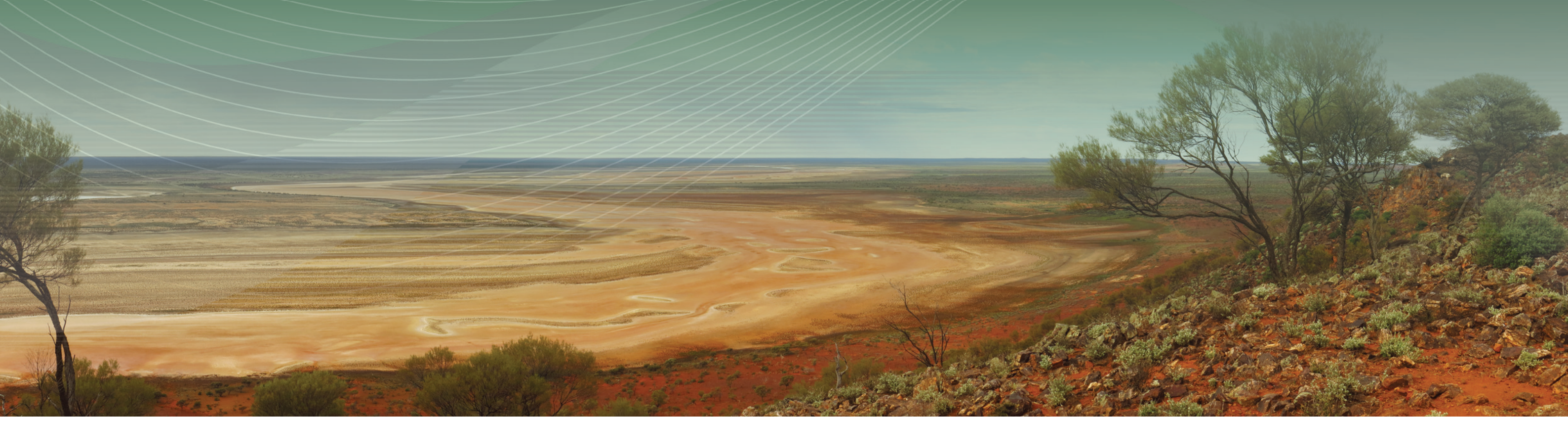
Government of **Western Australia**
Department of **Mines, Industry Regulation and Safety**

RECORD 2018/11

THE CRYOGENIAN ARALKA FORMATION, AMADEUS BASIN: A BASINWIDE BIOSTRATIGRAPHIC CORRELATION

by
HJ Allen, K Grey, PW Haines, CJ Edgoose and VJ Normington



Geological Survey of Western Australia

NORTHERN TERRITORY GOVERNMENT

Government of **Western Australia**
Department of **Mines, Industry Regulation and Safety**

RECORD 2018/11

THE CRYOGENIAN ARALKA FORMATION, AMADEUS BASIN: A BASINWIDE BIOSTRATIGRAPHIC CORRELATION

by
HJ Allen, K Grey, PW Haines, CJ Edgoose[*] and VJ Normington[*]

[*] Northern Territory Geological Survey, NT 0800 Australia

PERTH 2018

Geological Survey of Western Australia

MINISTER FOR MINES AND PETROLEUM
Hon Bill Johnston MLA

DIRECTOR GENERAL, DEPARTMENT OF MINES, INDUSTRY REGULATION AND SAFETY
David Smith

EXECUTIVE DIRECTOR, GEOLOGICAL SURVEY AND RESOURCE STRATEGY
Jeff Haworth

REFERENCE
The recommended reference for this publication is:
Allen, HJ, Grey, K, Haines, PW, Edgoose, CJ and Normington, VJ 2018, The Cryogenian Aralka Formation, Amadeus Basin: a basinwide biostratigraphic correlation: Geological Survey of Western Australia, Record 2018/11, 32p.

ISBN 978-1-74168-823-8
ISSN 0728-2311

Grid references in this publication refer to the Geocentric Datum of Australia 1994 (GDA94). Locations mentioned in the text are referenced using Map Grid Australia (MGA) coordinates, Zones 52 and 53. All locations are quoted to at least the nearest 100 m.

NORTHERN TERRITORY GOVERNMENT

Published 2018 by the Geological Survey of Western Australia
This Record is published in digital format (PDF) and is available online at <www.dmp.wa.gov.au/GSWApublications>.

Further details of geological products and maps produced by the Geological Survey of Western Australia are available from:
Information Centre
Department of Mines, Industry Regulation and Safety
100 Plain Street
EAST PERTH WESTERN AUSTRALIA 6004
Telephone: +61 8 9222 3459 Facsimile: +61 8 9222 3444
www.dmp.wa.gov.au/GSWApublications

Cover image: Elongate salt lake on the Yilgarn Craton — part of the Moore–Monger paleovalley — here viewed from the top of Wownaminya Hill, 20 km southeast of Yalgoo, Murchison Goldfields. Photograph by I Zibra, DMIRS

Contents

Figures

Appendices

The Cryogenian Aralka Formation, Amadeus Basin: a basinwide biostratigraphic correlation

by

HJ Allen, K Grey, PW Haines, CJ Edgoose* and VJ Normington*

Abstract

Stratigraphically constrained stromatolite assemblages have been useful in Australia-wide correlations of Neoproterozoic successions, and particularly in helping to establish recent Geological Survey of Western Australia (GSWA) and Northern Territory Geological Survey (NTGS) revisions to Neoproterozoic–Cambrian stratigraphy and correlations in the Amadeus Basin. The Cryogenian Aralka Formation, a proven hydrocarbon source in the Northern Territory, was previously mapped in outcrop only in the northeastern part of the Amadeus Basin. Following recent fieldwork, it can now be recognized across much of the basin, including a previously unrecognized thick section in the Boord Ridges area in Western Australia. The discovery of new outcrop and drillhole intersections with stromatolite occurrences prompted systematic revision of stromatolites in the Aralka Formation and analysis of their distribution.

A distinct stromatolite assemblage, thus far restricted stratigraphically to the Aralka Formation and characterized by the presence of *Tungussia inna* and *Atilanya fennensis*, is documented in this Record. The assemblage also contains other stromatolites not yet systematically described that are similar to stromatolites in the Cryogenian Umberatana Group of the Adelaide Rift Complex. The interglacial Aralka Formation is commonly barren of organic-walled microfossils, but a new species, *Vandalosphaeridium* sp. nov., is documented from NTGS stratigraphic drillhole BR05DD01. The species is abundant in a single sample and, combined with stromatolite data, could prove to be a valuable stratigraphic marker if encountered elsewhere in the basin.

KEYWORDS: biostratigraphy, Cryogenian, hydrocarbon exploration, Neoproterozoic, Proterozoic, stratigraphy, stromatolites

Introduction

The Cryogenian Aralka Formation is a siltstone and shale unit with minor interbedded carbonate and sandstone. Defined in the late 1970s (Preiss et al., 1978), the Aralka Formation has been recognized only sporadically in drillholes, or wrongly assigned to different units in others. The geographic extent of the Aralka Formation has been underestimated because of poor-quality outcrop. Prior to recent fieldwork, the Aralka Formation was thought to be absent in the western part of the Amadeus Basin. A reassessment of the stratigraphy in Western Australia (Haines et al., 2010a,b, 2012a; Haines and Allen, 2014) and the south-central Amadeus Basin (Edgoose et al., 2018) has resulted in identification of the Aralka Formation across the Amadeus Basin.

Recognition of a distinct stromatolite assemblage, characterized by *Tungussia inna* and *Atilanya fennensis*, thus far restricted stratigraphically to the Aralka Formation, has supported stratigraphic revisions of the Amadeus Basin. This Record documents the distribution of the assemblage from four outcrop areas and one drillhole. These include the Boord Ridges in Western Australia (WA); and, in the Northern Territory (NT), the area surrounding Mount Conner in the south-central part of the basin at Fenn Gap (27 km west-southwest of Alice Springs), in the Ringwood area of the eastern Amadeus Basin, as well as in NTGS stratigraphic drillhole BR05DD01 in the Bloods Range area. Also documented are other stromatolites yet to be systematically described from the Ringwood area, together with the occurrence of an unnamed stromatolite in clasts, probably derived from the Aralka Formation, in the overlying Olympic Formation, approximately 40 km east of Alice Springs. The Aralka Formation commonly lacks organic-walled microfossils, but a new species, *Vandalosphaeridium* sp. nov., was recently extracted from 155.28 m in the Aralka Formation in NTGS stratigraphic drillhole BR05DD01. The species is abundant in a single sample and could prove to be a valuable stratigraphic marker if encountered in other drillholes.

Geological setting

The Amadeus Basin (Wells et al., 1967, 1970; Korsch and Kennard, 1991; Edgoose, 2012, 2013) is a Neoproterozoic–Paleozoic depositional system exposed in central Australia. The Amadeus Basin stratigraphic succession can be divided into two phases of deposition (Munson et al., 2013): a lower Neoproterozoic – earliest Cambrian succession up to and including deposits of the Petermann Orogeny; and a younger early Paleozoic depositional system that followed the Petermann Orogeny. Deposits of the early Paleozoic system are thickest in the eastern Amadeus Basin and largely missing in the WA section of the basin.

* Northern Territory Geological Survey, NT 0800 Australia

The Neoproterozoic component of the Amadeus Basin was linked to a number of other basins covering an estimated two million square kilometres of central Australia as part of the greater Centralian Superbasin (Fig. 1). As originally defined (Walter et al., 1995) the Centralian Superbasin included Neoproterozoic successions of the Amadeus, Officer, Ngalia and Georgina Basins; however, this has since been extended to include Neoproterozoic successions of the Yeneena, Murraba, Louisa, Wolfe and Victoria Basins (Tyler and Hocking, 2002; Munson et al., 2013) and extensions of these beneath the Canning Basin (Haines et al., 2018). This single large intracratonic depositional system was contiguous with the Adelaide Rift Complex (Munson et al., 2013) which evolved into a continental margin succession during deposition. The Centralian Superbasin maintained stratigraphic integrity across a large expanse, with common biostratigraphic elements occurring in far-reaching parts (Walter, 1972a; Walter et al., 1979; Grey and Corkeron, 1998; Grey, 2005; Grey et al., 2005, 2011, 2012; Grey and Calver, 2007; Allen et al., 2012).

The Neoproterozoic succession of the Centralian Superbasin was divided into four supersequences (Fig. 1) to facilitate regional correlations (Walter et al., 1995). The Aralka Formation lies between two glacial episodes that mark the base of Supersequences 2 and 3, respectively (Fig. 2). This allows the formation to be placed in its regional stratigraphic context and correlated with equivalent Cryogenian units across Australia. Correlations are based on both field sections and continuous core from drillholes, using a variety of integrated techniques, such as lithostratigraphy, biostratigraphy (organic-walled microfossils and stromatolites), chemostratigraphy ($\delta^{13}C$ and $^{87}Sr/^{86}Sr$), as well as well-log and other geophysical data (Walter, 1972a,b; Walter et al., 1995, 2000; Hill and Walter, 2000; Hill et al., 2000a,b; Grey, 2008; Grey et al., 2005, 2011, 2012; Allen et al., 2012).

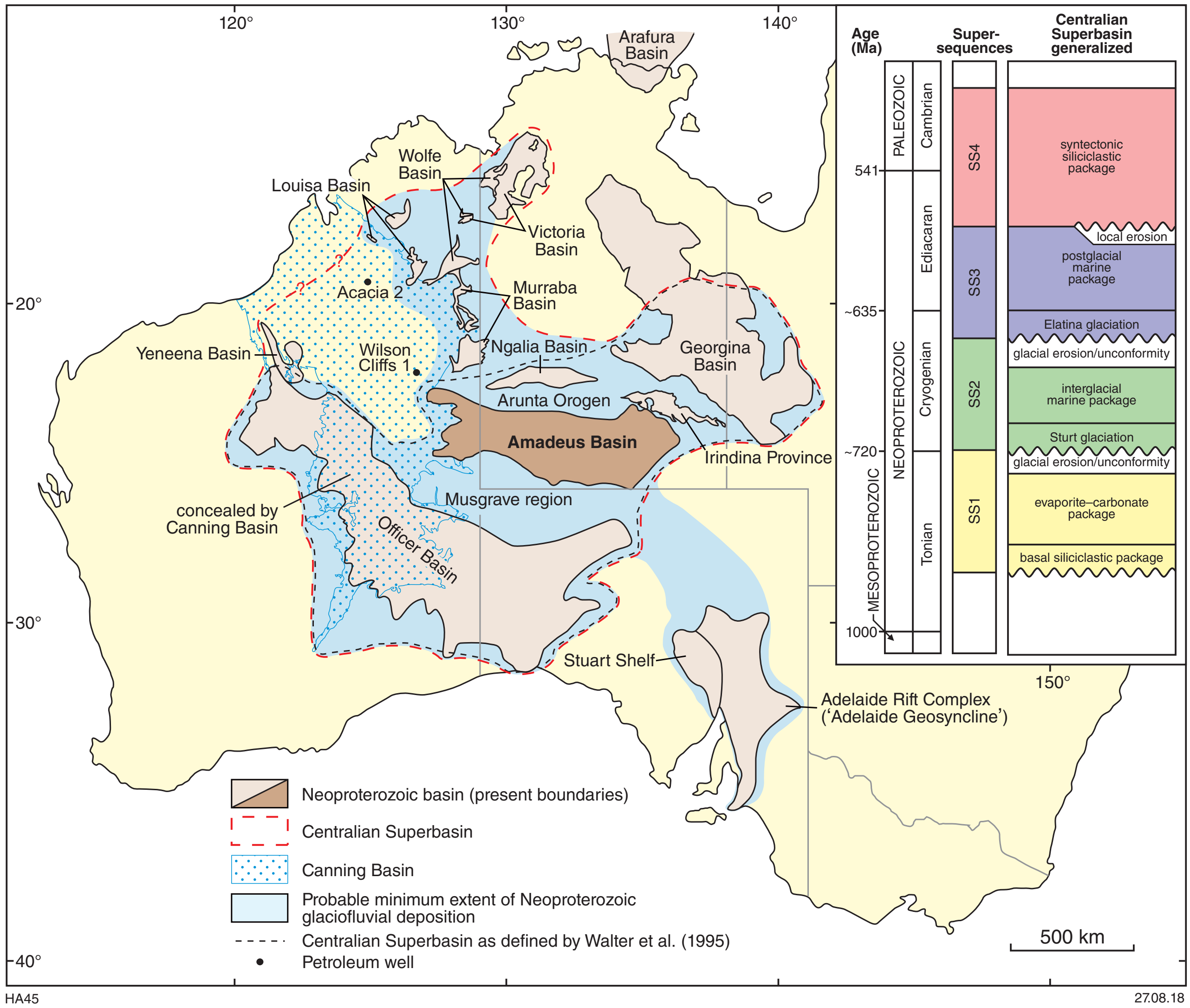


Figure 1. **The Centralian Superbasin (modified after Munson et al., 2013), with the Amadeus Basin highlighted. A generalized stratigraphy of the Centralian Superbasin is shown in the inset**

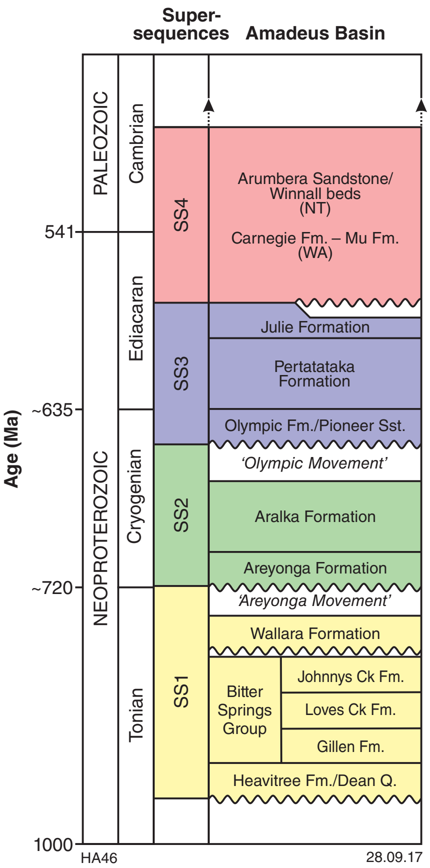


Figure 2. Neoproterozoic stratigraphy of the Amadeus Basin

Amadeus Basin Neoproterozoic stratigraphy

Neoproterozoic units (Fig. 2) of the Amadeus Basin were deposited in a shallow-marine setting intermittent with discrete sediment pulses resulting from regional orogenic events. Tonian deposition began with a basal siliciclastic package: the Heavitree Formation in the north, and the Kulail Sandstone and Dean Quartzite in the south (Haines et al., 2012a). The overlying Bitter Springs Group is dominated by carbonate rocks with fine siliciclastic interbeds. The group includes evaporites within the Gillen Formation near the base responsible for the halotectonic structural overprint in large portions of the basin, stromatolitic carbonate of the Loves Creek Formation and an upper Johnnys Creek Formation that includes red mudstone and interbedded carbonate, with a local volcanic component. The overlying Wallara Formation, similarly deposited in a shallow-marine setting, includes ooid chert and carbonate that contains the biostratigraphic marker stromatolite *Baicalia burra* (Grey et al., 2012).

The Cryogenian succession of alternating carbonate and fine- to coarse-grained siliciclastics, includes two widespread glacial intervals: the Sturt ('Sturtian') and Elatina ('Marinoan') glaciations that can be correlated throughout the Centralian Superbasin and adjacent Adelaide Rift Complex. The lower of these, the Sturt glaciation, was coeval with deposition of the Areyonga Formation. The upper of these, the Elatina glaciation, was coeval with deposition of the Olympic Formation and correlative Pioneer Sandstone.

The latest Ediacaran succession in the Amadeus Basin is an immature deltaic to non-marine package of red sandstone and minor interbedded mudstone deposited during the Petermann Orogeny (Edgoose, 2013). The Precambrian–Cambrian boundary is recorded within the Arumbera Sandstone of the eastern Amadeus Basin by the first appearance of a Cambrian trace fossil assemblage; however, this assemblage is not recorded in the correlated Carnegie Formation, Ellis Sandstone and Maurice Formation in the west, due to a facies change.

The Aralka Formation

The subject of this Record, the Cryogenian Aralka Formation, is the interglacial interval within upper Supersequence 2 (Fig. 2).

Definition

In the northern and eastern Amadeus Basin, the interval now comprising the Aralka Formation was originally included in the Pertatataka Formation (Wells et al., 1967, 1970). A redefinition of much of the Neoproterozoic stratigraphy by Preiss et al. (1978) subdivided the original Pertatataka Formation into five formations. From base to top, these included the Aralka Formation; the Olympic Formation (former Olympic Member) and laterally equivalent Pioneer Sandstone; the revised Pertatataka Formation; and finally, the Julie Formation (former Julie Member). The Aralka Formation included the Ringwood and Limbla Members and all previously undifferentiated siltstone and shale units underlying the glacigene Olympic Formation and its equivalent. The Aralka Formation was named after Mount Aralka (Hale River, Zone 53J, MGA 548820E, 7343634N). The currently published type section is shown in Wells et al., 1967 (ASR4 Plate 10) and is located 6.5 km southeast of Ringwood Homestead, on a ridge approximately 1.4 km east of Halfway Dam (Illogwa Creek approximately Zone 53K, MGA 501637E 7360086N).

Distribution

The Aralka Formation, when originally defined, was confined to outcrop sections in the northeastern part of the Amadeus Basin. As a result of stratigraphic reassessment, its extent is now documented across the basin (Haines and Allen, 2014; Allen et al., 2016; Edgoose et al., 2018). Drillhole sections have previously been documented in Wallara 1 (Indigo Oil and Sirgo Exploration, 1990), Illogwa Creek 6, Murphy 1, Ooraminna 1 and Ooraminna 2 (Ambrose et al., 2012). More recently, the Aralka Formation has been recognized in drillholes CPDD001, CPDD002, and CPDD003 in the northeastern part of the Amadeus Basin (Normington and Edgoose, 2018) and in NTGS stratigraphic drillhole BR05DD01 (Allen et al., 2016) in the central part of the basin.

