Revised Neoproterozoic stratigraphy in the Mount Conner area, Amadeus Basin, Northern Territory

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SUMMARY

This Record presents the results of a joint Northern Territory Geological Survey (NTGS)–Geological Survey of Western Australia (GSWA) reconnaissance field trip to the Mount Conner area in the central south of the Amadeus Basin. The purpose of the trip was to assess whether recent revisions by GSWA of the Neoproterozoic–early Cambrian stratigraphy in the far west Amadeus Basin (WA) could be recognised in the Mount Conner area.

The revision of the stratigraphy at Mount Conner reported herein involves two components. The first is correlating Neoproterozoic–early Cambrian units with part of the succession in the WA portion of the basin – exposures formerly mapped as Winnall beds at Mount Conner are now identified as Carnegie Formation and Ellis Sandstone (WA). If correct, these correlations would extend the age of the Winnall beds into the early Cambrian. The second component comprises revised stratigraphy related to Neoproterozoic units exposed in the northeast of the basin – recognition of the Loves Creek Formation of the Bitter Springs Group, probable Wallara Formation, the Areyonga Formation (including a newly defined member) and the Aralka Formation (including its Ringwood Member) in units previously mapped collectively as Inindia beds.

The report includes rock descriptions of the Neoproterozoic–early Cambrian succession and a revised geology map of the Mount Conner region.
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INTRODUCTION

The Amadeus Basin is a large (~170,000 km²) intracratonic basin, mostly within the NT (Figure 1) and about one fifth extending into WA. The basin succession ranges from late Neoproterozoic to Devonian in age. The eastern and northern parts of the basin, where broad correlations are possible, have been studied since the 1960s (eg Wells et al 1965, 1966, 1967, Preiss et al 1978); the Neoproterozoic to Early Cambrian stratigraphy has largely been formalised from exposures in these areas. However, the succession in the southern and western parts of the basin is not as well defined due to discontinuous outcrop and changes in unit names across the NT/WA border.

Mapping in the western Amadeus Basin by GSWA (Haines et al 2010, 2012) indicated that substantial revision of the Neoproterozoic and early Cambrian stratigraphy in WA was necessary. NTGS conducted a brief field trip to the Mount Conner area in the southern part of the basin (AYERS ROCK; Figure 1) with GSWA colleagues to further establish the validity and regional application of the proposed WA stratigraphic changes and to relate these changes to the stratigraphic nomenclature in use in the NT.

The first and second edition mapping of AYERS ROCK (Forman 1965; Young et al 2002a) identified two Neoproterozoic units in the Mount Conner area - the Inindia beds and overlying Winnall beds (Figure 2). The Inindia and Winnall beds are widely distributed across the central, southern, and western parts of the Amadeus Basin in the NT (Figure 1) where they represent all of the Neoproterozoic sedimentary succession above the Bitter Springs Group. The first basin-wide Neoproterozoic stratigraphic correlation was published by Wells et al (1970). There have been significant modifications made to the nomenclature and correlations since 1970 such as the major stratigraphic review undertaken by Preiss et al (1978). Until recently, these modifications have largely been applied to the better-exposed succession in the northeast of the basin (eg Korsch and Kennard 1991). Haines et al (2012) suggested a revised Neoproterozoic–early Cambrian stratigraphic framework of the southern, central, and western Amadeus Basin using the stratigraphy of the northeast (Figure 3). This concept is herein applied to the succession in the Mount Conner area.

Mount Conner is located 285 km southwest of Alice Springs and 100 km east of Yulara (Figure 1). It rises about 300 m above the surrounding landscape as a horseshoe-shaped, sandstone-capped mesa, dissected by rocky gorges and topped with a summit ringed by near vertical cliffs (Figure 4). Two sandstone ridges surround Mount Conner within an expansive landscape of sandplains and dunefields.

