as described by Allen *et al* 2016). This is only the second reported occurrence of the Ringwood Member outside of exposures in the north

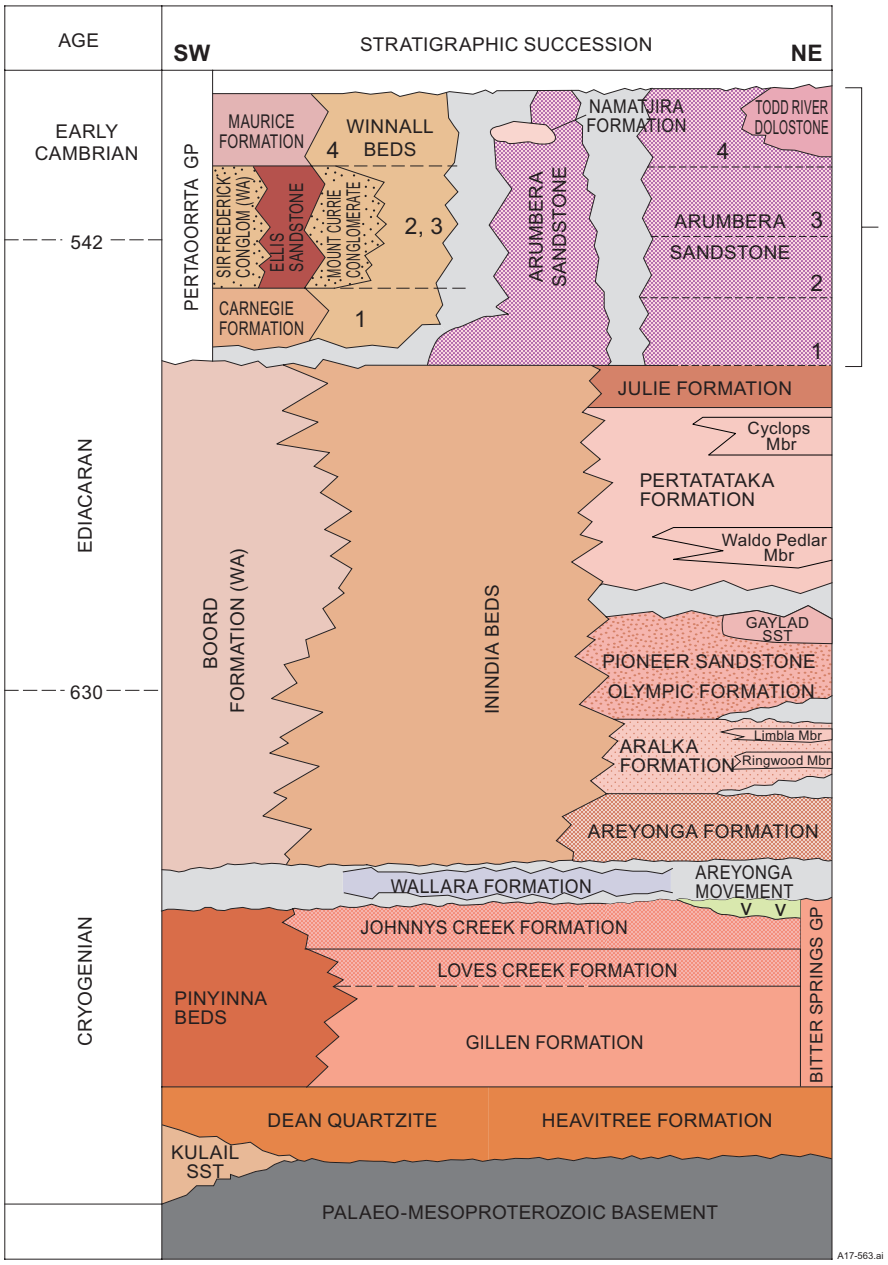

Figure 2. Revised stratigraphy of the Neoproterozoic Amadeus Basin succession (Normington 2018).

and northeast of the basin – the other is at Mount Conner (**Figure 1**) described in Allen *et al* (in prep) and Edgoose *et al* (in review).