Outcrop sections include those on Illogwa Creek as above (see 'Definition') and also Alice Springs, Rodinga and Hale River. Newly documented outcrop sections include those at Fenn Gap in the central part of the basin (Allen et al., 2016), Mount Conner in the southern part of the basin (Allen et al., 2016; Edgoose et al., 2018), on Henbury (Donnellan et al., in prep.) and the Boord Ridges in the western part of the basin (Haines and Allen, 2014).

Lithology

In drillcore, the Aralka Formation is interbedded black siltstone and mudstone with minor stromatolitic carbonate. In outcrop, the unit is typically expressed as carbonate strike bands that form low-lying ridges separated by poorly exposed siltstone.

Members

The Aralka Formation includes two formally defined members, but is dominated by siltstone sections that sit between, above and below these named members. The lower Ringwood Member (Wells et al., 1967) is carbonate dominated and commonly stromatolitic (Walter, 1972a; Allen et al., 2016). The upper Limbla Member (Wells et al., 1967) is characterized by festoon cross-laminated sandstone in its upper part and sandy calcarenite in the lower part (Munson, 2014).

Recently, Verdel and Campbell (2017) referred to all of the Aralka Formation beneath the Limbla Member (including a cap carbonate directly overlying the Areyonga Formation) as the Ringwood Member. By this convention, the Ringwood Member consists of four parts: 1) the Sturt glacial cap carbonate, as well as siltstone and thin-bedded carbonate that overlie this basal carbonate; 2) a carbonate-rich interval characterized by a unique stromatolite assemblage that includes *Tungussia inna* (Allen et al., 2016; Walter, 1972a) — the Ringwood Member as defined; 3) overlying carbonate parasequences with stromatolitic intervals, both above and below; and 4) an upper siltstone and laminated carbonate unit.

The convention of Verdel and Campbell (2017) has not been adopted in this publication. To avoid confusion and for clarification, the Aralka Formation comprises the following (in descending order):

- A poorly exposed, recessive siltstone interval which sits between the Olympic Formation and Limbla Member in the type area of the Hi Jinx Syncline.
- Limbla Member — as defined (Wells et al., 1967). An upper interval of festoon sandstone and calcarenite.
- A poorly exposed siltstone and shale interval between the defined Ringwood and Limbla Members.
- Ringwood Member — as defined (Wells et al., 1967). A carbonate-dominated and commonly stromatolitic interval, best exposed in the northeastern part of the basin.
- A siltstone and shale interval that lies above the cap carbonate that sits at the top of the Areyonga Formation and below the stromatolitic Ringwood Member.

Thickness

The thickness of the Aralka Formation is highly variable across the Amadeus Basin due to its stratigraphic position beneath deposits of the Elatina glaciation, the base of which is commonly marked by glacial erosion. The Aralka Formation is 1019 m thick at the type section (Preiss et al., 1978). In outcrop in Western Australia (Haines et al., 2010a,b, 2012a; Haines and Allen, 2014; Allen et al., 2016), it is estimated to be up to 450 m thick. A 26 m-thick section of Aralka Formation in Wallara 1 overlies the Areyonga Formation at 1306.64 m and underlies the Pioneer Sandstone at 1280.85 m (Indigo Oil and Sirgo Exploration, 1990). In BR05DD01, the Aralka Formation — originally reported as Pertatataka Formation in Ambrose et al. (2010) but reassigned by Allen et al. (2016) — is approximately 331 m thick and overlies the Areyonga Formation at 484.6 m. In drillholes Ooraminna 1 and Ooraminna 2, it was estimated to be approximately 280 m thick (Ambrose et al., 2012). In the central part of the Amadeus Basin, the Aralka Formation (presumably, only the lower part of the Formation, as no carbonate is present) was reported in outcrop 4.6 km west of Ellery Creek by Barovich and Foden (2000). We estimate the thickness of the formation in this section to be approximately 80 m.

Relationships and boundaries

The Aralka Formation lies above the glacial Areyonga Formation, which was deposited coevally with the Sturt glaciation, and is overlain by the Olympic Formation (and equivalent Pioneer Sandstone) which was deposited coevally with the Elatina glaciation (Fig. 2).

At the type section, the base of the unit is concealed, so a stratotype lower boundary is referenced on the northern flank of the Limbla Syncline. At this stratotype locality, Aralka Formation siltstone conformably overlies a dolomite unit at the top of the Areyonga Formation (Preiss et al., 1978). At the top of the type section, the Aralka Formation is disconformably overlain by the Olympic Formation (Preiss et al., 1978). These relationships are consistent at other locations where boundaries are exposed.

In Wallara 1, the base of the Aralka Formation (at 1306.64 m) corresponds to a sharp colour and lithology change from grey diamictite below, to dark grey to black siltstone above. The contact between the siltstone of the Aralka Formation and the basal sandstone of the Pioneer Sandstone (at 1280.85 m) was reported to be load-casted by Calver (1995), suggesting the Aralka Formation was unconsolidated when the Pioneer Sandstone was deposited.

In BR05DD01, the base of the Aralka Formation (484.6 m) is marked by a colour change from red–brown siltstone and diamictite (Areyonga Formation), to black siltstone of the Aralka Formation. The broken nature of the drillcore does not allow assessment of the boundary type in BR05DD01, but a colour change is evident across less than a centimetre. The Aralka Formation is unconformably overlain by red–brown siltstone and sandstone of Supersequence 4 (153.80 m), which extend to the top of the drillhole (Allen et al., 2016). The upper boundary in BR05DD01 is presumably erosive with all of Supersequence 3 missing. An abrupt colour change, with millimetre-scale pebbles observed at 153.08 m, is sharp but not obviously erosive. An alternative boundary at 153.80 m, marked by centimetre-scale clasts of red and black siltstone and dolomite, seems less likely on account of the lithology (between 153.80 and 153.08 m) but cannot be discounted.

In the Boord Ridges section of the western Amadeus Basin, the lower boundary with the Areyonga Formation is not exposed (Haines and Allen, 2014). In the same section, the upper boundary is irregular and obviously erosive, with the overlying Olympic Formation incising into the Aralka Formation. Large clasts of Aralka Formation, including metre-scale erratics, are present in the overlying Olympic Formation.

Depositional environment

The Aralka Formation was deposited in a marine environment during a post-glacial eustatic rise in sea level. The lower siltstone component of the Aralka Formation, commonly not exposed in outcrop but intersected in subsurface, was deposited under relatively deepwater conditions (below storm wave base). A shallowing in the upper part of the formation is indicated by deposition of stromatolitic carbonate (Allen et al., 2016). In the Boord Ridges section, this stromatolitic carbonate is restricted to the upper third of the formation, although stromatolites could be obscured by regolith below this point (Haines and Allen, 2014; Allen et al., 2016).

Intrabasin correlation

Munson et al. (2013) previously recognized the lower part of the Inindia beds as Supersequence 2 and so considered it to be a lateral correlative, in part, of the Aralka Formation. This correlation has been revised in the area of Mount Conner (Fig. 3) where outcrops of Inindia beds are considered the equivalent of a succession extending from upper Supersequence 1 to at least Supersequence 3 (Edgoose et al., 2018). Donnellan and Normington (2017) have recently revised the Inindia beds on HENBURY. Outcrops previously mapped as Inindia beds are now variously assigned to the Aralka Formation, Areyonga Formation and Pioneer Sandstone.

Interbasinal correlation

Interbasinal correlation of the Aralka Formation remains unclear, often because of uncertainties surrounding identification of the underlying and overlying glacial units. The Aralka Formation most probably correlates with the lower part of the Umberatana Group of the Adelaide Rift Complex, although precise correlations remain uncertain and various possibilities have been proposed. A correlation between the Ringwood Member of the Aralka Formation and the Brighton Limestone of the Adelaide Rift Complex, based on lithology and isotope curves, was suggested by Walter et al. (2000), Kendall et al. (2006) and Grey et al. (2011). However, none of the stromatolites present in the Brighton Limestone have yet been identified in the Aralka Formation.

The Aralka Formation taxon *Tungussia inna* has similarities to some specimens of *Tungussia etina*, including the holotype, S435, (Preiss, 1974, fig. 11c), although other specimens show diagnostic differences, particularly those that have thick, wavy, pinching and swelling light laminae that alternate with darker thin, fine-grained lamina and only a few continuous laminae. The similarities and differences between *Tungussia inna* and *Tungussia etina* require further investigation, especially as there could be stratigraphic implications.

There are similarities, including the possible presence of micro-pillared architecture, between *Atilanya fennensis* and *Omachtenia* f. indet. from the Balcanoona Formation that require further investigation. These Forms may indicate that part of the Aralka Formation correlates with the Balcanoona Formation if the two taxa are synonymous. This biostratigraphic correlation is supported by recent carbon-isotope stratigraphy of Verdel and Campbell (2017). Walter and Veevers (1997) correlated the Aralka Formation with the Tapley Hill Formation (including the Wockerawirra Dolomite) of the Umberatana Group of the Heysen Supergroup. The flaggy dolomitic Wockerawirra Member of the Tapley Hill Formation may correlate with the unnamed siltstone interval that includes carbonate interbeds below the Ringwood Member in the Aralka Formation.

The Aralka Formation was correlated with the Rinkabeena Shale because Walter et al. (1995) considered carbonate-concretion-bearing shales at the base of Aralka Formation to be a possible correlative of the cap dolomite at the top of the Naburula Formation in the Ngalia Basin (Walter and Veevers, 1997; Walter et al., 2000). In the Georgina Basin, a post-glacial interval, equivalent to the Aralka Formation, is missing. In both basins, the hiatus below the Elatina glaciation equivalents has been attributed to the Rinkabeena Movement (Munson et al., 2013).

In the Western Australian Officer Basin succession there is a depositional hiatus at the interval of the Aralka Formation. Correlatives of the Aralka Formation in the South Australian part of the Officer Basin probably lie within the Lake Maurice Group (Morton, 1997), but this interval has been poorly studied. Limited palynological data (Gravestock et al., 1995, p. 90, fig. G), suggest that further investigations may reveal a correlation between the Aralka Formation and the Meramangye Formation of the Officer Basin (Grey, unpublished).

In northwestern Tasmania, black shale at the top of Black River Dolomite (above the Julius River Member) is considered a correlative of the Aralka Formation (Calver, 1998; Calver and Walter, 2000; Kendall et al., 2009).

Recent Geological Survey of Western Australia (GSWA) fieldwork in the Murraba Basin has recognized that an Aralka Formation equivalent interval might be present in the Redcliff Pound area of this basin (Haines and Allen, 2017).

Age

With the exception of detrital zircon analyses, geochronology data is very limited from the Amadeus Basin Neoproterozoic succession. A rhenium–osmium (Re–Os) age of 657.2 ± 5.4 Ma was obtained on black shale in the basal Aralka Formation between 1298.2 and 1300.2 m in Wallara 1 drillhole (Kendall et al., 2006).

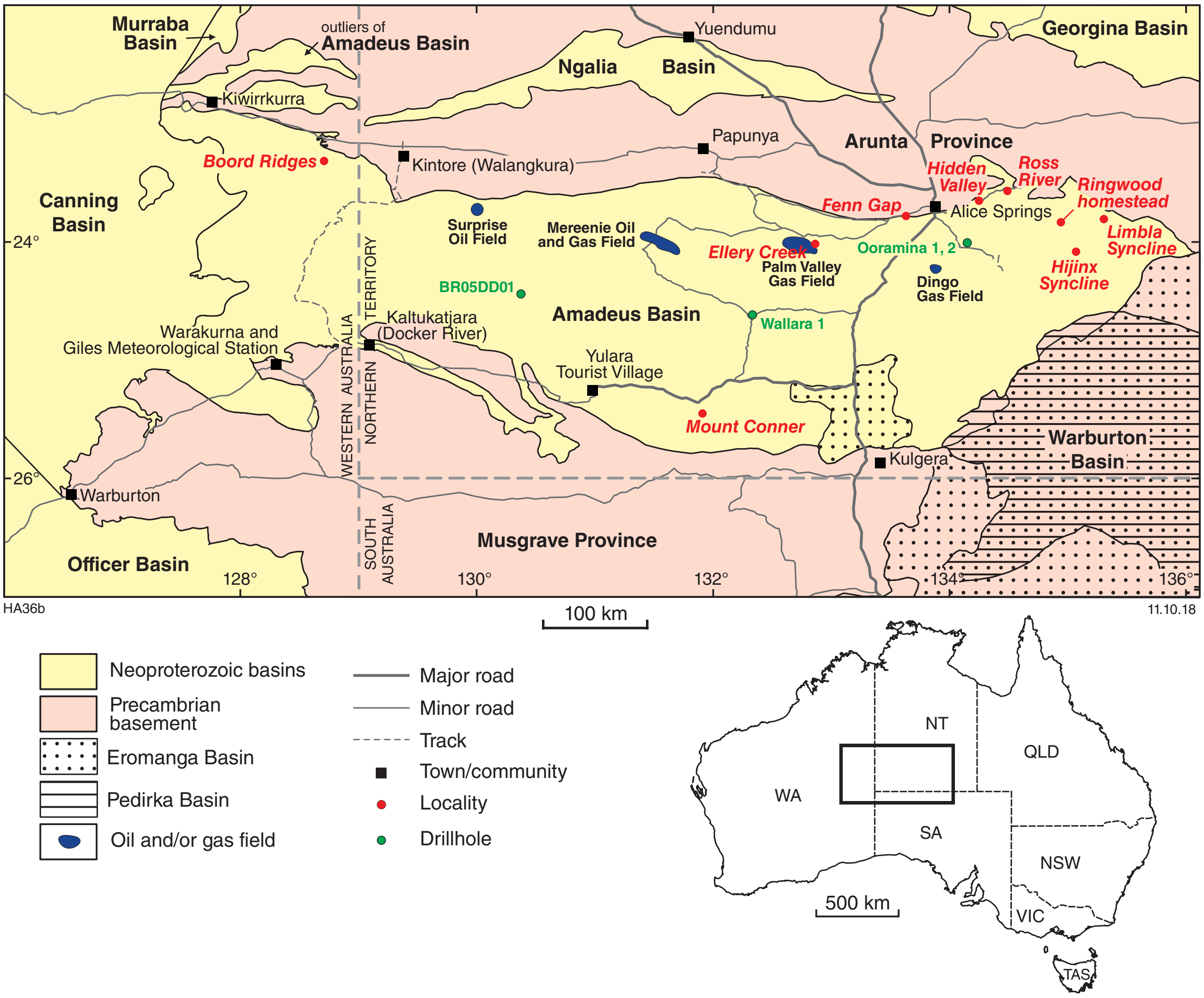


Figure 3. **Locality map**

This is currently the only dating available on the Aralka Formation. Comparable results of 643 ± 2.4 Ma on the Tindelpina Shale Member have been reported from the basal Tapley Hill Formation in the Adelaide Rift Complex and 641 ± 5 Ma from a black shale above the Julius River Member (of the Black River Dolomite) in Tasmania (Kendall et al., 2006, 2007, 2009).

The Aralka Formation in the Amadeus Basin can be geochronologically constrained by the following dates that rely on interbasinal correlations:

- In the western Officer Basin, a detrital zircon U–Pb sensitive high-resolution ion microprobe (SHRIMP) maximum depositional age of 725 ± 11 Ma was obtained from the upper Kanpa Formation in Empress 1A, about 200 m below the hiatus equivalent to the Sturt glaciation (Nelson, 2004), indicating that the glaciation and Aralka Formation is younger than c. 725 Ma. More recently, $^{40}Ar/^{39}Ar$ analyses of igneous pyroxene crystals yielded an age of c. 752 Ma for the Keene Basalt (Zi et al., 2017), a volcanic unit within the Kanpa Formation (Haines et al., 2004).
- In the Adelaide Rift Complex, a ‘porphyry’ intruding the Skillogalee Dolomite was dated at 795 ± 5 Ma (Preiss et al., 2009) using laser ablation inductively coupled plasma mass spectrometry (LA-ICP-MS). This conflicts with an age on an underlying rhyolite from the Boucaut Volcanics at the base of the Burra Group cited in Preiss (2000) as giving a U–Pb SHRIMP zircon age of 777 ± 7 Ma. However, the Boucaut Volcanics date was later considered unreliable by Fanning and Link (2008), compounded by uncertainty of its stratigraphic position due to outcrops occurring in isolation, possibly affected by structural complexities.
- A U–Pb zircon date on a thin volcaniclastic layer in the lower Wilyerpa Formation in the Adelaide Rift Complex, deposited during the waning phase of the Sturt glaciation, gave an age of 659 ± 6 Ma (Fanning and Link, 2008; Preiss et al., 2011).

Assuming that correlations between the Amadeus and Officer Basins and the Adelaide Rift Complex are correct, these dates imply the Aralka Formation was deposited after c. 660 Ma.

U–Pb ages from the top of the Cottons Breccia of King Island, considered to be a correlative of the Olympic Formation and Pioneer Sandstone that overlie the Aralka Formation in the Amadeus Basin, indicate an age of 636.41 ± 0.45 Ma for the end of the Elatina glaciation and the base of the Ediacaran Period (Calver et al., 2013).

Therefore, the current best estimate of the age of the Aralka Formation is between c. 660 Ma (allowing for the 657.2 ± 5.4 Ma Re–Os age of black shale in the basal Aralka Formation) and c. 636 Ma. This age is comparable to international estimates for the interglacial period of the Cryogenian (see Rooney et al., 2015).

The Aralka Formation is wholly Cryogenian in age following convention in the recent redefinition of the Cryogenian Period by the International Stratigraphic Commission (ISC) (Shields-Zhou et al., 2016).

Isotope chemostratigraphy

Parts of the Australian Neoproterozoic succession are now well correlated with global successions using $\delta^{13}C$ and $^{87}Sr/^{86}Sr$ isotope chemostratigraphy (Calver and Lindsay, 1998; Burgess, 1999; Hill et al., 2000a,b; Hill and Walter, 2000; Calver, 2000; Calver and Walter, 2000; Walter et al., 2000; McKirdy et al., 2001; Hill, 2005; Swanson-Hysell et al., 2010; Grey et al., 2011). However, until recent work by Verdel and Campbell (2016, 2017), data for the Cryogenian interval, and the Aralka Formation in particular, was comparatively sparser than for other parts of the Neoproterozoic succession.

Chemostratigraphic sections of the Aralka Formation include those from Wallara 1 (Walter et al., 2000; Grey et al., 2011), the Limbla Syncline (Walter et al., 2000; Grey et al., 2011) and numerous locations in the northeastern part of the basin (Verdel and Campbell, 2016, 2017). Recently, Verdel and Campbell (2017) identified key features of the Cryogenian section useful for correlation that include:

- negative $\delta^{13}C$ excursions in cap carbonates overlying the Areyonga (Rasthof excursion) and Olympic (Maieberg excursion) Formations
- a negative $\delta^{13}C$ excursion in the Ringwood Member of the Aralka Formation (equivalent to the Taishir excursion of southwest Mongolia)
- a positive $\delta^{13}C$ excursion (Keele Peak excursion) in the Limbla Member of the Aralka Formation.

The Aralka Formation interval appears unsuitable for $^{87}Sr/^{86}Sr$ chemostratigraphy because the data may not represent a primary seawater signature (Walter et al., 2000; Grey et al., 2011). Future studies on BR05DD01 and the western Amadeus Basin (in the event of drilling) might help to further refine the isotope chemostratigraphy of the interglacial interval in central Australia.

Stratigraphic revisions

Stratigraphic revision of the Neoproterozoic–Cambrian successions in the Amadeus Basin has been undertaken by GSWA and the Northern Territory Geological Survey (NTGS) to develop a basinwide stratigraphic framework (Haines et al., 2010a,b, 2012a,b; Edgoose, 2013; Munson et al., 2013; Donnellan and Normington, 2017; Edgoose et al., 2018). A number of changes in stratigraphic nomenclature are outlined in recent NTGS publications (see Normington et al., 2015; Donnellan and Normington, 2017; Normington and Edgoose, 2018, and references therein). In summary, the changes include:

- renaming the Heavitree Sandstone to the Heavitree Formation
- elevating the Bitter Springs Formation to the Bitter Springs Group
- reassignment of the Gillen and Loves Creek members to formations of the Bitter Springs Group
- formalizing the Johnnys Creek beds to Johnnys Creek Formation of the Bitter Springs Group
- formalizing the informal Finke beds (name invalid) as the Wallara Formation.

