New insights into the Neoproterozoic to early Palaeozoic stratigraphy, structure and palaeogeography of the Amadeus Basin, Northern Territory

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Introduction

The Neoproterozoic to Palaeozoic Amadeus Basin is a large (~170 000 km²), elongate, intracratonic basin in central Australia, located predominately in the Northern Territory (NT) and extending into Western Australia (Figure 1). The basin has a protracted depositional history extending from sedimentation of the Heavitree Formation and Dean Quartzite possibly in the early Tonian (~820 Ma) to molasse deposition of the Pertnjara and Finke groups in response to the ca 450–300 Ma Alice Springs Orogeny. Up to 14 km of marine and minor terrestrial sedimentary successions are preserved locally (Edgoose 2013). The depositional history is punctuated by a number of significant epeirogenic, orogenic and erosional episodes and includes a number of unconformities and time breaks of greater or lesser regional significance.

Since 2014, the Northern Territory Geological Survey (NTGS) has conducted studies in the Amadeus Basin from 1:100 000–1:250 000 map scale to regional- and basin-wide scales. The map- and regional-scale projects have largely focused on the Neoproterozoic successions where the biggest issues in intra-basin correlation occur. These studies began with characterising the Neoproterozoic stratigraphy in the northeast of the basin (Normington and Donnellan in review) where the stratigraphy is best exposed. This work was undertaken as a ‘base-line’ study on which subsequent projects on the lesser known Neoproterozoic successions in the central and southern parts of the basin could be founded. The knowledge gained from this study has been applied to delineating the Neoproterozoic succession in the north-central part of the basin in detail through geological mapping (HENBURY 1 and HENBURY Special; Donnellan et al in prep, and Donnellan and Normington in prep, respectively; Figure 1). The field-based studies have also improved the understanding of the basin-wide distribution and thickness variations of many Neoproterozoic units through stratigraphic revisions of a number of key drillholes (Normington and Edgoose 2015 and 2018, Normington et al in prep). Combined, the stratigraphic characterisation, geological and structural mapping, and drillhole revisions are being integrated with geophysical datasets to produce two interpretative mapping, and drillhole revisions are being integrated

Neoproterozoic to early Palaeozoic stratigraphy

Northeast study

The stratigraphic characterisation of the Neoproterozoic succession along the structurally-controlled northeast margin of the basin (Figure 1) has significantly improved understanding of this period of basin history. The study took a field-based approach to systematically describe, characterise and correlate the lithostratigraphic units, updating nomenclature where required (Figure 2). This work has been reported previously at AGES (Normington et al 2015, Donnellan and Normington 2017, Normington and Edgoose 2018), and is described in detail in Normington and Donnellan (in review). The work has:

- identified Johnnys Creek Formation as a widespread unit
- provided detailed descriptions of sub-facies within the Gillen Formation
- recognised the Wallara Formation in outcrop for the first time (previously only known from 2 drillholes in the central basin)
- created new and refined existing type sections for many lithostratigraphic units
- upgraded the Bitter Springs formation to Bitter Springs Group
- re-defined the Gillen and Loves Creek members as formations of the Bitter Springs Group
- formalised Johnnys Creek ‘beds’ as Johnnys Creek Formation of the Bitter Springs Group
- formalised the ‘Finke beds’ as the Wallara Formation
- renamed the Heavitree Quartzite as Heavitree Formation in recognition of the variation in siliclastic component lithologies.

Mapping - central Basin

The Neoproterozoic Inindia beds (Ranford et al 1965) is an informal unit that has been recorded and mapped across much of the central and southern basin (Figure 1). It comprises a sequence of siltstone, sandstone, conglomerate, chert, chert breccia, and dolostone (Ranford et al 1965), it is equivalent to almost the entire post-Bitter Springs Group Neoproterozoic succession. (Figure 2). NTGS mapping in the central basin (HENBURY in 2015–2017) has successfully subdivided areas previously mapped as Inindia beds into the formal units of the northeast margin, including recognising previously unmapped Johnnys Creek and Wallara formations; the Aralka Formation including its constituent Limbla Member; and the Pioneer Sandstone and Pertatataka Formation.

The overlying latest Neoproterozoic to early Cambrian Winnall beds has been divided into the newly-defined
Breaden, Gloaming, Froud, Liddle and Puna Kura Kura formations, and the Chookla Member in HENBURY Special and HENBURY, which are now collectively assigned to the Winnall Group (Figure 2). These definitions and unit descriptions are published in Donnellan and Normington (2017), Donnellan and Normington (in prep) and Donnellan et al (in prep).