Basin-wide implications

The newly recognised occurrences of the Johnnys Creek, Wallara and Aralka formations (**Figure 2**) in these drillholes has significantly extended the known regional distribution of these units within the Amadeus Basin. The Johnnys Creek Formation is not currently recorded on any published maps of the basin; however, it has previously been identified as unit 3 of the Loves Creek Member in outcrop in the northeast or assigned to the 'Johnnys Creek beds' in drillholes (Gorter 1982). The Johnnys Creek Formation has now been identified in outcrop in the northeast and central north of the basin (Normington and Donnellan in review). Recent mapping by NTGS in HENBURY (Donnellan and Normington 2017, Normington and Donnellan in prep, Donnellan *et al* in prep) in the central Amadeus Basin has recorded Johnnys Creek Formation (originally mapped as undivided Bitter Springs Formation; Ranford and Mikolajczak 1963) The recognition of the Johnnys Creek Formation in BR05DD01 has significantly extended its westward distribution and therefore increased its importance as a regionally significant unit.

The Wallara Formation (**Figure 2**), formerly described as 'finke beds', had been recorded in drillholes Finke-1 and Wallara-1 (Gorter 1983, Geowest 1990). The known surface extent of the Wallara Formation is limited as a result of its relatively new identification as a unique stratigraphic unit, which is largely a consequence of its poor exposure. Like the Johnnys Creek Formation, it is not currently recorded on any published maps of the basin. The unit has now been observed by the authors at Ellery Creek (HERMANNSBURG; Normington and Donnellan in review), at Fenn Gap (ALICE SPRINGS; Normington *et al* 2015, Normington and Donnellan in review) and tentatively at Mount Conner (AYERS ROCK; Edgoose *et al* in review). Recent mapping by NTGS in HENBURY (**Figure 1;** Donnellan and Normington 2017, Normington and Donnellan in prep, Donnellan *et al* in prep) in the central Amadeus Basin has recorded thin, localised exposures of the Wallara Formation. The occurrence of the Wallara Formation within drillhole CPDD003 is the most easterly known occurrence of the unit. The westerly extent is confidently constrained by BR05DD01, however rubbly exposure of probable Wallara Formation in the Boord Ridges (MACDONALD; **Figure 1**) in WA (Haines and Allen 2014) suggests it likely extends further west. The Wallara Formation may have a thin but continuous basin-wide distribution varying from 20 m in thickness

Figure 3. Core from drillhole CPDD01 showing the transitional contact (between the yellow dashed lines) for the Aralka Formation (grey-green mudstone) and the Johnnys Creek Formation (red calcareous mudstone) at 100 to 101 m (Normington 2018).

Figure 4. Dark grey, variably calcareous siltstone of the Aralka Formation, showing buff, fine laminations at 204 m in drillhole CPDD003 (Normington 2018).

in CPDD003 (Normington 2018) in the northeast of the basin to 86 m in Wallara-1 (Geowest 1990, Normington *et al* 2015) and 150 m in BR05DD01 (Normington *et al* in prep). Determining the full distribution of this unit is key to understanding the Neoproterozoic palaeogeography and architecture of the basin as it has a unique biostratigraphy that makes it an important time marker for the late Neoproterozoic both nationally and internationally.

One of the most significant changes from the drillhole revisions is the increase in the known distribution of the Aralka Formation. The stratigraphic revisions in drillholes CPDD001, CPDD002, CPDD003 and BR05DD01 where the younger Pertatataka Formation is now recognised as Aralka Formation (**Figure 2**) has significantly extended the known distribution of this unit: the Aralka Formation is most likely continuous across much of the basin with thicknesses varying from 30 m in Wallara-1 (Geowest 1990) to over 100 m in CPDD001 and BR05DD01 (Normington 2018, Normington *et al* in prep).