A review of stratigraphy in the southern central part of the basin, specifically, the Mount Conner area (Fig. 3), led to stratigraphic units previously mapped as Inindia beds (Ranford et al., 1965) being assigned to several formations better known from the northeastern part of the basin (Edgoose et al., 2018). This includes stratigraphic units extending from Supersequence 1 to at least Supersequence 3, including an interval now recognized as the Aralka Formation. These revisions were based on lithostratigraphy, surface expression of units and stromatolite distributions.

Revision in the Western Australia Amadeus Basin, and in particular of the stratigraphy exposed in the Boord Ridges, revealed that the Neoproterozoic succession in this area is more complete than previously thought (Haines and Allen, 2014). The stratigraphy in this area is directly comparable to that known from outcrop and drilling in the central and eastern Amadeus Basin. Units that were previously part of the now defunct 'Boord Formation' have been assigned to Supersequence 1–3 (Haines and Allen, 2014).

A continuously cored stratigraphic drillhole, BR05DD01 BLOODS RANGE (Ambrose et al., 2010) in the western part of the central Amadeus Basin (about 200 km southeast of the Boord Ridges) provides a link between the Western Australia succession and type, and drillhole sections recorded elsewhere in the basin. Initially, the interval from 55 m to the top of a diamictite at 484.6 m was logged as the Pertatataka Formation (Ambrose et al., 2010; Smith, 2011). A preliminary reassessment by Grey et al. (2012) suggested that a thin stromatolitic carbonate at 186.25 – 191.05 m might represent the Julie Formation based on the tentative identification of *Tungussia julia* and that the overlying interval might be better assigned to the Arumbera Sandstone. Further examination of the drillcore, acetate peels of the stromatolites and palynological analysis (see 'Palynology' below for details) now indicate that the interval from 153.08 – 484.6 m is the Aralka Formation (Allen et al., 2016). This reinterpretation is additionally supported by lithology, downhole geophysics, and the lack of an obvious disconformity at the base of the unit.

More recently, revision to key drillholes in the northeastern Amadeus Basin (CPDD001, CPDD002 and CPDD003) has increased the known distribution of the Aralka Formation (Normington and Edgoose, 2018).

Prospectivity

At least five petroleum systems have been recognized in the Amadeus Basin (Marshall et al., 2007; Haines et al., 2010a,b; Munson, 2014; Jarrett et al., 2016). Historically, hydrocarbon production within the basin has been from the younger Ordovician Larapintine system, but recent piping of gas from the Dingo Gas Field to Alice Springs marks the first production of Neoproterozoic-sourced hydrocarbons within the basin (Department of Mines and Energy, Energy Directorate, 2016).

Neoproterozoic – Early Cambrian petroleum systems, such as those in Oman, Russia and China, provide incentive to explore similarly aged successions within Australia (Ghori et al., 2009). Four petroleum systems of this age have been recognized in the Amadeus Basin (Marshall et al., 2007), one of which includes potential source rocks in the upper Bitter Springs, Areyonga and Aralka Formations and equivalents in the Inindia beds, with gas-prone source rocks reported from the Aralka Formation. Middle–Late Neoproterozoic transgressive organic-rich black shales associated with interglacial episodes, such as the Aralka Formation, and post-glacial phases of Neoproterozoic glaciations, are proven hydrocarbon source rocks (Le Heron and Craig, 2012; Craig et al., 2013). The role of glaciation in petroleum prospectivity is two-fold: glacial episodes can drive biotic turnover; but also, create favourable topographical settings for the deposition and accumulation of hydrocarbon resources (Le Heron and Craig, 2012).

In the Amadeus Basin, the Aralka Formation shows strong source-rock characteristics and has generated (or could generate) gas with some oil (Marshall, 2005; Munson, 2014). Earlier studies were undertaken by McKirdy (1977) before definition of the Aralka Formation and have not been stratigraphically reassigned for this publication but included favourable results for the hydrocarbon-generating potential of the then Pertatataka Formation (this interval now includes rocks of the Aralka, Olympic, Pertatataka and Julie Formations). The Aralka Formation is the likely source of significant gas flows in the Pioneer Sandstone, in Ooraminna 1 and 2, south of Alice Springs. In Ooraminna 2, gas saturations were continuous to the top of the Aralka Formation in tight calcareous siltstone (Ambrose et al., 2012). In the south of the basin, samples from Erldunda 1 record total organic carbons (TOCs) of between 1.5% and 3.5% (Marshall, 2003), with a low hydrogen index (HI) that indicates a bias towards gas with subordinate oil potential (Munson, 2014). In Murphy 1, TOC values range from 2.3 – 3.2% (Marshall, 2003; Munson, 2014).

Lower TOC values have been recorded elsewhere in the basin, but TOC reduction as a result of earlier hydrocarbon generation has been speculated in some cases (Munson, 2014). The presence of 'fluffy' kerogen, noted during the palynological investigation of BR05DD01, may also be suggestive of hydrocarbon generation. The source potential of the Aralka Formation in the western part of the basin remains untested as there has been no drilling west of Northern Territory drillhole BR05DD01, located 140 km east of the Western Australia border.

An oil stain (477.5 m) and bitumen extract (481.8 m) within the Aralka Formation in BR05DD01 share geochemical characteristics with oils from the Neoproterozoic of Oman and the eastern Siberian Platform and have been geochemically matched to a source rock extract from the same formation in this well (Ambrose et al., 2010). The oil stain is significant as it indicates that the Aralka Formation has the ability to generate oil, but would also suggest significant unroofing in this part of the Amadeus Basin, considering the shallow depth at which it occurs.

Cryogenian deposits elsewhere in the Centralian Superbasin and adjacent Adelaide Rift Complex have also shown hydrocarbon potential. Aralka Formation equivalent units within the Adelaide Rift Complex from Marmot MMDD-1, on the Stuart Shelf, and the Tapley Hill Formation have recorded TOC values of up to 2% (McKirdy et al., 2001; Le Heron and Craig, 2012). This interval is also considered prospective in the Ngalia Basin, where the interglacial Rinkabeena Shale flared gas during the drilling of Davis 1 (Deckelman and Davidson, 1994).

Biostratigraphy

Proterozoic biostratigraphy has been used with considerable success in Australian Neoproterozoic basins since the 1970s. Initially, it was based on stromatolites, but palynology, using organic-walled microfossils, became a significant tool in the 1990s. In the past three decades, the development of stable isotope correlation methods on the same successions has allowed proposed biostratigraphic correlations to be tested. Current high-resolution correlations are based on an integrated approach using all of these methods.

Palynology

As is the case elsewhere in the world, palynological records in Australia from the beginning of the Sturt glaciation to the end of the Elatina glaciation remain meagre (Timofeev, 1962, 1966; Zang and Walter, 1992; Grey, 2005; Grey et al., 2011; Riedman, 2014; Riedman et al., 2014; Riedman and Porter, 2016). There are few sections of the Aralka Formation or its equivalents suitable for palynological sampling as outcrops tend to be too weathered and only a few drillhole sections have been recorded in the Amadeus Basin (i.e. Wallara 1, Illogwa Creek 6, Murphy 1, Ooraminna 1 and 2, and BR05DD01), all located in the Northern Territory part of the basin.

Zang and Walter (1992) examined several samples from Illogwa Creek 6 and found them to be barren, apart from small fragments of organic matter. They also reported several species from a single field sample (86Z206) at Ellery Creek (Zang and Walter, 1992). However, their results could not be verified, either by later re-collecting samples or by examination of the original slides (Grey, 2005), which contained only mineral grains, poorly preserved fragments of amorphous organic matter and recent contaminants. Grey (2005) examined one field sample of Aralka Formation from Ellery Creek and four samples from the Hi Jinx Syncline, collected as part of an extensive study of Ediacaran successions of Australia, but all proved barren. No identifiable microfossils were extracted from more than 300 field samples processed as part of the Ediacaran project, presumably as a result of leaching of organic material from the 50 m (or more) deep-weathering profile. However, eight samples from core in Wallara 1 from well below the weathering zone (samples 910528.136, 910528.138 – 910528.144, 1279.20 m to 1306.50 m — originally incorrectly assigned to Pertatataka Formation) examined by Grey were also barren (Grey, 2005 and unpublished data). A further 13 samples from Wallara 1 and 35 samples from the Limbla Syncline, collected for a post-doctoral carbon-isotope stratigraphy study of the Aralka Formation by SWF Grant (Walter et al., 2000), were also processed for palynology, but yielded no results.

Riedman (2014) and Riedman et al. (2014) studied the palynology of the Aralka Formation in drillholes Wallara 1 and BR05DD01. In Wallara 1, 16 samples of Aralka Formation yielded low numbers of organic-walled microfossils assigned to *Leiosphaeridia crassa*, *L. jacutica*, *L. minutissima* and *L. tenuissima*, *Synsphaeridium* sp., *Pterospermopsimorpha* sp., and one ornamented acritarch (Riedman et al., 2014 and supplementary data). A similar assemblage was reported from the underlying Areyonga Formation with the addition of poorly preserved fragments of *Cerebrosphaera buickii* and *Pterospermopsimorpha* sp. In BR05DD01, they reported 22 palynomorphs, assigned to four taxa, from 484.5 m (Riedman et al., 2014). This sample was assigned to the Areyonga Formation following the stratigraphic assignment of Ambrose et al. (2010). The top of the Areyonga Formation is revised to 484.6 m (Allen et al., 2016 and herein), placing this sample at the base of the Aralka Formation. The number of specimens is low and as in Wallara 1, the species listed are common, long-ranging Forms *Leiosphaeridia crassa*, *L. minutissima*, *Synsphaeridium* spp., and *Siphonophycus* sp. Lower in the drillhole Areyonga Formation samples yielded fragments of *Cerebrosphaera buickii*.

The fragmentation and poor preservation of many of the specimens recorded in the Areyonga Formation diamictite and Aralka Formation indicate that these specimens were probably reworked from the underlying Wallara Formation (Fig. 2). Similar preservation has been encountered in other Australian glacial and interglacial intervals; for example, in Nicholson 2 (Eyles et al., 2007) and Vines 1 (Haines et al., 2008) in the Officer Basin. *C. buickii* and some of the other long-ranging taxa appear to be derived from small flakes of siltstone derived from the late Tonian succession underlying the Sturt glacial equivalents. Palynological results from diamictite should be regarded as unreliable because of the high potential for reworking.

More recently, 49 palynological samples (GSWA 139048–139096, 155.28 m – 545.96 m) were prepared from drillhole BR05DD01 using standard maceration techniques by Global Geolab Ltd., Medicine Hat, Alberta, Canada, then examined by Kath Grey. Thermal maturity slides, normally used to test depth of burial, were not prepared. Core lithologies appeared to have good potential for palynology and were similar to those in the younger Pertatataka Formation, which generally produces high yields. Yields for Proterozoic rocks are commonly poorer than for Phanerozoic rocks, although the quantity of organic material extracted varies in successions of all ages, depending on constraints such as depth of burial (thermal maturity), distance from shore and position in sea-level cycles, and can also be affected by other factors, including preparation techniques. Medium-grey mudstone to siltstone commonly provides the highest yields. Sampling every few metres at regular intervals as lithology permits overcomes some of the problems and makes it possible to identify intervals with overall good or poor preservation. Because this was only a preliminary study, several lithological variants were sampled at intervals spaced about 50 m apart. Initial examination indicated that all samples were barren of identifiable palynomorphs.

This result was unexpected in light of the successful recovery of rich assemblages from other Neoproterozoic stratigraphic units in Amadeus Basin drillholes, and it was difficult to account for such poor yields, especially if the unit was the normally high-yielding Pertatataka Formation as originally logged. The interval was subsequently reassigned to the low-yielding Aralka Formation (Allen et al., 2016). Preparation using non-vigorous techniques and filtration, instead of heavy mineral separation, were found to increase yields considerably in other Neoproterozoic samples from Australia (Grey, 2000, 2005). If large specimens had been broken up by vigorous preparation methods, samples would probably have contained a large amount of fine organic debris. However, the samples appear to lack such debris. Further preparations using the modified method of Grey (2000) were made in the palynology laboratory at Uppsala University, Sweden. Similar yields were obtained; therefore, the problem does not lie with preparation techniques — rather some other factor appears to be influencing recovery rates.

Regardless of preparation methods and depth below the weathering profile, yields from the Aralka Formation are abnormally low and preservation is poor. Apart from the sample reported in the basal Aralka Formation by Riedman et al. (2014), only one sample (155.28 m) has yielded identifiable palynomorphs that can be regarded as being in situ, rather than reworked. Preliminary examination indicates that the remaining slides contain only a few poorly preserved organic fragments and some minor contamination. More detailed logging is still in progress.

The single sample so far found to contain organic-walled microfossils was not different from the others, but it yielded dozens of specimens of a single taxon, *Vandalosphaeridium* sp. nov. (Fig. 4). This species is small (between 30 and 40 µm in overall diameter) and is often dark and dense. However, particularly in the fine-fraction mounts, large numbers of light-coloured spheres with numerous holes appear to be badly corroded specimens of the same species.

Vandalosphaeridium is a spherical to ovoid organic-walled microfossil with a single-walled vesicle that has numerous, short processes with furcated or trumpet-shaped tips. These tips support an external membrane, which completely encloses the vesicle and processes. The genus is widespread in Europe, Greenland and North America. Three species have been described: *Vandalosphaeridium reticulatum* Vidal 1981, *Vandalosphaeridium varangeri* Vidal 1981 and *Vandalosphaeridium walcottii* Vidal and Ford 1985. The Australian specimens (Fig. 4) appear to be a new species that differs from the other three in that the processes are much shorter and more robust, the process tips are wide, and the ratio of process length to vesicle diameter is different. Processes are about 5 µm in length, and the vesicle is mostly about 30 µm to 35 µm. More detailed measurements are in progress to characterize the species and differentiate it from the other three species. A single specimen illustrated from the Meramangye Formation in Meramangye 1 in the Officer Basin of South Australia may be similar to the Aralka Formation species (Gravestock et al., 1995), but further investigation is required to confirm this.

Analyses of this species and a more detailed study of the BR05DD01 samples are in progress. From the results so far, it appears that the Sturt glaciation was responsible for a major decline in biota. Assemblages were diverse at the time of deposition of the late Tonian Bitter Springs Group, particularly in the Loves Creek and Johnnys Creek Formations (Schopf, 1968; Schopf and Blacic, 1971; Zang and Walter, 1992; Grey and Cotter, 1997; Cotter 1997, 1999; Hill et al., 2000a,b). Assemblages from the overlying Wallara Formation have less diversity, but contain the distinctive species *Cerebrosphaera buickii* Butterfield, Knoll and Swett 1994 (Grey and Cotter, 1997; Cotter, 1999; Hill et al., 2000; Grey et al., 2005 and unpublished data). Fragments of *C. buickii*, a very robust form, are found in diamictite of the Sturt glaciation but are apparently reworked from the underlying succession (Eyles et al., 2007; Haines et al., 2008; Riedman et al., 2014). Very few palynomorphs have been recorded from glacial sediments, and those that have been are almost certainly reworked, or should not be considered further due to the nature of diamictite.

The Aralka Formation and its equivalents seem to be almost devoid of palynomorphs, despite containing suitable lithologies for preservation. This suggests a major decline in the biota as a result of the Sturt glaciation. Assemblages in Australia remained depleted for some time after the Elatina glaciation and then began a slow recovery during which assemblages were dominated by leiospheres. As post-glacial sea level rose, leiosphere numbers increased, but it was not until the second sea-level rise, after the Elatina glaciation and after the Acraman impact event, that assemblages showed a rapid diversification and the introduction of many large acanthomorph species, which became the dominant component in the assemblage (Grey, 2005).

The sparsity of sections of the interglacial interval represented by the Aralka Formation and the poor recovery rates have meant that many attempts to obtain assemblages have not even been recorded in the literature; whereas, a depauperate flora is a significant result in its own right. Further study of the depleted interval should add much to our understanding of biotic behaviour during the interglacial interval and the subsequent rapid post-glacial diversification.

Stromatolite biostratigraphy

The use of stromatolites as a mapping tool is well established in Australian Neoproterozoic basins as a result of detailed studies in the Amadeus and Georgina Basins (Walter, 1972a,b; Walter et al., 1979; Allen et al., 2012), the Adelaide Rift Complex (Preiss, 1972, 1973, 1974), the Officer Basin (Grey, 2005, 2008; Grey et al., 2005, 2011),

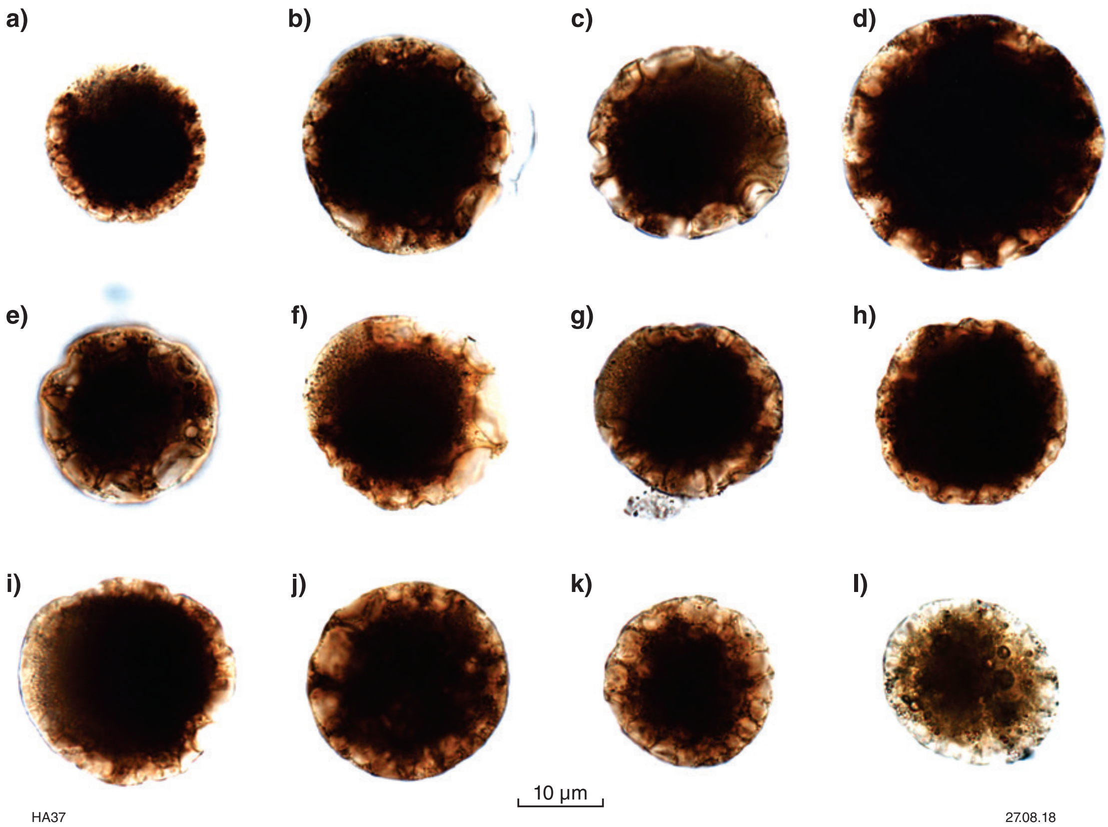


Figure 4. ***Vandalosphaeridium* sp. nov., Aralka Formation, BR05DD01, 155.28 m, slide 1. England Finder positions: a) 49Q0; b) 49S2; c) 50S0; d) 50T2; e) 50Y0; f) 51N0; g) 51V3; h) 52K0; i) 53S2; j) 54O2; k) 58R2; l) 54O0, degraded specimen**

and the Wolfe and Louisa Basins (Grey and Corkeron, 1998; Grey and Blake, 1999).