Names of 1:100 000 and 1:250 000 mapsheets are shown in small and large capital letters respectively, ie LIMBLA, ILLOGWA CREEK.
PREVIOUS GEOLOGICAL WORK

Mount Conner was first described by Basedow (1905), and the area was mapped by the Bureau of Mineral Resources (BMR; now Geoscience Australia) during the 1960s for the 1st edition AYERS ROCK (Forman 1965). Mount Conner was also investigated by Ranford et al (1965) as part of the BMR research and mapping of the Amadeus Basin and greater central Australia. The generation of the second edition AYERS ROCK (Young et al 2002a) lead to detailed mapping of the area (Figure 5). The geology of the region is also described by Young (1992) and Camacho (1991). Provenance studies by Camacho et al (2002) included samples of the lower and upper Inindia beds and Winnall beds from the Mount Conner area.

STRATIGRAPHY

The lithostratigraphic descriptions herein are based on field observations in the Mount Conner area. Stratigraphic unit names are those from Haines et al (2012) revised stratigraphic framework (see Discussion below; Figure 6).

Inindia beds

The area surrounding Mount Conner is depicted as Inindia beds on the published geological maps (Figure 5; Young et al 2002a). The Inindia beds are equivalent to most of the Neoproterozoic succession (Areyonga to Julie formations) of the north and northeast Amadeus Basin. Field observations indicate that the low rises in the peripheries of the Mount Conner area can be recognised as Loves Creek Formation of the Bitter Springs Group, probably overlain by Wallara Formation (Figure 6). The prominent ridges surrounding Mount Conner are recognised as Areyonga Formation (including a new constituent Conner Member); the low-lying area between these ridges and Mount Conner is formed of the overlying Aralka Formation (Figure 6).

Bitter Springs Group - Loves Creek Formation

A small, isolated outcrop (52J 796964mE 7182872mN), interpreted to belong to the Bitter Springs Group (formerly Bitter Springs Formation), was observed 8 km northeast of Mount Conner (Figure 6). The outcrop is composed of chert (silicified carbonate) with preserved columnar stromatolites delineated by laminations of black chert and massive buff chert (Figure 7). The stromatolites are too silicified to be identified; however, their general form indicates they belong to the Loves Creek Formation. The Loves Creek Formation (Figure 3) is the middle member of the Bitter Springs Group and was deposited in a series of upward-shallowing cycles (Southgate 1991).

Previous mapping (Forman 1965; Young et al 2002a) did not record any exposures of Bitter Springs Formation in...
the Mount Conner area (Figure 5). The closest occurrences shown on AYERS ROCK are two small, isolated outcrops of grey to cream massive dolostone located 60 km north-northwest of Mount Conner (Young et al 2002b). Subsurface occurrences were recorded in stratigraphic drillhole Ayers Rock 2 (Figure 1) about 50 km to the northwest (Bladon and Davies 1982), which intersected carbonate rocks and basalts.

**Wallara Formation**

The Wallara Formation (formally ‘finke beds’) is a newly defined unit (Normington et al 2015; Normington and Donnellan in review) that sits, probably unconformably, above the Bitter Springs Group and beneath the Areyonga Formation (Figure 3). Previously only described in some petroleum wells in the central part of the basin, the Wallara Formation has been recognised in outcrop in the far west of the basin in WA (Haines et al 2011) and in the central north and the central part (HENBURY; Donnellan and Normington 2017) of the basin in NT. The Wallara Formation generally comprises sandstone, siltstone, chert (surface exposures only) and carbonate lithofacies. The formation contains a diagnostic stromatolite Bacalita burra, which has been recorded in most exposures (Allen et al 2012, Haines and Allen 2014, Normington et al 2015) and in drillholes (Grey et al 2012).

Surficial calcrete with occasional low exposures of well silicified, grey sandstone or chert, caps a low 5 km strike length rise centred at 52J 783621mE 7183495mN. The calcrete may indicate the presence of subsurface carbonate rocks or calcareous siliciclastic rocks. These lithologies, and the stratigraphic position of this subcrop (overlying rare local exposure of Bitter Springs Group and underlying the Areyonga Formation; see below) have led to the interpretation that this unit is likely to be Wallara Formation (Figure 6).