In addition to targeting the Neoproterozoic, the new mapping also covered the much better known and defined Palaeozoic succession in the central-northern basin. In northern HENBURY, early to mid-Palaeozoic successions are relatively thick by comparison with the same units exposed in southern HENBURY. This contrast in thickness can be better understood when viewed in the context of the current model of the basin architecture (Figure 1b), which formed in response to the ca 580–530 Ma Petermann Orogeny (see Edgoose 2013). The southern part of the mapping area coincides with the ‘southern platform’ element (Figure 1b) whilst the northern area largely coincides with the ‘Missionary Plains Trough’ (Lindsay and Korsch 1991, and references therein). These features are interpreted to have been separated by a high of basement rock and lower basin successions – the ‘central ridge’ (Lindsay and Korsch 1991, Shaw et al 1991). The southern platform lacks the major Palaeozoic depocentres present in the north; however, shallow marine depositional environments predominate in

Figure 1. (a) Regional geological setting of the Amadeus Basin in the Northern Territory. The surface distribution of the Neoproterozoic units across the basin is shown (Edgoose 2013), as well as the drillholes studied. Outcrop geology is derived from NTGS 1:2.5M-scale geological regions GIS dataset. (b) Architecture of the Amadeus Basin, showing drainage and locations of sub-basins, Missionary Plain Trough, Central Ridge and Southern Platform elements (slightly modified after Marshall et al 2007 and references therein).
both elements. Not only is the succession thinner in the south, the lithofacies for some units also vary across the architectural components. One example is the Ordovician Stairway Sandstone (Larapinta Group) where a newly recognised interval with distinctive ichnofauna is mapped (and being defined as a member) across a wide area in the north of HENBURY (Missionary Plain Trough) but not in the south. The observed variation in thickness and facies within the one unit provides lithostratigraphic evidence to support the basin architectural model shown in Figure 1b.

Additionally, brittle fault structures, previously unrecognised in the central part of the Amadeus Basin, have been identified from both mapping and the interpretation of geophysical data. Structural analyses of outcrop data

Figure 2. Revised stratigraphy of the Amadeus Basin succession (modified after Edgoose 2013, Haines and Allen 2014, Haines et al 2015, Donnellan and Normington 2017, and Normington 2018). The Neoproterozoic to early Cambrian succession is preliminary and will be revised based on 2019 field observations by NTGS.
have shown that the characteristic km-scale folding in the central part of the Amadeus Basin is fault-related (Weisheit and Donnellan 2018; Weisheit et al 2018; Normington and Donnellan in prep). The age-relationships of folded and faulted stratigraphy indicates that deformation was initiated during the ca 580–530 Ma Petermann Orogeny and continued during the ca 450–300 Ma Alice Springs Orogeny.

Mapping - western Amadeus Basin

The western part is the most remote, inaccessible and therefore least known and understood region of the Amadeus Basin. However, significant exposures of the post-Bitter Springs Group Neoproterozoic successions (Inindia and Winnall beds) are scattered in low ranges and isolated outliers across this region (LAKE AMADEUS, BLOODS RANGE; Figure 1). Commencing in 2019, NTGS will undertake systematic 1:250 000-scale mapping across this area aimed at continuing the revision of the Neoproterozoic succession and interpretation of the structural architecture that has been achieved in the central area of the basin (see above). It is anticipated that the Inindia beds will be divided into the formalised units of the northeast and central basin, and that the subdivision of the Winnall Group into separate formations will continue. In addition, this work aims to correlate NT stratigraphic units and nomenclature with the revised Neoproterozoic succession in WA published by GSWA (Haines et al 2012, Haines and Allen 2014, Allen et al 2018). An additional objective is to further improve the understanding of the basin’s tectonic history as expressed through surface observations of faults and folds, in conjunction with the subsurface interpretation at 1:500 000-scale (see below).