Correlations using the late Ediacaran *Tungussia julia* and the Tonian *Acaciella australica* and *Baicalia burra* assemblages are well documented, extend across Australia, and are consistent with correlations based on lithostratigraphy, isotope chemostratigraphy, sequence and seismic stratigraphy, and well-log correlations (Grey et al., 2011, 2012; Allen et al., 2012 and references therein). However, the Cryogenian interglacial interval had received little attention. Recent studies have considerably improved understanding of stromatolite distributions within the Aralka Formation and provide a valuable tool for recognizing the unit in isolated outcrops and poorly exposed sections.

The discovery of the stromatolites *Atilanya fennensis* and *Tungussia inna* in the Boord Ridges section of the western Amadeus Basin (Haines and Allen, 2014) prompted a re-examination of stromatolites first recorded by geologists from the Bureau of Mineral Resources at Fenn Gap (Fig. 3), where they were first considered to be in the Pioneer Sandstone, and from Pacific Oil and Gas Pty Ltd at Mount Conner (Grey, 2005). As a result of these studies, a new Form, *Atilanya fennensis* was described and the diagnosis of *Tungussia inna* emended (Allen et al., 2016). Both Forms show a basinwide distribution (Allen et al., 2016).

Field images and limited samples suggest that other Forms are present in Aralka Formation outcrops in the Ringwood area and as clasts in diamictite at ‘Hidden Valley’. Further systematic studies and comparisons with previously described South Australian specimens are required, but there are similarities to *Inzeria* f. indet. (initially described by Preiss as *I.* cf. *tjomusi*) and *Linella munyallina* described from the Enorama Shale of the Umberatana Group of the Adelaide Rift Complex (Preiss, 1973, 1974, 1987).

Locality details of stromatolites from the Aralka Formation are given below. For diagnostic description of the stromatolite Forms, see Appendix 2.

Locality data

Stromatolitic carbonate is common in outcrop of the Aralka Formation. This Record focuses on stromatolites from six outcrop areas and one drillhole (see Fig. 3). These areas contain key localities that are either readily accessible, have a well understood stratigraphic context, or are represented by material available for study in the GSWA paleontology collection, the Commonwealth Paleontology Collection (CPC) or the Adelaide University paleontology collection. It is very likely that many more stromatolitic localities will be discovered in the Aralka Formation as investigations progress.

All locality information is included in Appendix 1 which provides details of each of the localities mentioned in the text. A summary of key stromatolite localities is given below in stratigraphic context.

Boord Ridges

The Boord Ridges (Fig. 5) are located on the MACDONALD 1:250 000 map sheet (Haines et al., 2018), approximately 20 km south of the Kiwirrkurra Road in Western Australia. Previous mapping of Neoproterozoic units in the Boord Ridges area by Wells et al. (1968) included the Bitter Springs ‘Formation’ (now Bitter Springs Group, see Normington et al., 2015), the ‘Boord Formation’ and the Ellis Sandstone. The stratigraphy of the area was substantially revised by Haines and Allen (2014), as detailed below. Due to poor outcrop, it has not been possible to differentiate individual formations of the Bitter Springs Group (SS1 on Fig. 2), but stromatolite identifications indicate that the Loves Creek Formation is present. The overlying ‘Boord Formation’ is now considered obsolete, being replaced by the Wallara (‘unnamed unit’ in Haines and Allen, 2014), Areyonga, Aralka, Olympic, Pertatataka and Julie Formations in ascending order. The top of the section, originally restricted to Ellis Sandstone by Wells et al. (1968), is revised to include both the Carnegie Formation and Ellis Sandstone. Outcrop at formation level is often poorly exposed and often without stratigraphic context, but the combined section is a semi-continuous interval of the complete Neoproterozoic succession previously documented for the northeastern Amadeus Basin.

Aralka Formation

On the northern limb of the Boord Ridges Syncline, the contact between the Aralka Formation and underlying Areyonga Formation is not exposed, but can be inferred where chert rubble in regolith overlying the Areyonga Formation is replaced up-section by a covered interval displaying weak strike trend lines evident in aerial photography (Fig. 5). The Aralka Formation itself crops out poorly at a higher stratigraphic level but exposure is largely restricted to strike bands of buff-coloured stromatolitic carbonate. Ten, possibly 12, shallowing-upwards carbonate cycles are exposed in the upper third of the formation where it does crop out. The carbonate bands are separated by extensive areas of no exposure, which presumably consist of recessive siltstone. In places, the formation is represented by float of friable siltstone and rare flaggy sandstone. The top of the unit is locally capped by a pink, sandy limestone that is ridge-forming where present, but in most of the area it has been incised or removed before deposition of the overlying Olympic Formation.

Numerous Aralka Formation stromatolite localities are now known from the Boord Ridges (Fig. 5) with stromatolites being present in both the cyclical dolomite forming the strike bands in the upper third of the formation and in the local pink sandy limestone ridge at the top of the formation. Stromatolites identified from the Boord Ridges are described below.

Atilanya fennensis (Fig. 6)

Atilanya fennensis was formally described from the type locality in the Boord Ridges (Allen et al., 2016). *Atilanya fennensis* bioherms occur in outcrops of the cyclical

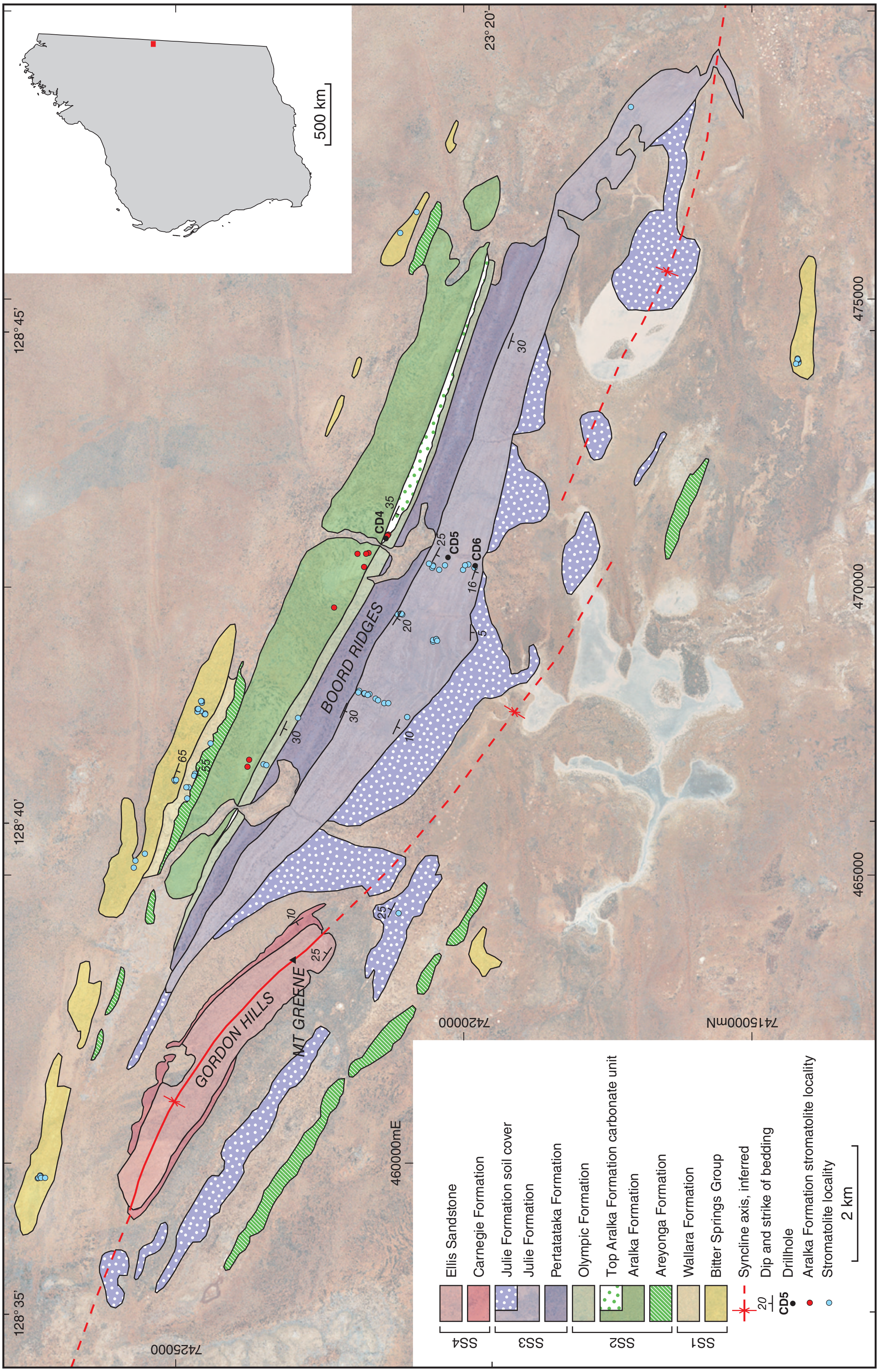


Figure 5. **Stromatolite localities of the Boord Ridges, western Amadeus Basin (modified after Haines and Allen, 2014)**

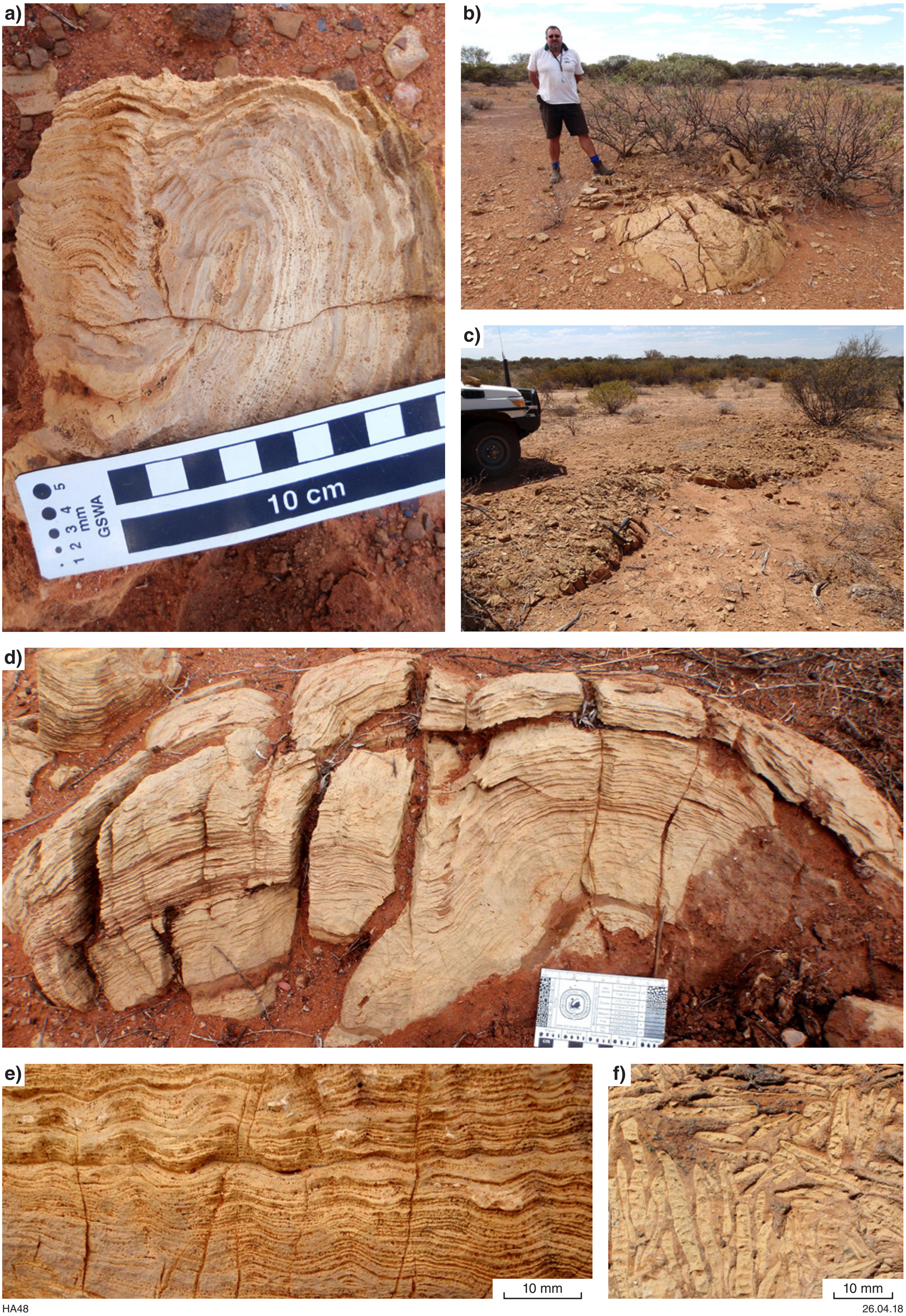


Figure 6. ***Atilanya fennensis*, Boord Ridges western Amadeus Basin: a) a plan view of stromatolite, showing nucleation on intraclast. The intraclast was not fully lithified at the time of stromatolite development; b) typical preservation of bioherms at this locality; c) laterally linked bioherms; d) holotype of *Atilanya fennensis*; e) wavy laminations, a manifestation of the underlying pillared microstructure; f) intraclasts commonly interbedded with stromatolitic carbonate at this location. These intraclasts, where inclined, are commonly a nucleation point for *Atilanya fennensis***

buff-coloured carbonate. This Form predominantly occurs as large-scale bioherm complexes laterally linked along strike. At some localities, elongation of the domes in a south-southwest to north-northeast direction is probably indicative of current activity.

At this locality, *Atilanya fennensis* develops upwards into hemispherical domes — from several centimetres to approximately one metre in diameter (Fig. 6b,c,d). Preservation is commonly as unlinked bioherms, commonly in situ, and mostly infilled by soil. Lithology is dominantly dolomite with rare silicification. Thin sections reveal good preservation of microstructure.

Atilanya fennensis is characterized by its encrusting habit, which selectively overgrows carbonate intraclasts (Fig. 6a). Clasts at Boord Ridges display a degree of bending, suggesting that they were semi-lithified at the time of stromatolitic growth (see Fig. 6a).

Well-developed 'wrinkles', obvious at the macroscale, are common on the outer periphery of bioherms (Fig. 6e), and are a manifestation of the underlying micro-pillared microstructure. In some examples, this wrinkling is enhanced by silicification in the outer portion of the bioherm.

Tungussia inna (Fig. 7)

At the Boord Ridges, *Tungussia inna* occurs in two outcrop modes: small, loaf-shaped bioherms (Fig. 7a,b) are interbedded with *Atilanya fennensis* stromatolites in the cyclical buff-coloured carbonate; and also form pinnacle bioherms (Fig. 7c,d) within the pink, sandy limestone ridge that locally caps the Aralka Formation.

Tungussia inna bioherms in the cyclical buff-coloured carbonate are generally smaller in size (typically, 30–40 cm in diameter) than bioherms of *Atilanya fennensis*. Not all show full column development (their preferred architecture); commonly, only incipient columns are present (Fig. 7e). *Tungussia inna* bioherms are commonly pink, whereas those of *Atilanya fennensis* are buff, and can be further distinguished by having less continuous laminae than are present in basal bioherms of *Atilanya fennensis*. *Tungussia inna* may have colonized *Atilanya fennensis* in some bioherms; however, microstructural analysis is needed to determine this, as both Forms have similar bases.

Tungussia inna is the only stromatolite Form observed in the ridge that caps the Aralka Formation. Well-developed tungussiform columns are present, although bioherm bases are not exposed.

Biostratigraphic context

Stromatolites are also present as clasts in the overlying Olympic Formation (Fig. 8). Clasts in the diamictite range in size from 10 cm to several metres across. Some smaller clasts of grey dolomite include columnar stromatolites resembling Loves Creek Formation taxa (possibly *Acaciella australica* and *Boxonia pertaknurra*), *Baicalia burra* (present in the Wallara Formation — both in the Boord Ridges succession and elsewhere in the basin), and *Atilanya fennensis*. Some larger rafts of pink sandy limestone up to 3 m in diameter include *Tungussia inna* bioherms (Fig. 8b,c,e,f) and are common in parts of the Olympic Formation, mostly within 10 m of the formation base.

Stromatolites that are common in other formations in the Boord Ridges will be described in later publications. These include the Loves Creek Formation taxa *Kulparia alicia*, *Boxonia pertaknurra* and *Basisphaera irregularis,* and the Wallara Formation Form, *Baicalia burra*. The Julie Formation is also commonly stromatolitic and contains *Tesca stewartii* — originally described from the top of the 'Boord Formation' (Walter et al., 1979) — associated with *Tungussia julia* and at least two currently undescribed Forms.

Mount Conner

Mount Conner is located in the Northern Territory (Fig. 3), on the Ayers Rock 1:250 000 map sheet, first mapped in the 1960s (Forman, 1965). The second edition (Young et al., 2002) focused largely on updating basement geology, and the overlying Amadeus Basin sedimentary units were mostly inherited from the previous map edition. The area surrounding Mount Conner (within a 15 km radius of the summit) was previously mapped as two Neoproterozoic to Early Cambrian units: the Inindia beds and the Winnall beds (Young et al., 2002). Collaboration between GSWA and NTGS is developing a basinwide stratigraphic framework and outcrops in the Mount Conner area were recently revised and the stratigraphy recognized as being directly comparable with that of the northeastern Amadeus Basin (Edgoose et al., 2018).

In the Mount Conner area, the stratigraphic succession now includes units assigned to Supersequences SS1–SS4 (Fig. 2). Recognized SS1 units include the Bitter Springs Group and Wallara Formation. SS2 units include the Areyonga Formation, which comprises a lower diamictite and an upper member (Conner Member) of ridge-forming eolian sandstone (previously mapped as Inindia beds), and the Aralka Formation; in an area previously having no mapped units, only colluvium. SS4 units include the Carnegie Formation and Ellis Sandstone, which were previously mapped together as Winnall beds. The Ellis Sandstone forms the sandstone capping on the peak of Mount Conner. Outcrop in this area is sparse and large areas of no exposure may hide a more continuous section or, more likely, stratigraphic breaks in an incomplete section.

Aralka Formation

The Aralka Formation crops out to the north and southwest of Mount Conner and overlies a ridge-forming, eolian sandstone included in the Areyonga Formation. The outcrops are limited to stromatolitic dolomite interbedded with distinctive intraclastic dolomite. Similar interbeds of intraclasts have been observed in association with *Atilanya fennensis* in other outcrops of the Aralka Formation elsewhere in the basin and consist of lenticular intraclasts of varying size (with the majority in the size range of 1–10 cm).

Aralka Formation stromatolites are known to occur in the Mount Conner area at four localities and comprise a single Form, *Atilanya fennensis*, as described below.