Further evidence for the presence of the Wallara Formation in this area are the presence of a stromatolitic domal feature within rubbly subcrop of the sandstone and clasts of the Bacalita burra stromatolite in conglomerate of the overlying Areyonga Formation (Figure 8).

![Figure 3. Revised stratigraphy of the Neoproterozoic–early Cambrian Amadeus Basin succession.](image-url)
Areyonga Formation

The Areyonga Formation is correlated with deposits of the late Neoproterozoic Sturtian glaciation; it comprises sandstone, mudstone, diamicite and conglomerate facies. It is exposed in low to prominent arcuate strike ridges surrounding Mount Conner (Figure 6). It stratigraphically overlies the Bitter Springs Group and probable Wallara Formation (Figure 3). Exposed lithologies from base to top comprise: flaggy and low angle cross-bedded sandstone in a low, discontinuous ridge 7 km northwest (52J 788909mE 7184160 mN) and about 5 km northeast (52J 797387mE 7181012mN) of Mount Conner; a middle facies of poorly exposed conglomerate (52J 784002mE 7181186mN); and an upper prominent ridge-forming cross-bedded sandstone unit (52J 797588mE 7177749mN and 783649mE 7174436mN).

The middle lithofacies of the Areyonga Formation is comprised of diamicite or fluvo-glacial sedimentary rocks. The diamicite has a mudstone matrix and angular clasts. The clasts are dominantly black laminated (banded) or oolitic chert; lesser components include vein quartz,
Figure 6. Revised stratigraphy of the Mount Conner area.

Figure 7. Silicified stromatolites tentatively assigned to the Loves Creek Formation of the Bitter Springs Group (52J 796964 mE 7182872mN).
quartzite and pale chert. The diamictite is interbedded with
calcareous cemented sandstone and mudstone beds.

The uppermost lithofacies of the Areyonga Formation
forms a prominent outer ridge (Figure 9a) of clean quartz
sandstone composed of well rounded, medium-grained,
well sorted quartz grains. The lower part is thickly bedded
and well laminated. The weathered surface is pale orange.
The rock is well-sorted and silicified (Figure 9b), and
contains large scale cross-beds with <2 m thick foresets
dipping at about 30°. The matrix contains occasional white
spots, likely former feldspar grains weathered to white clay,
probably kaolinite. Some quartz grains appear to be frosted.

The uppermost part of the upper lithofacies is herein
formally described as a new member – the Conner
Member – on the basis that it is a distinctive, unique,
and restricted sandstone unit interpreted to be aeolian in
origin (see Appendix). The Conner Member is regularly
bedded and contains high angle (30 to 40°) foresets up

Figure 8. a and b) Silicified stromatolites (Baicalia burra) of the Wallara Formation preserved as clasts within conglomerate of the Areyonga Formation (52J 796721mE 7181794mN).

Figure 9. a) Outer ridge of Mount Conner consists of aeolian sandstone of the Areyonga Formation. Photo taken looking east from 52J 783538mE 7173938mN. b) Base of aeolian sandstone. c) and d) Large foresets within the Conner Member of the Areyonga Formation.
to 10 m in thickness (Figure 9c, d). The sandstone has a platy appearance due to weathered pieces breaking along the bedding planes. The scale and angle of foresets, plus the well-sorted frosted quartz grains, are all consistent with an aeolian depositional environment. Although aeolian sediments have not previously been described from the Neoproterozoic succession of the Amadeus Basin, this unit is interpreted to represent aeolian sands deposited during a (?local) glacial maxima when minimal fluvial activity was present to rework or consolidate loose surface materials.