The drillhole revisions are critical to understanding both the distribution and continuity of the Neoproterozoic succession across the Amadeus Basin. The increase in the known distribution of these units has a positive impact on the petroleum and mineral potential of this succession. For example, the Heavitree–Aralka succession contains proven petroleum systems (petroleum systems 1 and 2: Marshall 2003; **Figure 2**). The Johnnys Creek Formation (largely identified as Loves Creek Formation at the time of drilling) is considered a petroliferous succession with oil shows in wells across the basin. Munson (2014) suggests that these shows may be due to migrated hydrocarbons from the underlying Gillen Formation. The Wallara Formation has oil shows in Finke-1 where Marshall *et al* (2007) noted no permeability and little remaining intergranular porosity within the unit. Munson (2014) listed the Wallara Formation as one of the most promising reservoirs in the Neoproterozoic. The Aralka Formation, where intersected in drill core, also has strong petroleum system indicators. Marshall (2004) noted high TOC levels in a number of wells in the east of the Amadeus Basin. Munson (2014) suggests that the Aralka Formation shows strong source rock characteristics and has (or could) generate gas with some subordinate oil potential.

As noted above, some of the recorded Pertatataka Formation drillhole intersections in the north and west of the basin are now confidently revised to Aralka Formation. The Pertatataka Formation is a known petroleum source (Munson 2014). It is a viable gas-prone source rock in the north of the basin and has been geochemically matched to the gas resource in the Dingo and Orange gas fields (Munson 2014). However, the apparent reduction in distribution of the Pertatataka Formation and increase in distribution of the Aralka Formation does not necessarily downgrade the petroleum potential of these areas. In BR05DD01, Ambrose *et al* (2010) noted a minor oil stain in the revised succession (ie from Pertatataka to Aralka), indicating there is an ability to generate oil within the Aralka Formation in this area at least.

There have only been few investigations into the mineral system potential of the Amadeus Basin. A recent basin-wide study based on the depositional environment, geochemical composition and mineralogy of the units suggests that the Johnnys Creek Formation has the potential to host or be the source of redbed copper-style mineralisation (Schmid *et al* 2016). The Johnnys Creek and Wallara formations were also recognised as having potential for sourcing or hosting MVT-style base metal mineralisation. The Wallara and Aralka formations were also assessed to have the potential to source or host sedex-style base metal mineralisation.

Ongoing investigations into the Neoproterozoic stratigraphy of drillholes in the Amadeus Basin is planned to continue improvements of the known distribution of the succession. This will enhance understanding of the palaeogeographic setting of the period, better define and constrain the petroleum and mineral potential, and provide seamless and up to date basin-wide stratigraphic nomenclature.

References

Allen HJ, Grey K and Haines PW, 2016. Systematic description of Cryogenian Aralka Formation stromatolites, Amadeus Basin, Australia. *Alcheringa* 40, 62–82.

Allen HJ, Grey K and Haines PW, in prep. The Cryogenian Aralka Formation, Amadeus Basin: a basin-wide biostratigraphic correlation. *Geological Survey of Western Australia Record.*

Ambrose GJ, Dunster JN, Munson TJ and Edgoose CJ, 2010. Well completion reports for NTGS stratigraphic drillholes LA05DD01 and BR05DD01, southwestern Amadeus Basin. *Northern Territory Geological Survey, Record* 2010-015.

Chopra PN, 1987. Results of a geophysical well-logging survey, central Australia, 1986. *Bureau of Mineral Resources, BMR Record* 1897/27.

Donnellan N and Normington VJ, 2017. Towards a revised stratigraphy for the Neoproterozoic and probable early Cambrian in the central Amadeus Basin, Northern Territory: in *'Annual Geoscience Exploration Seminar (AGES) Proceedings, Alice Springs, Northern Territory, 28–29 March 2017'*. Northern Territory Geological Survey, Darwin.

Donnellan N, Edgoose CJ, Normington VJ and Weisheit A, in prep. *Henbury, Northern Territory (Second Edition). 1:250 000 geological map series explanatory notes, SG 5301*. Northern Territory Geological Survey, Darwin.

Edgoose CJ, 2013. Chapter 23 - Amadeus Basin: in Ahmad M and Munson TJ (compilers), '*Geology and mineral resources of the Northern Territory.' Northern Territory Geological Survey, Special Publication* 5.

Edgoose CJ, Normington VJ, Haines PW and Allen HJ, in review. Revised Neoproterozoic stratigraphy in the Mount Conner area, Amadeus Basin, Northern Territory. *Northern Territory Geological Survey, Record.*

Gorter JD, 1982. Definition of the Johnny's Creek Beds, Amadeus Basin. Pancontinental Petroleum Ltd, PPL Report 56. *Northern Territory Geological Survey, Open File Petroleum Report* PR1982-0057.