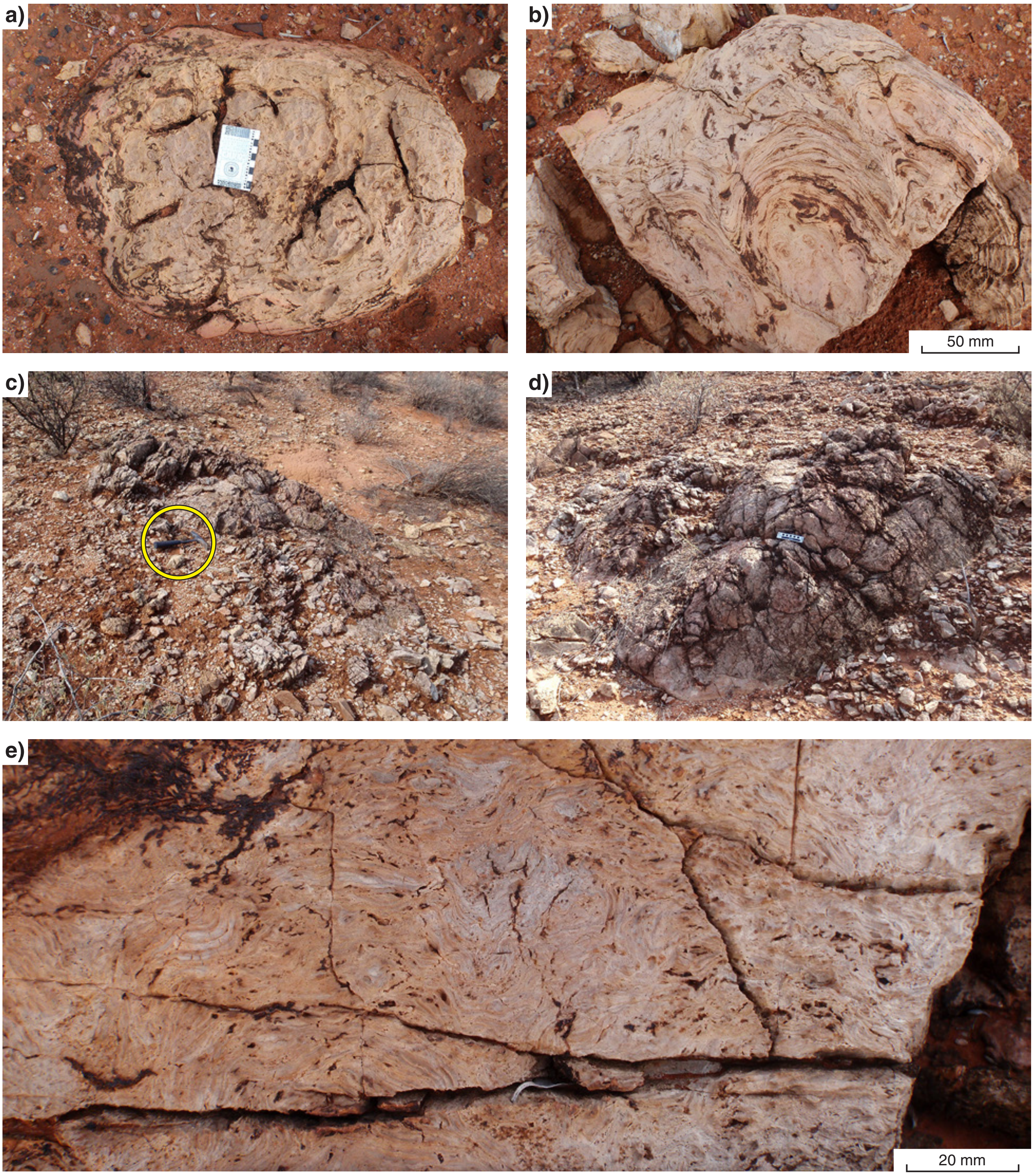


Figure 7. ***Tungussia inna*, Boord Ridges western Amadeus Basin: a) bioherm in plan view; b) typical pink colouration of *T. inna*. Circular features in cross-section are column 'buds', true columns are not developed in this example; c) larger pinnacle bioherms of *T. inna* near the top of the Aralka Formation at this location (note hammer for scale); d) the bioherms are 2–3 m in scale and often elongate in one direction, presumably due to current mediation; e) up-close field view of the pinnacle bioherms, showing characteristic Tungussiform lamination**

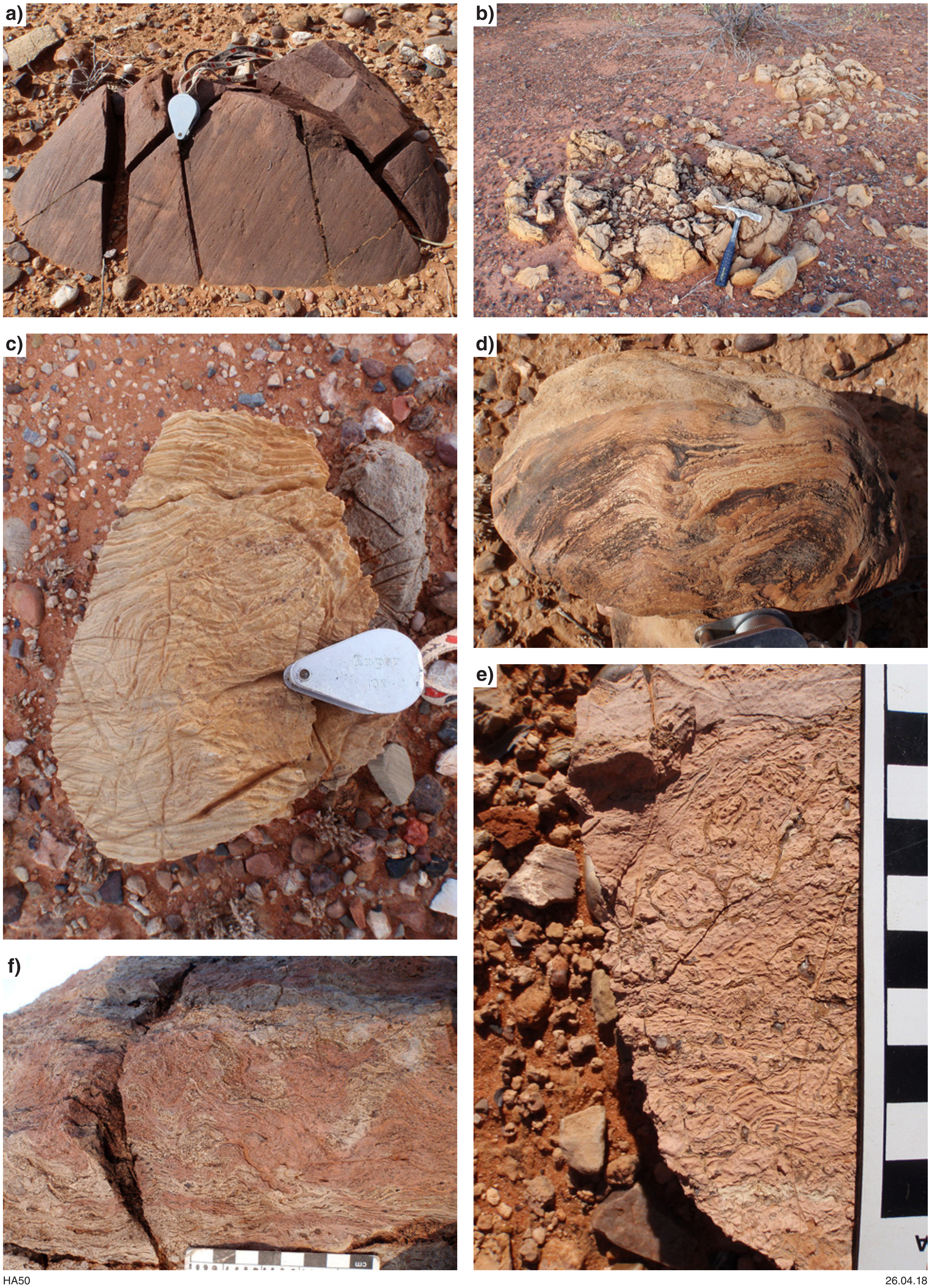


Figure 8. Olympic Formation, Boord Ridges, western Amadeus Basin: a) glacially striated clast; b–e) stromatolitic clasts within the Olympic Formation diamictite

Atilanya fennensis (Figs 9, 10)

At Mount Conner, domes of *Atilanya fennensis* are partly buried by scree and soil (Fig. 9a,b). Bioherms consist of layered, encrusting stromatolites that develop upwards into domes, commonly about 1 m in diameter and 0.5 – 1 m high (Fig. 9b). Hemispherical domes commonly form extensive complexes (Fig. 9b). Nucleation on dolomite intraclasts or clusters of intraclasts is common at Mount Conner (Figs 9d,e, 10). Wrinkled lamination is apparent in some bioherms, a manifestation of the underlying pillared microstructure (Fig. 9f).

Biostratigraphic context

Other stromatolite localities are known from the Mount Conner area. Possible Bitter Springs Group stromatolites, too coarsely recrystallized for identification, occur in an area approximately 7.5 km northeast of Mount Conner, and possible *Baicalia burra* is present as clasts in the Areyonga Formation diamictite.

Fenn Gap

Fenn Gap is located in the Northern Territory, approximately 26 km west-southwest of Alice Springs (Fig. 3). Stromatolitic siltstone on the southeast side of Fenn Gap was previously mapped as Pertatataka Formation (Offe and Shaw, 1983) but was later interpreted to be Pioneer Sandstone (Calver, 1995; Grey, 2005). Grey et al. (2011) listed the locality as Aralka Formation in their Table 8.1, and it was correlated with the Aralka Formation by Grey et al. (2012). This later correlation as Aralka Formation is followed here, based on its lithological similarity, stratigraphic context and stromatolite biostratigraphy.

The stromatolites at Fenn Gap were first discovered during mapping of the Amadeus Basin in the 1960s. Walter et al. (1995) referred to 'distinctive but as yet undescribed stromatolites at the base of the Pertatataka Formation' (p. 184). Samples were collected, and the similarities to those at Mount Conner were noted (Grey, 2005); however, they were not studied in detail until the new taxon, *Atilanya fennensis*, was described by Allen et al. (2016).

Aralka Formation

At Fenn Gap, the stromatolites are exposed in a large buildup, in cyclical carbonates interbedded with recessive siltstones and intraclastic dolomite.

Atilanya fennensis (Fig. 11)

Atilanya fennensis is known from a locality on the southeastern side of Fenn Gap. Domes tend to be hemispherical, commonly commencing with layered laminae and developing upwards into pseudocolumns. Columns of varying diameter are interspersed between the domes and are particularly common at Fenn Gap compared to other localities. Domes and columns are commonly nucleated on lenticular intraclasts that can be oriented vertically, or inclined at a high angle, and stromatolite heads develop directly from the substrate.

Biostratigraphic context

A stromatolitic horizon (Zone 53K, MGA 360895E 7367865N) approximately 200 m northeast of, and 75 m stratigraphically below, the *Atilanya fennensis* locality, contains *Baicalia burra*. This Form is widespread throughout the Centralian Superbasin and Adelaide Rift Complex, and found near the top of the late Tonian units (Allen et al., 2012 and references therein). Based on stromatolite correlations and the distribution of *Baicalia burra* elsewhere in the Amadeus Basin, the outcrop is assigned to the Wallara Formation.

Ringwood area

The Ringwood area is located in the northeastern part of the Amadeus Basin near Ringwood Homestead (Fig. 3). The area of study is located on both the ALICE SPRINGS and ILLOGWA CREEK 1:250 000 scale map sheets.

Aralka Formation

Nine stromatolite localities have been recorded from the Aralka Formation in the Ringwood area. Outcrop locality NTRA 094 is in undifferentiated Aralka Formation, while all others are in the Ringwood Member. They include NTRA 022 which was described by Walter (1972a) and sampled by Kath Grey in 1976, 13 km south-southwest of Ringwood Homestead; and NTRA 023, mentioned briefly by Walter (1972a), 9 km southwest of Ringwood Homestead. Both localities are recorded on the ALICE SPRINGS 1:250 000 scale map sheet. A further three localities, NTRA 068 (from the north Limbla Syncline); NTRA 069 (near Waldo Pedlar Bore); and NTRA 070 (near Ringwood Homestead), were examined and sampled in 2013. Preservation at NTRA 070 was too poor for identification or sampling. Another four localities (NTRA 093, NTRA 094, NTRA 096, and NTRA 109) are marked by stromatolite symbols on the LIMBLA 1:100 000 scale map sheet, but there are no recorded details and they do not appear to have been sampled.

Tungussia inna is present at NTRA 022, NTRA 023, NTRA 068, NTRA 069 and possibly NTRA 070. As discussed above, at least two additional taxa, ?*Linella munyallina* and ?*Inzeria* f. indet. are present at NTRA 068 and NTRA 069, respectively. All these localities require further investigation and detailed documentation of the stromatolites present. The following Forms are known from the Ringwood area.

Tungussia inna

Described from the type locality near Ringwood Homestead.

?Inzeria f. indet. (Fig. 12)

Interspersed with the dominant bioherms of *Tungussia inna* at NTRA 069, are bioherms consisting of vertical columns with niches. The branching is too straight for these columns to be *T. inna*, which is characterized by its gnarled, tuberous, widely divergent, randomly oriented branches. There are distinctive, short niches that lie within

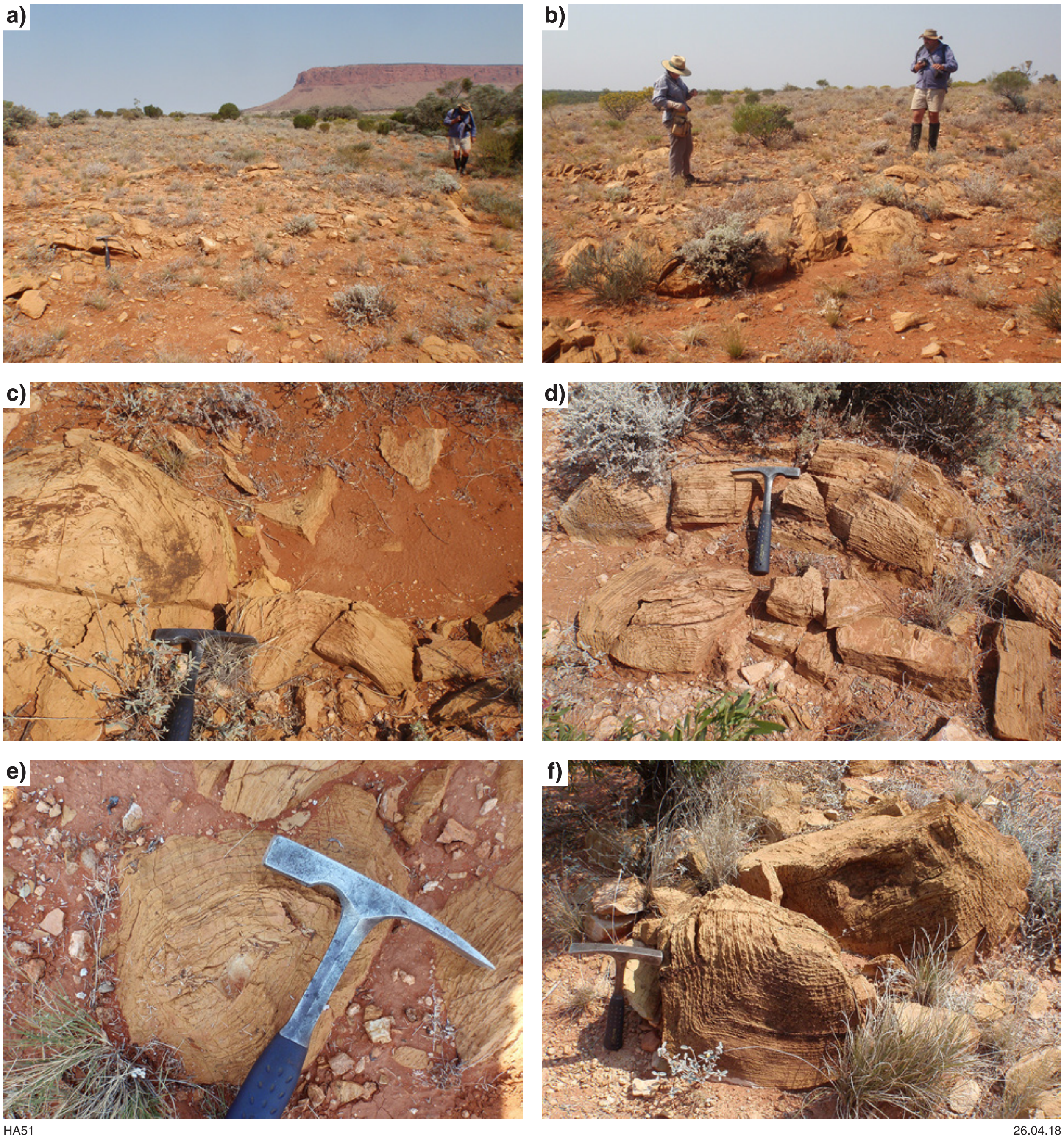


Figure 9. ***Atilanya fennensis*, Aralka Formation. Mount Conner, Northern Territory: a) Aralka Formation stromatolitic carbonate in the area surrounding Mount Conner (seen in the background); b) laterally linked metre-scale bioherms; c,d) characteristic wavy laminations well developed on the outer portion of the bioherm; e) intraclasts are common nucleation points for stromatolitic growth; f) typical preservation of bioherms at this location showing partially disarticulated bioherm**

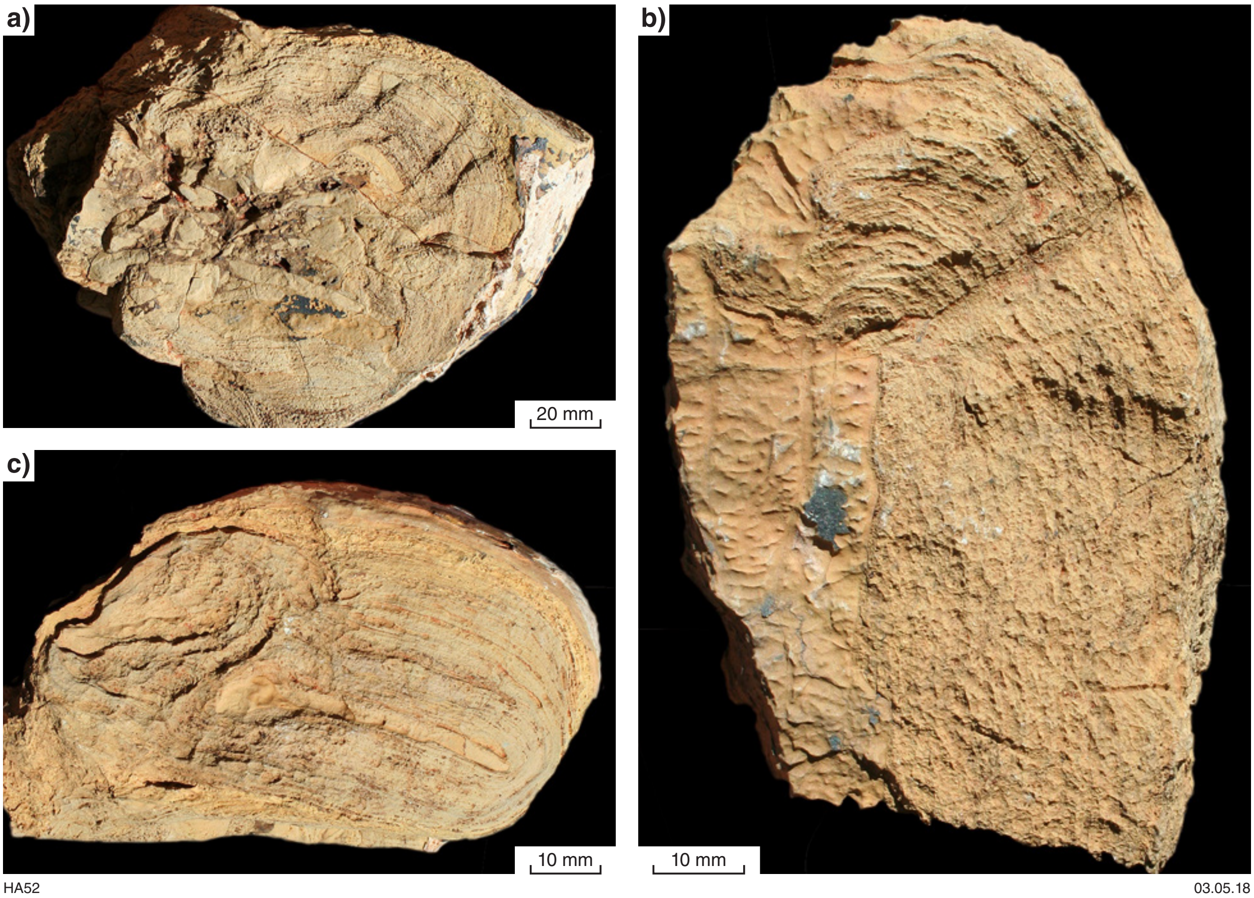


Figure 10. a)–c) *Atilanya fennensis* in plan view showing nucleation on intraclasts

the column width, with only a patchy wall or unwalled columns. Laminae are gently convex and transition gradually from gently convex to obtuse in vertical profile. Light laminae are considerably thicker than the dark laminae (Fig. 12). The presence of niches is characteristic of *Inzeria* and they have some features; particularly lamina shape that are diagnostic of *Inzeria* f. indet. Preiss, 1973 (originally assigned to *I.* cf. *tjomusi*) from the Wundowie Limestone Member of the Enorama Shale in the Cryogenian of the Adelaide Rift Complex. Additional sampling and laboratory examination will be required to confirm this tentative identification. The same Form appears to be present in clasts of Aralka Formation in the Olympic Formation in 'Hidden Valley' (NTRA 037). This stromatolite differs from *T. inna* in that it has branches with upright orientation.