**Aralka Formation – Ringwood Member**

Small, discrete exposures of well laminated, buff, stromatolitic dolostone were observed amongst recent colluvium, alluvium and calcrete between the Conner Member and the base of the scree-covered slopes of Mount Conner (Figure 6; 52J 793087mE 7180341mN). Large domal bioherms within the dolostone are at least 1.5 m across (Figure 10a). These stromatolite bioherms (Figure 10b) previously have been informally reported as ‘clast-supported’ stromatolites (Walter 1972, Grey 2005); they are diagnostic of the Ringwood Member of the Aralka Formation (Grey 2005, Allen et al. 2012, Normington et al. 2015, Normington and Donnellan in review). These stromatolites are an important biostratigraphic marker within the Ringwood Member of the Aralka Formation as they commonly nucleate on intraclasts and thus, are stratigraphically constrained. This stromatolite form has now been formally named (*Atilanya fennensis*) and is fully described by Allen et al. (2015). Interbeds of lenticular intraclastic breccia were also observed within the unit, another facies commonly observed in the Ringwood Member of the Aralka Formation (Normington and Donnellan in review).

**Winnall beds**

Mount Conner is mapped as Winnall beds on the published geological maps (Figure 5; Young et al. 2002a). Historically the Winnall beds have been interpreted as equivalent to the Pertatataka Formation of the northeastern and central eastern parts of the basin. As discussed earlier, work in the WA portion of the basin suggests that the Winnall beds (NT) are correlative to the Carnegie Formation, Ellis Sandstone, Maurice Formation, and Sir Frederick Conglomerate. Field observations at Mount Conner indicate that the lowermost unit of Winnall beds exposed at the base, on the lower northern slopes, and on low ridges immediately to the north, is recognisable as Carnegie Formation. The overlying unit forming the scarp is recognisable as Ellis Sandstone (Figure 6). The Carnegie Formation is late Neoproterozoic; however, the Ellis Sandstone is dominantly early Cambrian in age (see Figure 2). These new correlations indicate that the depositional time span for the Winnall beds would be extended up into the early Cambrian, and therefore the Winnall beds may correlate with the Arumbera Sandstone of the northeast basin succession.

**Carnegie Formation**

The base and lower slopes of Mount Conner (Figure 11a), as well as several low sandstone ridges to the immediate north (52J 791465mE 7179066mN) comprise (Figure 6) friable, felspathic and micaceous, fine-grained sandstone and occasional siltstone; all are characteristic of the Carnegie Formation in WA. The sandstone is dark brown with a pale brown weathering surface (Figure 11b), occasionally with a red tinge when slightly ferruginised. The lower ridges are often pale brown and consist of cross-bedded clean, quartz sandstone. In some exposures, the sandstone varies from flaggy to well-bedded; some surfaces have abundant flute casts (Figure 11c).

**Ellis Sandstone**

The cliff-forming unit that caps Mount Conner (52J 790538mE 7176142mN; Figure 12a, b) is a poorly sorted, clean, cross-bedded, silicified, quartz sandstone with variable bed thickness. It includes numerous lenses of conglomerate comprised of quartzite and black chert clasts (Figure 6). Clasts are rounded and up to 10 cm in diameter. The unit also contains beds of kaolinitic quartz sandstone, and pebbly sandstone (Figure 12c) with minor calcareous sandstone (Figure 12d) and siltstone. As a whole, it dips shallowly to the north (10° to 010°); trough cross beds show transport towards 360°, 040°, 015°, 060°.
Figure 11. a) Sheer cliffs of Mount Conner, slopes comprised of Carnegie Formation overlain by cliff-forming Ellis Sandstone. Photo taken looking north from 52J 791379mE 7175915mN towards Mount Conner. b) Brown, feldspathic and micaceous sandstone of Carnegie Formation (52J 793342mE 717959mN). c) Flute clasts within the Carnegie Formation at the base of Mount Conner (52J 793342mE 717959mN).