Gorter JD, 1983. Finke No.1 well completion report. Pancontinental Petroleum Ltd, PPL Report 96. *Northern*

Territory Geological Survey, Open File Petroleum Report PR1984-0015.

Haines PW and Allen HJ, 2014. Geology of the Boord Ridges and Gordon Hills: key stratigraphic section in the western Amadeus Basin, Western Australia. *Geological Survey of Western Australia Record* 2014/11.

McKinnon-Matthews L, 2009. Casey Project, EL24646, Third annual technical report for the period 16th December 2007 to 15th December 2008. Mithril Resources. *Northern Territory Geological Survey, Open File Company Report* CR2008-881.

Marshall TR, 2003. Petroleum systems and source rocks in the Amadeus Basin, Northern Territory: in Cowie M (editor). '*Queensland 2003 exploration and development.' Petroleum Exploration Society of Australia (Qld/NT) 2003 Symposium*, 37–42.

Marshall TR, 2004. Review of the source rocks in the Amadeus Basin. *Northern Territory Geological Survey, Record* 2004-008.

Marshall TR, Dyson IA and Liu Keyu, 2007. Petroleum systems in the Amadeus Basin, central Australia: Were they oil prone?: in Munson TJ and Ambrose GJ (editors). *'Proceedings of the Central Australian Basins Symposium, Alice Springs, 16–18th August, 2005'. Northern Territory Geological Survey, Special Publication 2*, 136–146.

Munson TJ, 2014. Petroleum geology and potential of the onshore Northern Territory, 2014. *Northern Territory Geological Survey, Report* 22.

Normington VJ, 2018. Revised stratigraphy of drillholes CPDD001, CPDD002 and CPDD003, Pipeline Prospect, northeast Amadeus Basin, Northern Territory. *Northern Territory Geological Survey, Record* 2017-015.

Normington VJ, Donnellan N, Edgoose CJ and Kositcin N, 2015. Neoproterozoic evolution of the Amadeus Basin; evidence from sediment provenance and mafic magmatism: in '*Annual Geoscience Exploration Seminar (AGES) 2015. Record of abstracts*'. *Northern Territory Geological Survey, Record* 2015-002.

Normington VJ and Edgoose CJ, 2015. Revised stratigraphy of drillhole BMR Alice Springs 27, northeast Amadeus Basin, Northern Territory. *Northern Territory Geological Survey Technical Note* 2015-003.

Normington VJ, Edgoose CJ, Donnellan N, Thompson J and Meffre S, 2016. Summary of Results NTGS LA–ICP–MS U–Pb program: Amadeus Basin, July 2014–June 2015. *Northern Territory Geological Survey, Record* 2016-005.

Normington VJ and Donnellan N, in review. Characterisation of the Neoproterozoic stratigraphy of the northeast Amadeus Basin, Northern Territory, *Northern Territory Geological Survey, Record*.

Normington VJ and Donnellan N, in prep. Geology of the Henbury 1:100 000 geological map, central Amadeus Basin, Northern Territory. *Northern Territory Geological Survey Record*.

Normington VJ, Edgoose CJ, Haines PW, Allen HJ and Grey K, in prep. Revised stratigraphy for NTGS stratigraphic drillholes LA05DD01 and BR05DD01, southwestern Amadeus Basin. *Northern Territory Geological Survey, Record.*

Nowland J, 2008. *What caused Rodinia breakup? Integrating basalt geochemistry and sedimentology to assess plume model for Rodinian breakup.* BSc (Hons) thesis, School of Earth and Environmental Sciences, James Cook University, Townsville.

Ranford LC and Mikolajczak AS, 1963. *Henbury, Northern Territory (First Edition). 1:250 000 geological map series, SG53-1.* Bureau of Mineral Resources, Canberra.

Schmid S, Schaubs P, Austin J, Foss C, Gray D, Laukamp C, Kempton R, Bourdet J, Trefry C and leGras M, 2016. COBRA – Amadeus Basin Assessment of Resource Potential. *Northern Territory Geological Survey, Digital Information Package* DIP 016.