?Linella munyallina Preiss, 1974 (Figs 13, 14)

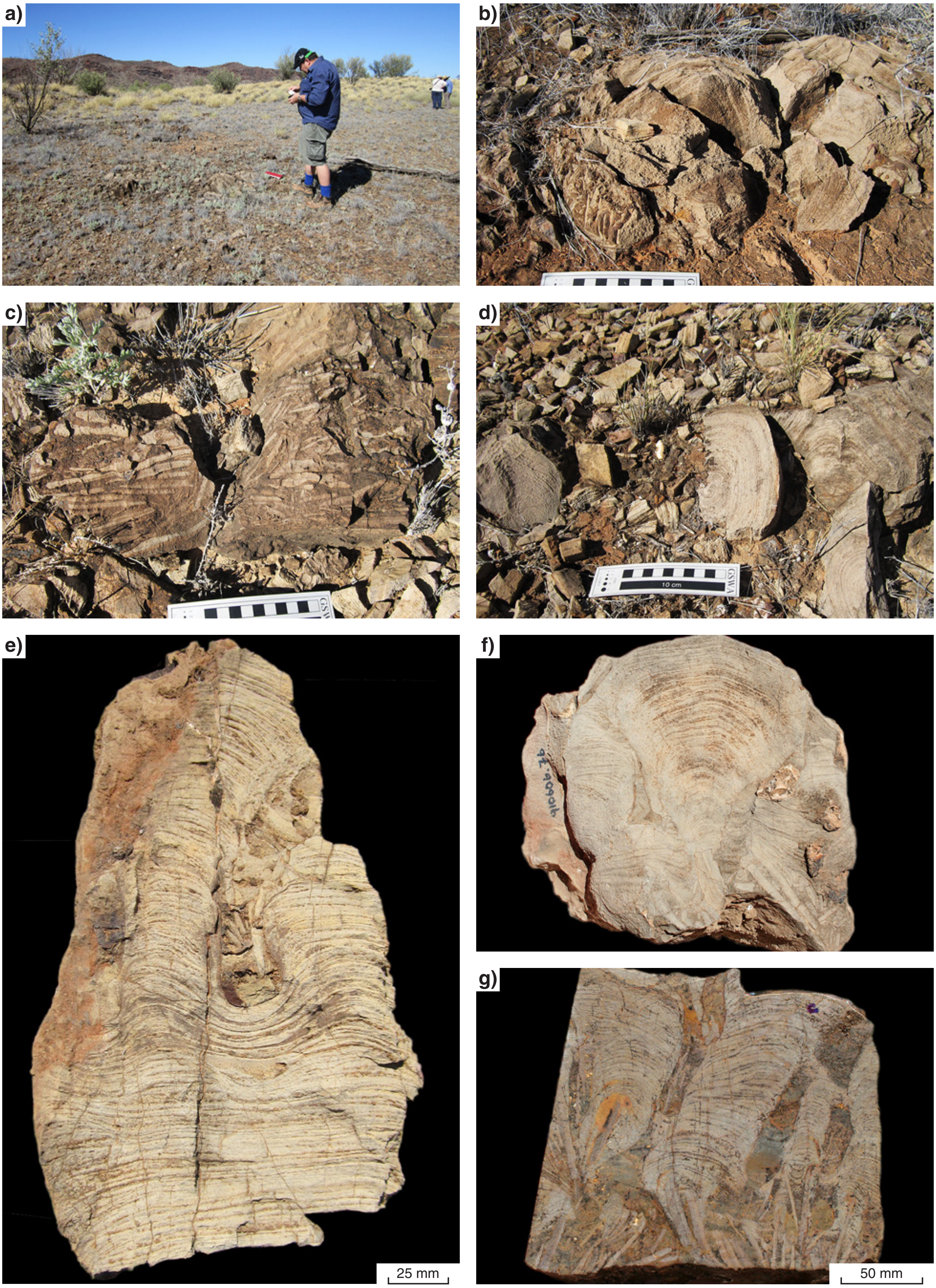
A second Form, tentatively identified as *Linella munyallina* Preiss, 1974 and comparable to specimens from the Enorama Shale of the Adelaide Rift Complex, is also interspersed with the bioherms of *T. inna* in the Ringwood area at NTRA 069. It is characterized by predominantly parallel branching (Fig. 13c), with a near-vertical growth habit (Fig. 13), a partly discontinuous wall, bumpy column margins with subordinate pointed projections, and highly variable lamina profiles (Fig. 14a). These features distinguish it from the widely divergent, randomly oriented branches of *T. inna*.

'Hidden Valley'

'Hidden Valley' is an informally named strike valley (Calver, 1995; Skotnicki et al., 2008), 40 km east of Alice Springs (Fig. 3). Diamictite and cap carbonate of the Olympic Formation overlie a succession of older units within, and east and south, of the valley. At some locations east and south of the valley, the diamictite has a mounded surface and the cap carbonate drapes over the irregularities forming an east-dipping, resistant ridge. The cap carbonate in this area includes the same digitate stromatolite found in the cap carbonate elsewhere. Stromatolitic clasts from the Olympic Formation in this location are presumably sourced from the Aralka Formation judging by their similarities to Forms known from the Aralka Formation elsewhere in the Amadeus Basin.

Inzeria f. indet. (Fig. 15)

Stromatolites are present in brown, dolomitic boulders in the Olympic Formation diamictite at NTRA 037. The clasts are randomly oriented and are most probably derived from the Aralka Formation. Preliminary analysis indicates that they are *Inzeria* f. indet (Fig. 15). They are similar to some found in the Aralka Formation in the Ringwood area, where they are associated with *T. inna*. Further study is required to confirm these identifications.



HA53 03.05.18

Figure 11. Aralka Formation, Fenn Gap, Northern Territory: a,b, d–g) *Atilanya fennensis*, Aralka Formation; c) intraclasts that occur with stromatolites

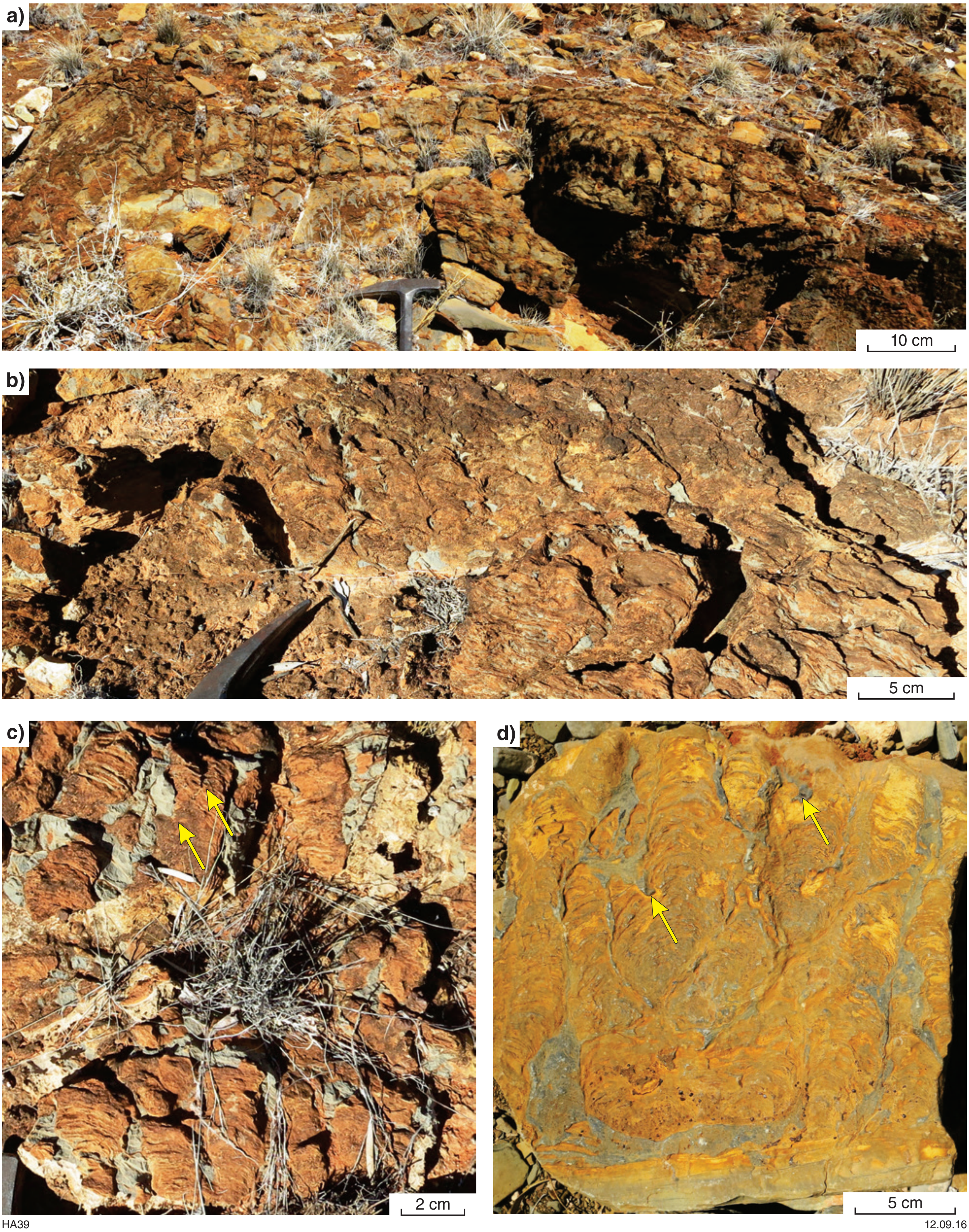


Figure 12. ***Inzeria*** **f. indet. (cf.** ***Inzeria*** **f. indet, Preiss, 1973) from the Ringwood area (a,d, from NTRA 068; b,c, from NTRA 069): a) view of tabular bioherm developing upwards into medium, then smaller, columns. Columns have a vertical orientation and have niches; b) tangential view of infrequently branching columns with niches; c) detail of columns showing niche development mainly confined to width of column; d) detail of small fascicle, showing niche development, areas of no wall to patchy wall, and laminae gradually transitioning from gently domical to obtusely conical. Niches are arrowed**

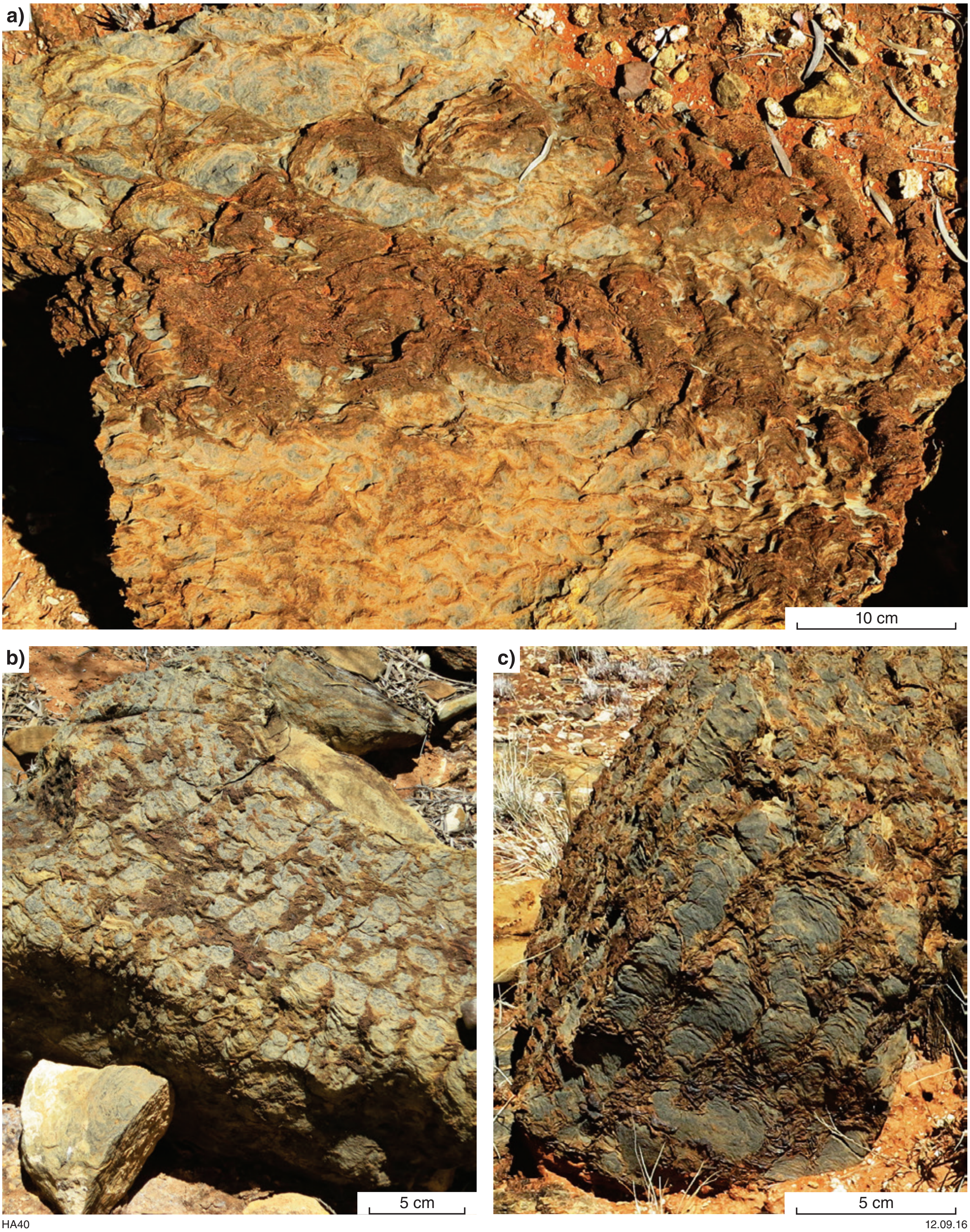


Figure 13. ?*Linella munyallina* (Preiss, 1974) locality in the Ringwood area NTRA 068: a,b) outcrop view of parallel branches with bumpy margins; c) branches with bumpy margins and highly variable laminae

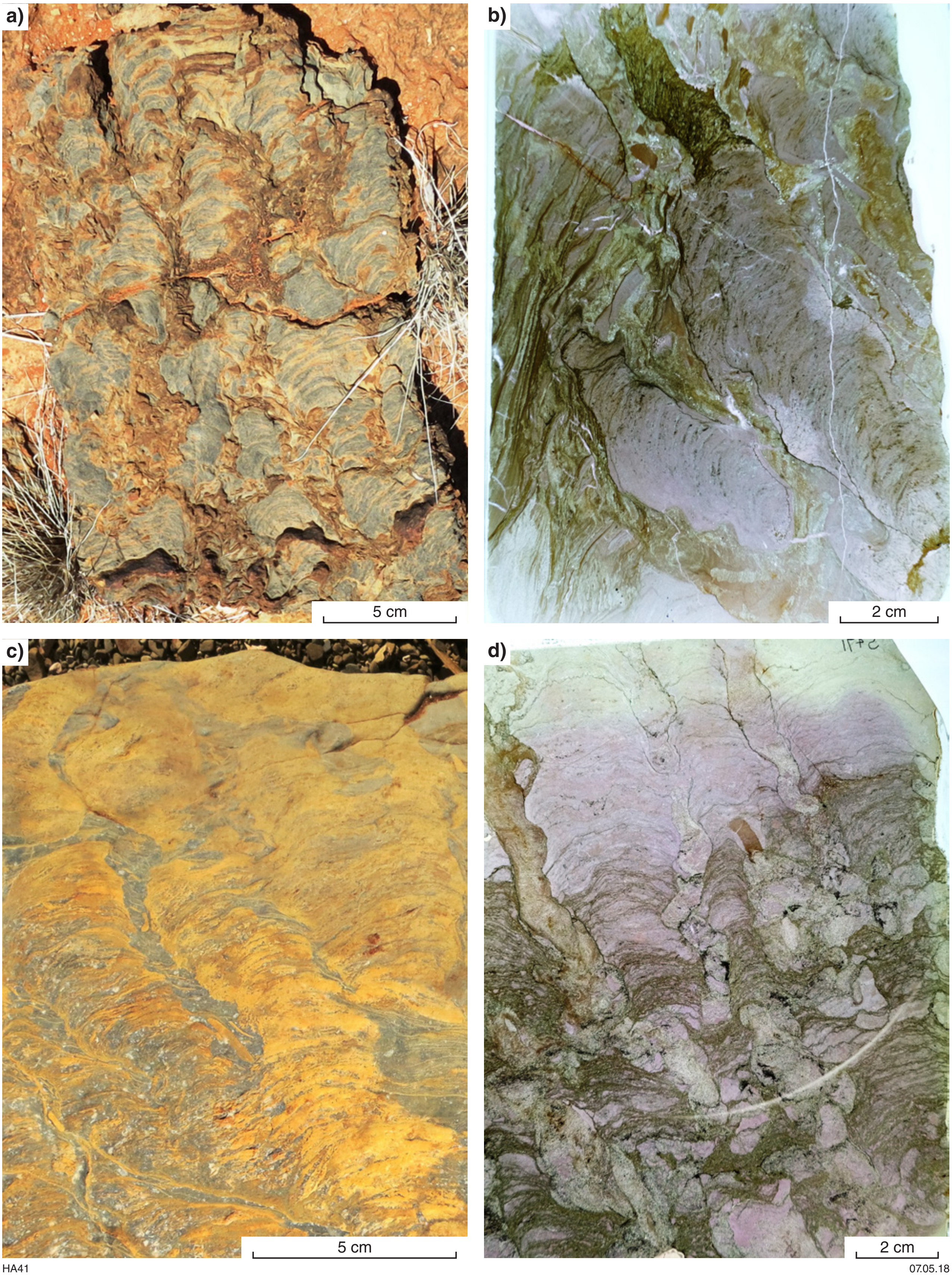


Figure 14. ?*Linella munyallina* (Preiss, 1974): a,c) detail of branches at NTRA 068, showing comparison with S471, Adelaide University Collection, *Linella munyallina* (b,d)

Figure 15. ***Inzeria*** **f. indet. (cf.** ***Inzeria*** **f. indet Preiss, 1973) glacial clast of Aralka Formation in the Olympic Formation in 'Hidden Valley', NTRA 037: a) weathered surface; b) mirror images of cut faces; c) detail of columns, mostly unwalled; d) showing niche development mainly confined to width of column (arrowed) and gradual variation in lamina profile; e) detail of rhombic and gently convex laminae; f) detail of obtusely conical laminae**

Biostratigraphic context

Boulders of stromatolitic carbonate, presumably of Loves Creek Formation, containing *Kulparia alicia* are caught up in a fault zone separating Gillen Formation and Johnnys Creek Formation at NTRA 075 west of 'Hidden Valley'. A basalt just above this locality is within the Johnnys Creek Formation. *K. alicia* is a widespread component of the Loves Creek Formation. The cap carbonate of the Olympic Formation contains the small digitate stromatolite *Anabaria juvensis*, a Form that occurs in the 'Hidden Valley' area and at Ellery Creek. Systematic revision of this Form is currently in progress. It was originally named *Anabaria juvensis* by Cloud and Semikhatov (1969) but was transferred to *Kotuikania juvensis* by Walter et al. (1979), who also erected the apparently synonymous *Elleria minuta*. The transfer to *Kotuikania* seems to be incorrect, so it is better to use *Anabaria juvensis* until the revised systematics are formalized. The cap carbonate containing *A. juvensis* follows the underlying contours of the diamictite and appears to have formed as a more or less continuous sheet of stromatolites extending over several square kilometres.