Figure 12. a) Scarp of Mount Conner comprising Ellis Sandstone, photo taken looking south towards Mount Conner. b) Typical Ellis Sandstone outcrop (52J 791379mE 7175915mN). c) Pebble layer within Ellis Sandstone (52J 791360mE 7175973mN). d) Finely laminated sandstone and pebble layer of Ellis Sandstone (52J 791360mE 7175973mN).
DISCUSSION AND CONCLUSIONS

This study in the Mount Conner area has resulted in significant improvements to the known distribution and correlation of the Neoproterozoic succession in the south-central Amadeus Basin. The revisions and correlations herein are based on lithostratigraphy but are also supported in part by detrital zircon biostratigraphy.

A sedimentary succession spanning from the Loves Creek Formation of the Bitter Springs Group to the Aralka Formation is now recognised in outcrops formerly attributed to the Inindia beds in the surrounds of Mount Conner. Overlying this succession, outcrops formerly assigned to the Winnall beds are now correlated with the Carnegie Formation and Ellis Sandstone of the WA succession. Furthermore, this study suggests that the four informal subdivisions of the Winnall beds (Wells et al. 1970) can be now be correlated as follows: Carnegie Formation with unit 1; Ellis Sandstone (and Sir Frederick Conglomerate, not exposed at Mount Conner) with unit 2; and the Maurice Formation (not exposed at Mount Conner) with units 3 and 4 of the western Amadeus Basin. These new correlations extend the depositional age of the Winnall beds succession into the early Cambrian. Haines et al. (2010) have also suggested that the Winnall beds and WA correlatives above may be equivalent to the Arumbera Sandstone of the northeast basin succession (see Figure 2). However, it should be noted that further work is required to test the regional veracity of these correlations with other exposures of Winnall beds across the extent of the southern basin.

The recognition of the possible presence of the Wallara Formation is particularly important. If correct, the known exposure of this newly formalised unit would be extended into the southern part of the basin. In addition, work in WA (PW Haines and H Allen, GSWA, pers comm 2011) and work on correlating the Cryogenian of Australia (Grey et al. 2011) has identified that the Wallara Formation has a distinct biostratigraphy of particular significance to Australian and probably global correlations of the Cryogenian. Since that study, outcrop of the Wallara Formation has also been recognised in the central and northern parts of the basin (Donnellan and Normington 2017; Normington et al. 2015).

A unit of cross-bedded sandstone within the upper Areyonga Formation, interpreted to have an aeolian origin, is unique and apparently restricted to the Mount Conner area. It is herein formally named the Conner Member of the Areyonga Formation (Appendix 1). U–Pb zircon dating of this sandstone would provide useful provenance information, particularly with reference to the existing Inindia beds detrital zircon data from this region (Camacho et al. 2002).

The uppermost Neoproterozoic units of the basin succession (Olympic/Pioneer, Pertatataka, and Julie formations) were not observed at Mount Conner. They are also absent from both stratigraphic drillhole BR05DD01, 190 km to the northwest (Figure 1), and Murphy 1 petroleum well, about 75 km to the east-northeast (Figure 1). Donnellan and Normington (2017) reported isolated exposures of Pertatataka Formation and Pioneer Sandstone in the central basin (southeastern HENBURY). The Olympic/Pioneer and Julie formations are largely confined to the northeast of the basin; they disappear from outcrop westwards from the central northern margin, with the Julie Formation reappearing and thickening along the northern margin in WA. In this context, their absence at Mount Conner is not notable. The Carnegie Formation has herein been equated to the lower part of the Winnall beds, and by inference, the lower part of the Arumbera Sandstone (Figures 2 and 3). However, as interpreted by earlier studies (see Figure 2), it is possible that the Winnall beds may also partly correlate with the Pertatataka Formation. Significant work is required to refine the subdivision and correlations of the succession currently depicted as Winnall beds across the basin.

The results from this study suggest that similar advances in the known distribution of Neoproterozoic formations are likely to be possible in areas currently depicted as Inindia or Winnall beds across the southern extent of the basin. An expanded study to undertake this work would enhance understanding of early basin architecture, leading to increased knowledge of the distribution and correlation of individual formations and a greater understanding of changing basin dynamics throughout the Neoproterozoic to early Cambrian.