Basin-wide program

1:500 000-scale pre-Mesozoic interpreted geology and structure

NTGS is continuing to re-interpret the pre-Mesozoic geology and structure of the entire Amadeus Basin in the NT by integrating the results of mapping in the central basin with interpretation of basin-wide geophysical datasets. Preliminary outcomes of this project have been presented in Weisheit and Donnellan (2018) and Weisheit et al (2018). They include the recognition that much of the km-scale folding in the Amadeus Basin is fault-related. Structures that formed during the Petermann Orogeny are recognised in the southern and central Amadeus Basin as thick-skinned, north-to northeast-directed fault-propagation folds, possibly reactivating pre-existing basement structures. During the Alice Springs Orogeny, these structures were partly reactivated and overprinted by several sets of 100 km long, south-directed fault-bend folds and fault-propagation folds, which are widely recognised across the basin. Later, sets of thick-skinned, oblique-slip to strike-slip faults developed, causing the disruption of pre-existing structures. This protracted, syn-depositional tectonic development of the Amadeus Basin resulted in variable stratigraphic relationships and varying degrees of preservation of the succession throughout the basin (eg stratigraphic thinning/thickening; allochthonous versus autochthonous; lateral changes). The recognition that much of the development of the Amadeus Basin is fault-related has implications for both mineral and petroleum systems via the possible existence of multiple fluid pathways in both space and time, potential tapping of basement source rocks, and the formation of traps and seals.

Drillhole correlations

Given the increased understanding of the Neoproterozoic succession of the Amadeus Basin through field-based studies, a need for applying this work to update the stratigraphy of key drillholes was recognised. To date, seven key drillholes have been reassessed: mineral exploration holes CPDD001, CPDD002 and CPDD003 from the Pipeline Prospect, BL002 from Blueys Prospect, and stratigraphic drillhole BMR Alice Springs 27, all located in the northeast of the Amadeus Basin; and NTGS drillholes LA05DD01 and BR05DD01 in the western-central Amadeus Basin (Figure 1). The revised drill logs were compiled from a combination of relogging (where necessary), correlation with hyperspectral data sets (HyLogger®), review of published logs and existing lithological descriptions, and incorporation of recent biostratigraphic studies.

Stratigraphic units not previously identified or well-described in these drillholes include the Gillen, Loves Creek and Johnnys Creek formations of the Bitter Springs Group, and the Wallara, Areyonga and Aralka formations. These stratigraphic revisions, along with field observations in HENBURY and in the western basin in WA (Haines et al 2012, Haines and Allen 2014, Allen et al 2018), have considerably expanded the known distribution and thickness variations of these units across the basin. The results have been released through a number of NTGS publications comprising Normington and Edgoose (2015), Normington (2018) and Normington and Edgoose (2018), plus soon to be released Normington et al (in prep).

Geochronology and isotope geochemistry

Given the limitations of biostratigraphic control in Neoproterozoic successions, U–Pb detrital zircon geochronology can be a useful tool in determining intra-basin stratigraphic relationships where field evidence of rock relationships is missing or ambiguous. All units studied in the northeast and central basin have now been dated, with maximum deposition ages and provenance spectra compiled. There is now sufficient data to enable some trends in zircon population ages to be observed across the Neoproterozoic and Palaeozoic successions. For example, the spectra of early Palaeozoic units in the central basin can be distinguished from the spectra of Neoproterozoic units by the greater proportion of zircon in the age range ca 700–500 Ma, as well as by generally younger maximum deposition ages. Although the Neoproterozoic-early Palaeozoic succession includes sedimentation prior to the Petermann Orogeny (which comprised deformation and uplift of the Musgrave Province and basal formations of the basin) as well as post-orogenic deposition, the Musgrave Province is the dominant
sediment source for all units. In some instances where field relationships are difficult to decipher (eg missing intervening stratigraphy), the detrital zircon spectra has been able to provide another line of evidence for interpreting the most likely age of poorly constrained units.

New isotopic data for the Neoproterozoic and Cambrian has been obtained from several University of Adelaide honours projects supported by SANTOS and NTGS. Detrital zircon provenance spectra for the Heavitree Formation indicates that there is a consistent maximum deposition age of ca 1030 Ma and no zircon grains with U–Pb ages <1000 Ma (Al-Kiyumi 2018). This result is in line with previous data collected from samples of this unit and equivalents from both northern and southern basin margins. Al-Ghafri (2018) further constrained the maximum depositional ages of the Areyonga and Pertattata formations to ca 685 Ma and ca 650 Ma respectively. Wong (2018) suggested the prominent zircon source for the Neoproterozoic–Cambrian succession may have been the Musgrave Province with lesser input from the Aileron and Warumpi provinces, and the Paterson and Rudall provinces in WA. New Ce anomaly data from some Cambrian carbonate units are interpreted to suggest a progressive change from oxygenated to more anoxic waters up stratigraphy (Albusaidi 2018). New δ13C and 87Sr/86Sr data for the Aralka Formation (Al-Khanjari 2018) correlates well with both local and global Neoproterozoic isotope records.

References


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