Ross River diamictite

A single, well-rounded cobble of *Atilanya fennensis* was found embedded as an erratic in the Olympic Formation, about 1 km north of Ross River Homestead (Fig. 3) at NTRA 040. Despite an extensive search, no other examples of stromatolitic clasts were found at this locality, but its identification as *Atilanya fennensis* indicates derivation from the Aralka Formation, which is not exposed in the immediate vicinity.

BR05DD01

Stratigraphic drillhole BR05DD01 (Fig. 3) was drilled by the NTGS 140 km east of the Western Australian border in 2005 and was fully cored from 55 m to a total depth of 1224.98 m (Ambrose et al., 2010). It was reported as intersecting a Neoproterozoic succession extending from the Loves Creek Formation (Bitter Springs Group) to the Pertatataka Formation. Dark siltstones were sampled for palynology and stromatolites examined throughout the core.

The lower part of the diamictite in the core has a greyish matrix, typical of the marine Areyonga Formation, although the upper part is more reddish in colour, which is more typical of the Olympic Formation (Elatina glaciation). However, there is no evidence of a cap carbonate. The diamictite is massive and many of the clasts are derived from the underlying Bitter Springs Group and Wallara Formation. Clasts consist of fine-grained, silty dolomite in a brown to grey–brown, sandy to silty matrix, with some dolomitic mudstone and scattered fine to coarse sand.

The contact between the diamictite and the overlying siltstone appears to be gradational. The predominantly siltstone interval between 484.6 and 55 m was logged by Ambrose et al. (2010) as Pertatataka Formation; however, the stratigraphy was revised by Allen et al. (2016) and now includes 331 m of Aralka Formation (153.80 – 484.6 m). A redbed succession overlying the Aralka Formation and continuing to the top of the core is probably an equivalent of the Arumbera Sandstone. The Aralka Formation consists mainly of light to medium-grey, planar-laminated siltstone and mudstone, similar to that seen in other drillholes. The upwards-shallowing succession includes thin, fining-upwards cycles, probably deposited from distal turbidity currents.

The upper part of the formation, between 154 and 191 m, includes a series of thin stromatolitic carbonate beds. Initially, it was suggested from photographic evidence that these might be *Tungussia julia* and that the carbonates might be Julie Formation (Grey et al., 2012). However, examination of vertical faces cut through the stromatolites, and peels, have indicated that there is an upper horizon (between 154 and 156 m) that consists of *Tungussia inna* and an interval between 186.5 m and 191.3 m that contains *Atilanya fennensis*, supporting the interpretation based on lithology and well-log data that this interval is Aralka Formation rather than Pertatataka and Julie Formations.

Conclusions

A stratigraphically constrained stromatolite assemblage, characterized by the presence of *Tungussia inna* and *Atilanya fennensis*, has been used in the basinwide stratigraphic revision and correlation of the Cryogenian Aralka Formation. Furthermore, the possibility that *Atilanya fennensis* is present in the Balcanoona Formation of the Umberatana Group and the recognition of additional taxa resembling *Inzeria* f. indet. and *Linella munyallina* in the Ringwood area, currently known only from the Adelaide Rift Complex, indicates further potential for interbasin correlation. A new species of organic-walled microfossils, *Vandalosphaeridium* sp. nov., documented from NTGS stratigraphic drillhole BR05DD01, could provide a stratigraphic marker if encountered elsewhere in the basin.

References

Allen, H-J, Grey, K and Haines, PW 2012, Neoproterozoic stromatolite biostratigraphy in the western Amadeus Basin, *in* Proceedings of the Petroleum Exploration Society of Australia (PESA); Central Australian Basins Symposium III, Alice Springs, Northern Territory, 16–17 July 2012 *edited by* GJ Ambrose and J Scott: PESA, Special Publication, 11p.

Allen, H-J, Grey, K and Haines, PW 2016, Systematic description of Cryogenian Aralka Formation stromatolites, Amadeus Basin, Australia: Alcheringa, v. 40, p. 62–82, 10.1080/03115518.2016.1092065.

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, 30p.

Ambrose, GJ, Heugh, JP and Shortt, T 2012, Ooraminna-2, a gas discovery in the Neoproterozoic Pioneer Sandstone, eastern Amadeus Basin, *in* Proceedings of the Petroleum Exploration Society of Australia (PESA); Central Australian Basin Symposium III, Alice Springs, Northern Territory, 16–17 July 2012 *edited by* GJ Ambrose and J Scott: Petroleum Exploration Society of Australia; CD-ROM, 9p.

Barovich, KM and Foden, J 2000, A Neoproterozoic flood basalt province in southern-central Australia: geochemical and Nd isotope evidence from basin fill: Precambrian Research, v. 100, p. 213–234.

Burgess, J 1999, Carbon isotope stratigraphy of the interglacial Umberatana Group, Adelaide Fold Belt, South Australia: Adelaide University, Adelaide, PhD thesis (unpublished).

Calver, CR 1995, Ediacaran isotope stratigraphy of Australia: Macquarie University, Sydney, New South Wales, PhD thesis (unpublished), 195p.

Calver, CR 1998, Isotope Stratigraphy of the Neoproterozoic Togari Group, Tasmania. Australian Journal of Earth Sciences, v. 45, p. 865–874.

Calver, CR 2000, Isotope stratigraphy of the Ediacaran (Neoproterozoic III) of the Adelaide Rift Complex, Australia, and the overprint of water column stratification: Precambrian Research, v. 100, p. 121–150.

Calver, CR, Crowley, JL, Wingate, MTD, Evans, DAD, Raub, TD and Schmitz, MD 2013, Globally synchronous Marinoan deglaciation indicated by U–Pb geochronology of the Cottons Breccia, Tasmania, Australia: Geology, v. 41, no. 10, p. 1127–1130.

Calver, CR and Lindsay, JF 1998, Ediacaran sequence and isotope stratigraphy of the Officer Basin, South Australia: Australian Journal of Earth Sciences, v. 45, p. 513–532.

Calver, CR and Walter, MR 2000, The late Neoproterozoic Grassy Group of King Island, Tasmania: correlation and palaeogeographic significance: Precambrian Research, v. 100, p. 299–312.

Cloud, PE and Semikhatov, MA 1969, Proterozoic stromatolite zonation: American Journal of Sciences, v. 267, p. 1017–1061.

Cotter, KL 1997, Neoproterozoic microfossils from the Officer Basin, Western Australia: Alcheringa, v. 21, p. 247–270.

Cotter, KL 1999, Microfossils from Neoproterozoic Supersequence 1 of the Officer Basin, Western Australia: Alcheringa, v. 23, p. 63–86.

Craig, J, Biffi, U, Galimberti, RF, Ghori, KAR, Gorter, JD, Hakhoo, N, Le Heron, DP, Thurow, J and Vecoli, M 2013, The palaeobiology and geochemistry of Precambrian hydrocarbon source rocks: Marine and Petroleum Geology, v. 40, p. 1–47, 10.1016/j.marpetgeo.2012.09.011.

Deckelman, JA and Davidson, JK 1994, A closer look at the petroleum potential of the Ngalia Basin, Northern Territory: PESA Journal, no. 22, p. 92–100.

Department of Mines and Energy, Energy Directorate 2016, Energy NT 2015: Northern Territory Government, Darwin, 23p.

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.

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: Northern Territory Geological Survey; Alice Springs, Northern Territory, 19 March 2017, p. 80–85.

Edgoose, CJ 2012, The Amadeus Basin, central Australia: Episodes, v. 35, p. 256–263.

Edgoose, CJ 2013, Chapter 23: Amadeus Basin, *in* Geology and mineral resources of the Northern Territory *compiled by* M Ahmad and TJ Munson: Northern Territory Geological Survey, Darwin, Northern Territory, Special Publication 5, p. 23.1–23.70.

Edgoose, CJ, Normington, VJ, Haines, PW and Allen, HJ 2018, Revised Neoproterozoic stratigraphy in the Mount Conner area, Amadeus Basin, Northern Territory: Northern Territory Geological Survey, Record 2018-08.

Eyles, CH, Eyles, N and Grey, K 2007, Palaeoclimate implications from deep drilling of Neoproterozoic strata in the Officer Basin and Adelaide Rift Complex of Australia: a marine record of wet-based glaciers: Palaeogeography, Palaeoclimatology, Palaeoecology, v. 248, p. 291–312.

Fanning, CM and Link, PK 2008, Age constraints for the Sturtian glaciation; data from the Adelaide Geosyncline, South Australia and Pocatello Formation, Idaho, USA, *in* Selwyn Symposium of the GSA Victoria Division Extended Abstracts *edited by* SJ Gallagher and MW Wallace: Geological Society of Australia; Neoproterozoic Extreme Climates and the Origin of Early Metazoan Life, September 2008, p. 57–62.

Forman, DJ 1965, Ayers Rock, Northern Territory, SG 52-8: Bureau of Mineral Resources, 1:250 000 Geological Map Series and Explanatory Notes.

Ghori, KAR, Craig, J, Thusu, B, Lüning, S and Geiger, M 2009, Global Infracambrian petroleum systems: a review, *in* Global Neoproterozoic petroleum systems: the emerging potential in North Africa *edited by* J Craig, J Thurow, B Thusu, A Whitham and Y Abutarruma: The Geological Society, London, Special Publication 326, p. 109–136.

Gravestock, DI, Benbow, MC, Gatehouse, CG and Krieg, GW 1995, Eastern Officer Basin, *in* The Geology of South Australia, Volume 2: The Phanerozoic *edited by* JF Drexel and WV Preiss: Geological Survey of South Australia, Adelaide, South Australia, Bulletin 54, p. 35–41.

Grey, K 2000, A modified palynological preparation technique for the extraction of large Neoproterozoic acanthomorph acritarchs and other acid-insoluble microfossils: Geological Survey of Western Australia, Record 1999/10, 23p.

Grey, K 2005, Ediacaran palynology of Australia: Association of Australasian Palaeontologists, Memoir 31, 439p.

Grey, K 2008, Biostratigraphic correlation of Neoproterozoic glacial successions in Australia, *in* Neoproterozoic extreme climates and the origin of early metazoan life, Selwyn Symposium of the Geological Society of Australia Victoria Division, September 2008 *edited by* SJ Gallagher and MW Wallace: Geological Society of Australia, Extended Abstracts 91, p. 5–11.

Grey, K, Allen, H-J, Hill, A and Haines, PW 2012, Neoproterozoic biostratigraphy of the Amadeus Basin, *in* Proceedings of the Petroleum Exploration Society of Australia (PESA); Central Australian Basins Symposium III, Alice Springs, Northern Territory, 16–17 July 2012 *edited by* GJ Ambrose and J Scott: PESA, Special Publication, 18p.

Grey, K and Blake, DH 1999, Neoproterozoic (Cryogenian) stromatolites from the Wolfe Basin, east Kimberley, Western Australia: correlation with the Centralian Superbasin: Australian Journal of Earth Sciences, v. 46, p. 329–341.

Grey, K and Calver, CR 2007, Correlating the Ediacaran of Australia, *in* The Rise and Fall of the Ediacaran Biota *edited by* P Vickers-Rich and P Komarower, Geological Society, Special Publication 286, p. 115–135.

Grey, K and Corkeron, M 1998, Late Neoproterozoic stromatolites in glacigenic successions of the Kimberley region, Western Australia: evidence for a younger Marinoan glaciation: Precambrian Research, v. 92, p. 65–87.

Grey, K and Cotter, KL 1997, Palynology in the search for Proterozoic hydrocarbons, *in* Geological Survey of Western Australia Annual Review 1995–96: Geological Survey of Western Australia, p. 70–80.

Grey, K, Hill, AC and Calver, C 2011, Biostratigraphy and stratigraphic subdivision of Cryogenian successions of Australia in a global context, *in* The Geological Record of Neoproterozoic Glaciations *edited by* E Arnaud, GP Halverson and G Shields-Zhou: Geological Society of London, Memoir 36, p. 113–134.

Grey, K, Hocking, RM, Stevens, MK, Bagas, L, Carlsen, GM, Irimies, F, Pirajno, F, Haines, PW and Apak, SN 2005, Lithostratigraphic nomenclature of the Officer Basin and correlative parts of the Paterson Orogen, Western Australia: Geological Survey of Western Australia, Report 93, 89p.

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, 21p.

Haines, PW and Allen, HJ 2017, Geological reconnaissance of the southern Murraba Basin, Western Australia: Geological Survey of Western Australia, Record 2017/4, 38p.

Haines, PW, Allen, HJ and Grey, K 2010a, Reassessment of the geology and exploration potential of the Western Australian Amadeus Basin, *in* GSWA 2010 extended abstracts: promoting the prospectivity of Western Australia: Geological Survey of Western Australia, Record 2010/2, p. 27–29.

Haines, PW, Allen, HJ and Grey, K 2010b, The Amadeus Basin in Western Australia: a forgotten corner of the Centralian Superbasin, *in* Geological Survey of Western Australia Annual Review 2008–09: Geological Survey of Western Australia, p. 48–57.

Haines, PW, Allen, H-J, Grey, K and Edgoose, C 2012a, The western Amadeus Basin: revised stratigraphy and correlations, *in* Proceedings of the Petroleum Exploration Society of Australia (PESA); Central Australian Basins Symposium III, Alice Springs, Northern Territory, 16–17 July 2012 *edited by* GJ Ambrose and J Scott: PESA, Special Publication, 6p.

Haines, PW, Allen, HJ, Wingate, MTD, Kirkland, CL and Edgoose, CJ 2012b, Syn-tectonic (Petermann Orogeny) deposition tracked through detrital zircon geochronology, western Amadeus Basin, central Australia, in Abstracts: 34th International Geological Congress, Brisbane, Queensland, August 2012b, p. 1091.

Haines, PW, de Souza Kovacs, N, Spaggiari, CV, Eacott, G, Allen, HJ, Tyler, IM, Maidment, DW, and Murdie, RE 2018, Macdonald, WA Sheet SF 52-14 (2nd edition): Geological Survey of Western Australia, 1:250 000 Geological Series.

Haines, PW, Hocking, RM, Grey, K and Stevens, MK 2008, Vines 1 revisited: are older Neoproterozoic glacial deposits preserved in Western Australia?: Australian Journal of Earth Sciences, v. 55, p. 397–406.

Haines, PW, Mory, AJ, Stevens, MK, and Ghori, KAR 2004, GSWA Lancer 1 well completion report (basic data) Officer and Gunbarrel Basins: Geological Survey of Western Australia, Record 2004/10, 39p.

Haines, PW, Wingate, MTD, Zhan, Y and Maidment, DW 2018, Looking beneath the Canning Basin: new insights from geochronology, seismic and potential-field data, *in* GSWA 2018 extended abstracts: Geological Survey of Western Australia, Record 2018/2, p. 30–33.

Hill, AC 2005, Stable isotope stratigraphy, GSWA Lancer 1, Officer Basin, Western Australia, *in* GSWA Lancer 1 Well Completion Report (Interpretive Papers), Officer and Gunbarrel Basins, Western Australia *edited by* AJ Mory and PW Haines: Geological Survey of Western Australia, Record 2005/4, p. 1–11.

Hill, AC, Arouri, K, Gorjan, P and Walter, MR 2000a, Geochemistry of marine and non-marine environments of a Neoproterozoic cratonic carbonate/evaporite: the Bitter Springs Formation, Central Australia, *in* Carbonate sedimentation and diagenesis in the evolving Precambrian *edited by* JP Grotzinger and NP James: SEPM Special Publication 67, p. 327–344.

Hill, AC, Cotter, KL and Grey, K 2000b, Mid-Neoproterozoic biostratigraphy and isotope stratigraphy in Australia: Precambrian Research, v. 100, p. 283–300.

Hill, AC and Walter, MR 2000, Neoproterozoic (~830–750 Ma) isotope stratigraphy of Australia and global correlation: Precambrian Research, v. 100, p. 181–211.

Indigo Oil and Sirgo Exploration 1990, Wallara No. 1 well completion report. Indigo Oil Pty Ltd and Sirgo Exploration Inc.: Northern Territory Geological Survey, Open File Petroleum Report PR1990–0101 (unpublished).

Jarrett, A, Edwards, D, Boreham, C and McKirdy, D 2016, Petroleum geochemistry of the Amadeus Basin, *in* Annual Geoscience Exploration Seminar (AGES) 2016 Proceedings *edited by* GC MacDonald: Northern Territory Geological Survey; AGES 2016, Alice Springs, Northern Territory, 15 March 2016-16 March 2016, p. 37–42.

Kendall, B, Creaser, RA, Calver, CR, Raub, TD and Evans, DAD 2007, Neoproterozoic paleogeography, Rodinia breakup, and Sturtian glaciation: constraints from Re–Os black shale ages from southern Australia and northwestern Tasmania, *in* Geological Society of America Abstracts with Programs: Volume 39, p. 335.

Kendall, B, Creaser, RA, Calver, CR, Raub, TD and Evans, DAD 2009, Correlation of Sturtian diamictite successions in southern Australia and northwestern Tasmania by Re–Os black shale geochronology and the ambiguity of ‘Sturtian’-type diamictite–cap carbonate pairs as chronostratigraphic marker horizons: Precambrian Research, v. 172, no. 3–4, p. 301–310.

Kendall, B, Creaser, RA and Selby, D 2006, Re–Os geochronology of postglacial black shales in Australia: constraints on the timing of ‘Sturtian’ glaciation: Geology, v. 34, p. 729–732, doi:10.1130/G22775.1.

Korsch, RJ and Kennard, JM (editors) 1991, Geological and geophysical studies in the Amadeus Basin, central Australia: Bureau of Mineral Resources, Bulletin 236, 594p.

Le Heron, DP and Craig, J 2012, Neoproterozoic deglacial sediments and their hydrocarbon source rock potential, *in* Glaciogenic Reservoirs and Hydrocarbon Systems *edited by* M House, J Redfern, DP Le Heron, RJ Dixon, A Moscariello and J Craig: Geological Society, London, Special Publications 368, p. 381–393.

Marshall, TR 2003, Petroleum systems and source rocks in the Amadeus Basin, Northern Territory, *in* Queensland 2003, Exploration and Development *edited by* M Cowie: Petroleum Exploration Society of Australia (Queensland/Northern Territory) Symposium, Brisbane, Queensland, Proceedings, p. 37–42.

Marshall, TR 2005, Review of source rocks in the Amadeus Basin: Northern Territory Geological Survey, Record 2004-008, 42p.

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

McKirdy, DM 1977, The diagenesis of microbial organic matter: A geochemical classification and its use in evaluating the hydrocarbon-generating potential of Proterozoic and Lower Palaeozoic sediments in the Amadeus Basin, central Australia: Australian National University, Canberra, Doctor of Philosophy thesis (unpublished), 328p.

McKirdy, DM, Burgess, JM, Lemon, NM, Xinke, Y, Cooper, AM, Gostin, VA, Jenkins, RJF and Both, RA 2001, A chemostratigraphic overview of the late Cryogenian interglacial sequence in the Adelaide Fold-Thrust Belt, South Australia: Precambrian Research, v. 106, p. 149–186.

Morton, JGG 1997, Chapter 6: Lithostratigraphy and environments of deposition, 47–86, *in* Petroleum Geology of South Australia, Volume 3: Officer Basin, South Australia *edited by* JGG Morton and JF Drexel: Department of Mines and Energy Resources Report Book 97/19, 173p.

Munson, TJ 2014, Petroleum geology and potential of the onshore Northern Territory, 2014: Northern Territory Geological Survey, Report 22, 242p.

Munson, TJ, Kruse, PD and Ahmad, M 2013, Chapter 22: Centralian Superbasin, *in* Geology and mineral resources of the Northern Territory *compiled by* M Ahmad and TJ Munson: Northern Territory Geological Survey, Darwin, Northern Territory, Special Publication 5, p. 22.1–22.19.

Nelson, DR 2004, 154667: sandstone, Empress 1A; Geochronology Record 258: Geological Survey of Western Australia, 5p.