ACKNOWLEDGEMENTS

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REFERENCES


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*


## APPENDIX: CONNER MEMBER DEFINITION CARD

<table>
<thead>
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<th>NAME OF UNIT:</th>
<th>Conner Member</th>
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<td>STATUS OF UNIT:</td>
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<td>RANK:</td>
<td>Member</td>
</tr>
<tr>
<td>PROPOSER:</td>
<td>VJ Normington, CJ Edgoose</td>
<td>DATE:</td>
<td>January 2018</td>
</tr>
<tr>
<td>RESERVED IN STRATIGRAPHIC UNITS DATABASE:</td>
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<td></td>
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</tr>
<tr>
<td>PROPOSED PUBLICATION:</td>
<td>This Record</td>
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<td></td>
</tr>
</tbody>
</table>

### DERIVATION OF NAME
After Mount Conner (MGA94, 52J, 791349mN, 7177358mE), where this unit is exposed in the outer ridge of the structure. Mount Conner is on the eastern most portion of AYERS ROCK 250k mapsheet.

### SYNONYMY, UNIT NAME HISTORY
None

### CONSTITUENT UNITS
None

### PARENT UNIT
Areyonga Formation

### TYPE LOCALITY
Outer ridge on western side of Mount Conner (MGA94, 52J, 782684mN, 7176885mE), the ridge extends around most of Mount Conner. The most complete and best exposed rock is on the western to northwestern side.

### CONSTITUENT UNITS
None

### LITHOLOGY
The unit is clean, quartz sandstone with well-rounded and sorted, evenly sized, medium-sized quartz grains overlying a lower sandstone that is massively bedded and well laminated. The sandstone has large angle cross beds with foresets of ~ 30°. These sedimentary structures weather to form platy surfaces.

### THICKNESS
Not known

### FOSSILS
None observed

### DIASTEMS OR HIATUSES (if relevant)
N/A

### RELATIONSHIPS & BOUNDARY CRITERIA
The Conner Member sits stratigraphically between exposures of diamictite of the Areyonga Formation and stromatolitic dolostone units of the Aralka Formation; the Conner Member is therefore identified as part of the upper Areyonga Formation.

### DISTINGUISHING OR IDENTIFYING FEATURES
Well rounded, well sorted sandstone which has large angle cross bedded and in foresets of 30°.

### AGE & EVIDENCE
Assumed Sturtian in age due to the stratigraphic position in the upper part of the Areyonga Formation. The Areyonga Formation are glacial sediments deposited during the Sturtian glaciation (Preiss et al 1978).

### CORRELATION WITH OTHER UNITS
None known

### REGIONAL ASPECTS/GENERAL GEOLOGICAL DESCRIPTION
Red to orange sandstone resistant to weathering; often forming ridges.

### EXTENT
Outer ridge of Mount Conner, AYERS ROCK 250k mapsheet

### GEOMORPHIC EXPRESSION
Mostly continuous ridge of sandstone, with large cross beds. These cross beds weather to form a platy exposure.

### THICKNESS VARIATIONS
N/A

### STRUCTURE AND METAMORPHISM
Mount Conner is a mesa approximately 300 m above the surrounding landscape, with ridges with several near-vertical cliffs surrounding the mesa. The Conner Member forms the outermost ridge of the structure.

### ALTERATION AND MINERALISATION
None

### GEOPHYSICAL EXPRESSION
Some expression of the ridge in and 1VD magnetics and minor expression in ternary radiometrics.

### GEOCHEMISTRY
N/A

### GENESIS/DEPOSITIONAL ENVIRONMENT
Rounding and sorting of the sandstone as well as the nature of the cross beds indicate an aeolian depositional environment; it is possible that the deposition of the Conner Member was associated with the Sturtian glaciation when climatic conditions were dry and very cold (Rodríguez-López et al 2014).

### REFERENCES

### COMMENTS
N/A