Normington VJ and Edgoose, C 2018, Neoproterozoic stratigraphic revisions to key drillholes in the Amadeus Basin — implications for basin palaeogeography and petroleum and minerals potential, *in* Annual Geoscience Exploration Seminar (AGES) 2018 Record of abstracts: AGES 2018, Alice Springs, Northern Territory, 20–21 March 2018; Northern Territory Geological Survey, p. 106–112.

Normington, VJ, Donnellan, N and Edgoose, C 2015, Neoproterozoic evolution of the Amadeus Basin: evidence from sediment provenance and mafic magmatism, *in* Annual Geoscience Exploration Seminar (AGES) 2015 Record of abstracts: AGES 2015, Alice Springs, Northern Territory, 17–18 March 2015: Northern Territory Geological Survey Record 2015-002, p. 73–78.

Offe, LA and Shaw, DM 1983, Geology of the Alice Springs Region: Bureau of Mineral Resources, Geology and Geophysics.

Preiss, WV 1972, The systematics of South Australian Precambrian and Cambrian stromatolites, part I: Transactions of the Royal Society of Edinburgh: Earth sciences, v. 96, p. 67–100.

Preiss, WV 1973, The systematics of South Australian Precambrian and Cambrian stromatolites, part II: Transactions of the Royal Society of Edinburgh: Earth sciences, v. 97, p. 91–125.

Preiss, WV 1974, The systematics of South Australian Precambrian and Cambrian stromatolites, part III: Transactions of the Royal Society of Edinburgh: Earth sciences, v. 98, p. 185–208.

Preiss, WV (compiler) 1987, The Adelaide Geosyncline: late Proterozoic stratigraphy, sedimentation, palaeontology and tectonics: Geological Survey of South Australia, Bulletin 53, 438p.

Preiss, WV 2000, The Adelaide Geosyncline of South Australia and its significance in Neoproterozoic continental reconstruction: Precambrian Research v. 100, p. 21–63.

Preiss, WV, Drexel, JF and Reid, AJ 2009, Definition and age of the Kooringa Member of the Skillogalee Dolomite: host for Neoproterozoic (c. 790 Ma) porphyry-related copper mineralisation at Burra: MESA Journal, v. 55, p. 19–33.

Preiss, WV, Gostin, VA, McKirdy, DM, Ashley, PM, Williams, GE and Schmidt, PW 2011, The glacial succession of Sturtian age in South Australia: the Yudnamutana Subgroup, *in* The Geological Record of Neoproterozoic Glaciations *edited by* E Arnaud, GP Halverson and GA Shields-Zhou: Geological Society, London, Memoirs 36, p. 701–712.

Preiss, WV, Walter, MR, Coats, RP and Wells, AT 1978, Lithological correlations of Adelaidean glaciogenic rocks in parts of the Amadeus, Ngalia and Georgina Basins: BMR Journal of Australian Geology and Geophysics, v. 3, no. 1, p. 43–53.

Ranford, LC, Cook, PJ and Wells, AT 1965, The geology of the central part of the Amadeus Basin, Northern Territory: Bureau of Mineral Resources, Report 86, 48p.

Riedman, LA 2014, Studies in Neoproterozoic Paleontology: University of California, Santa Barbara, PhD thesis (unpublished).

Riedman, LA, Halverson, GP, Hurtgen, MT and Junium, CK 2014, Organic-walled microfossil assemblages from glacial and interglacial Neoproterozoic units of Australia and Svalbard: Geology, v. 42, p. 1011–1014.

Riedman, LA and Porter, SM 2016, Organic-walled microfossils of the mid-Neoproterozoic Alinya Formation, Officer Basin, Australia: Journal of Paleontology, v. 90, no. 5, p. 854–887.

Rooney, AD, Strauss, JV, Brandon, AD and MacDonald, FA 2015, A Cryogenian chronology: two long-lasting synchronous Neoproterozoic glaciations: Geology, v. 43, no. 5, p. 459–462, doi:10.1130/G36511.1.

Schopf, JW 1968, Microflora of the Bitter Springs Formation, Late Precambrian, central Australia: Journal of Paleontology, v. 42, no. 3, p. 651–688.

Schopf, JW and Blacic, JM 1971, New microorganisms from the Bitter Springs Formation (Late Precambrian) of the north-central Amadeus Basin, Australia: Journal of Paleontology, v. 45, no. 6, p. 925–960.

Shields-Zhou, GA, Porter, S and Halverson, GP 2016, A new rock-based definition for the Cryogenian Period (circa 720–635 Ma): Episodes, v. 39, no. 1, p. 3–8.

Skotnicki, SJ, Hill, AC, Walter, MR and Jenkins, RJF 2008, Stratigraphic relationships of Cryogenian strata disconformably overlying the Bitter Springs Formation, northeastern Amadeus Basin, Central Australia: Precambrian Research, v. 165, p. 243–259.

Smith, BR 2011, Drillhole report for BR05DD01, Amadeus Basin, Northern Territory (electronic resource): National Virtual Core Library NTGS Node: HyLogger 2-7: Northern Territory Geological Survey, Geological Survey Record 002.

Swanson-Hysell, NL, Rose, CV, Calmet, CC, Halverson, GP, Hurtgen, MT and Maloof, AC 2010, Cryogenian glaciations and the onset of carbon isotope decoupling: Science, v. 328, p. 608–611.

Timofeev, BV 1962, Sur l'âge des couches sedimentaires-métamorphiques de l'Antarctic oriental et de l'Australie méridionale (donées de l'analyse micro-paléontologique), *in* Abstracts International Conference on Palynology Tuscon, 1962, Pollen et Spores 4: International Conference on Palynology, Tuscon, p. 382–383.

Timofeev, BV 1966, Mikropaleofitologicheskoe issledovanie drevnikh svit [Microphytological investigations of ancient formations]: Isdatelskvo Nauka [Science Publishing House], Moscow, 147p.

Tyler, IM and Hocking, RM 2002, A revision of the tectonic units of Western Australia, *in* Geological Survey of Western Australia Annual Review 2000–01: Geological Survey of Western Australia, p. 33–44.

Verdel, C and Campbell, M 2016, Cryogenian interglacial stratigraphy of the Amadeus Basin, central Australia, *in* Australian Earth Science Convention: Geological Society of Australia; Australian Earth Science Convention — Uncover Earth's Past to Discover Our Future, Adelaide, South Australia: Geological Society of Australia, Abstract 118, p. 453–453, 495p.

Verdel, C and Campbell, M 2017, Neoproterozoic carbon isotope stratigraphy of the Amadeus Basin, central Australia: Geological Society of America Bulletin, v. 129, p. 1280–1299, doi:10.1130/B31562.1.

Walter, MR 1972a, Stromatolites and the biostratigraphy of the Australian Precambrian and Cambrian: The Palaeontological Association, Special Papers in Palaeontology 11, 190p.

Walter, MR 1972b, The biostratigraphic potential of Precambrian stromatolites: Precambrian Research, v. 5, p. 207–219.

Walter, MR, Krylov, IN and Preiss, WV 1979, Stromatolites from Adelaidean (Late Proterozoic) sequences in central and South Australia: Alcheringa, v. 3, p. 287–305.

Walter, MR and Veevers, JJ 1997, Australian Neoproterozoic palaeogeography, tectonics, and supercontinental connections: Australian Geological Survey Organisation (AGSO) Journal of Australian Geology and Geophysics, v. 17, p. 73–92.

Walter, MR, Veevers, JJ, Calver, CR, Gorjan, P and Hill, AC 2000, Dating the 840–544 Ma Neoproterozoic interval by isotopes of strontium, carbon and sulfur in seawater, and some interpretive models: Precambrian Research, v. 100, p. 371–433.

Walter, MR, Veevers, JJ, Calver, CR and Grey, K 1995, Neoproterozoic stratigraphy of the Centralian Superbasin, Australia: Precambrian Research, v. 73, no. 1–4, p. 173–195.

Wells, AT, Forman, DJ and Ranford, LC 1968, Macdonald, WA Sheet SF 52-14: Bureau of Mineral Resources, Geology and Geophysics, 1:250 000 Geological Series.

Wells, AT, Forman, DJ, Ranford, LC and Cook, PJ 1970, Geology of the Amadeus Basin, central Australia: Bureau of Mineral Resources, Bulletin 100, 222p.

Wells, AT, Ranford, LC, Stewart, AJ, Cook, PJ and Shaw, RD 1967, Geology of the north-eastern part of the Amadeus Basin, Northern Territory: Bureau of Mineral Resources, Report 113, 93p.

Young, DN, Duncan, N, Camacho, A, Ferenczi, PA and Madigan, TLA 2002, Ayers Rock, NT Sheet SG52-8 (2nd edition): Northern Territory Geological Survey, 1:250 000 Geological Series.

Zang, W and Walter, MR 1992, Late Proterozoic and Early Cambrian microfossils and biostratigraphy, Amadeus Basin, central Australia: Memoirs of the Association of Australasian Palaeontologists, v. 12, p. 1–132.

Zi, J-W, Jourdan, F, Wang, X-C, Haines, PW, Rasmussen, B, Halverson, GP and Sheppard, S 2017, Dating basalt by pyroxene $^{40}Ar/^{39}Ar$ with implications for large igneous provinces and correlations of Precambrian basins: 2017 TIGeR Conference: Timescales of Geological Processes, abstracts, p. 88.

Appendix 1

Locality information for Aralka Formation sites viewed or sampled during this study

Locality code	1:250 000 map sheet	Zone	Easting	Northing
Boord Ridges				
MCD017*	MACDONALD	52K	467016	7423708
MCD018	MACDONALD	52K	466916	7423737
MCD019	MACDONALD	52K	470380	7421720
MCD020	MACDONALD	52K	470917	7421306
MCD021	MACDONALD	52K	470938	7421298
MCD022	MACDONALD	52K	470925	7421295
MCD023	MACDONALD	52K	470951	7421290
MCD024	MACDONALD	52K	470611	7421629
MCD025	MACDONALD	52K	470598	7421833
MCD026	MACDONALD	52K	469683	7422233
MCD027	MACDONALD	52K	470601	7421670
Mount Conner				
NTRA042	AYERS ROCK	52J	793204	7180323
NTRA060	AYERS ROCK	52J	793087	7180340
NTRA061	AYERS ROCK	52J	793261	7180297
Central Amadeus Basin, Fenn Gap and Ross River area				
NTRA040	ALICE SPRINGS	53K	448395	7391677
NTRA041	ALICE SPRINGS	53K	360915	7367819
NTRA022*	ALICE SPRINGS	53K	493385	7352045
NTRA023	ALICE SPRINGS	53K	494317	7355497
NTRA068	ILLOGWA CREEK	53K	532613	7367484
NTRA069	ILLOGWA CREEK	53K	511346	7349904
NTRA070	ILLOGWA CREEK	53K	501419	7360582
Hidden Valley area				
NTRA037	ALICE SPRINGS	53K	424652	7384645
Bloods Range NTGS stratigraphic drillhole, BRD05DD01				
BR05DD01	BLOODS RANGE	52J	639878	7295253

NOTE: * denotes type locality

Appendix 2

Systematic paleontology

No new taxa are described or emended; however, we emphasize the main characteristics used for identification, include some additional observations, and discuss differences between localities.

Atilanya fennensis Allen, Grey and Haines, 2016

Figures 6, 9, 10, 11

2005 ‘domical and turbinate stromatolites with a distinctive wrinkled lamination’ Grey, p. 93

2010a ‘Large isolated domical stromatolite, Aralka Formation correlative’ Haines et al., fig. 3f

2012 ‘undescribed clast-supported stromatolite, Aralka Formation’ Allen et al., fig. 5c

2012 ‘Mount Conner type, clast-supported stromatolites’ Grey et al., fig. 10a–d

2013 ‘Clast-supported stromatolite, diagnostic of Aralka Formation, from Fenn Gap’ Edgoose, fig. 23.22, Ch. 23, p.16

2014 ‘large isolated hemispherical domical stromatolite in the upper Aralka Formation’ Haines and Allen, fig. 6f–g

Material

Holotype: GSWA F52346/197130 from the Aralka Formation in the Boord Ridges (MAC017), Amadeus Basin, Western Australia. Paratype: GSWA139022/F52369 from the Aralka Formation at Fenn Gap (NTRA041), Amadeus Basin, Northern Territory.

Diagnosis

For diagnosis, see Allen et al. (2016).

Remarks

Specimens conform to the description of *Atilanya fennensis* by Allen et al. (2016). *Atilanya fennensis* is an encrusting stromatolite that forms interspersed columns and large domes. Both morphological types arise directly from the substrate and are commonly nucleated on elongate intraclasts. It is characterized by distinctively wrinkled laminae in field and hand specimens, which echo a pillared architecture in the light laminae, visible microscopically. The formal description of *Atilanya fennensis* was based on stromatolites from Boord Ridges, Mount Conner and Fenn Gap (Allen et al., 2016). Below, we include some additional observations and discuss differences between localities.

There is good outcrop of a large buildup at Fenn Gap; although, at other localities across the Amadeus Basin, *Atilanya fennensis* consists of domes partly buried by scree and soil. Stromatolites occur in cyclical carbonates of the Aralka Formation interbedded with recessive siltstones and intraclastic dolomite. At the type locality, in the Boord Ridges, up to 10 (possibly 12) shallowing-upwards carbonate cycles are present.

Buildups consist of large (sometimes more than a metre in diameter) domical, bioherms that are spherical or loaf shaped to elongate in plan view, and hemispherical in vertical profile (especially in the case of large domes), interspersed with rarer, commonly short, individual columns that may be only a few centimetres (1.5 – 7 cm in diameter). Independent columns are particularly common at Fenn Gap. Lateral linkage is common in both domes and columns, and many are pseudocolumnar for at least part of their profile.

Domes and columns develop directly from the substrate and are commonly nucleated on lenticular intraclasts that can be oriented vertically, or inclined at a high angle. In some cases, a single stromatolite encrusts a cluster of clasts. Intraclast shape may influence the shape of both domes and columns, particularly in early stages. In plan view, stromatolites developed on lenticular clasts are initially ovoid or elongate, but gradually become more circular. In vertical profile, stromatolites that envelop vertical, or near-vertical, clasts are initially steeply convex and the column is commonly turbinate, but the profile gradually becomes gently convex. Where clasts are flat lying, closely spaced or where there are no clasts, initial laminae are layered and follow the contours of the substrate. Some clasts at the Boord Ridges and Mount Conner localities are distorted, suggesting they were not completely lithified at the time of stromatolite nucleation, and remained flexible during stromatolite growth. Lamina shape does not consistently follow the clast shape: column axes are commonly offset to the clast after the initial coating has formed; or clasts may be inclined, but surrounded by a vertical column.

Mount Conner domes are commonly separated by 1–4 m. At Boord Ridges, this is more variable and differs between beds where domes are contiguous for up to 20 m, or are unlinked, such as at Mount Conner. Spacing between columns varies from 2 to 10 cm. Variability of growth is uniform (most columns are cylindrical); columns are normal to slightly inclined and rare bridging is present.

Microscopically, *Atilanya fennensis* has distinctive laminae in which light laminae are characterized by a micro-pillared structure. Dark laminae tend to be continuous across the full width of the dome or column and are not disrupted by the presence of micro-pillars. The nature of the micro-pillars is uncertain: they appear to result from differential microstromatolitic growth within the lamina. Laminae are composed mainly of micrite with a grain size of less than 1 µm.

Discussion

Atilanya fennensis occurs in close association with *Tungussia inna* and in some cases *Tungussia inna* may have used *Atilanya fennensis* as a substrate. The two Forms are distinguished by differences in microstructure, the convoluted branching pattern of *Tungussia inna*, and differences in the degree of lamina inheritance. No other Amadeus Basin taxa resemble *Atilanya fennensis*, except that several have domical bases.

Distribution

Atilanya fennensis is widespread in the Aralka Formation. It is currently known in situ from localities at Mount Conner, Fenn Gap, the Boord Ridges and in drillhole BR05DD01. See Allen et al. (2016) for detailed locality information and Appendix 1 of this Record. In the Boord Ridges, *Atilanya fennensis* occurrences are coeval with and stratigraphically below *Tungussia inna,* which in the northeastern part of the Amadeus Basin, is restricted to the Ringwood Member. Although the Ringwood Member has not been recognized in the western Amadeus Basin, the association of *Atilanya fennensis* with *Tungussia inna* suggests that its range is restricted to the lower Aralka Formation (coeval with the Ringwood Member), although its occurrence higher in the Aralka Formation cannot be discounted.

Atilanya fennensis has also been found reworked as a clast in the overlying Elatina-equivalent glacial unit, the Olympic Formation and Pioneer Sandstone, at numerous locations.

Age

Between the Sturt and Elatina glaciations, Cryogenian.

Tungussia inna Walter, 1972; emend. Allen, Grey and Haines, 2016

Figure 7

1969	*Tungussia* sp. nov. 1 Glaessner et al., p. 1058, figs 2, 3
1972	*Tungussia inna* Walter, pp. 174–175, pl. 6, fig. 4; pl. 30, fig. 2; text-figs 8, 54
2012	'pinnacle bioherm' Allen et al., p. 8, fig. 5e–f
2014 cf.	*Tungussia* Haines and Allen, p. 13, fig. 7b–c, e
2016 emend.	*Tungussia inna* Walter, 1972; Allen et al., p.13–19, figs 7–9

Material

Allen et al. (2016) discussed the position of the type locality (NTRA 022), which is confirmed as being 12.9 km south-southwest (bearing 189°) of Ringwood Homestead, and a second locality (NTRA 023) mentioned in Walter (1972a), as well as reporting material from other localities in the eastern Amadeus Basin and the Boord Ridges.

From field observations, *Tungussia inna* is also present as clasts in diamictite in the overlying Olympic Formation.

Diagnosis

For diagnosis see Walter (1972a, p. 174) and the emended diagnosis of Allen et al. (2016).

Remarks

Specimens described here conform to the diagnosis of Walter (1972a) as emended by Allen et al. (2016). *Tungussia inna* is a complexly branching stromatolite that develops from a dome into numerous crooked and bumpy branches, which has a patchy to continuous wall with up to 10 laminae. Coalescence and bridging are common, and bridges are robust. Laminae are wavy. *Tungussia inna* is known from several localities across the Amadeus Basin.

In the northeast of the basin, particularly around Ringwood Homestead, *Tungussia inna* occurs in cyclical carbonates (mainly limestone) interbedded with siltstone, and is mostly restricted to the lower part of the Ringwood Member. It forms tabular biostromes, 30–45 cm high and isolated rounded bioherms, several tens of centimetres wide.

In the Boord Ridges, *Tungussia inna* occurs in cyclical carbonates within the Aralka Formation that are interbedded with recessive siltstones and intraclastic dolomite. Here, they form small bioherms up to a metre in diameter, but are predominantly several tens of centimetres wide. In a prominent carbonate ridge exposed at the top of the Formation (that was partially eroded before deposition of the overlying Olympic Formation), *Tungussia inna* occurs as large pinnacle bioherms up to several metres across. In the overlying Olympic Formation, clasts of these *Tungussia inna* pinnacle bioherms are several metres across.

?Inzeria f. indet. Preiss, 1973

Figures 12, 15

Material

See Preiss (1973) for described material. No new collected material, tentatively identified from outcrop observations at NTRA 068 and NTRA 069, NT, Amadeus Basin.

Diagnosis

For diagnosis, see Preiss (1973).

Remarks

Interspersed among the dominant Form of *Tungussia inna* at NTRA 068 and NTRA 069 in the Ringwood area, are bioherms of vertical columns with niches, so far only known from images. They resemble *Inzeria* f. indet. of Preiss (1973), that were originally assigned to *I.* cf. *tjomusi*, from the Wundowie Limestone Member of the Enorama Shale in the Cryogenian of the Adelaide Rift Complex. Further sampling and laboratory examination are needed to confirm the identification.

Probable Aralka Formation erratics from the Olympic Formation in 'Hidden Valley' (NTRA 037) may be the same Form. This stromatolite differs from *T. inna* because it has branches with upright orientation, distinct short niches that lie within the width of the column, has no wall or only a patchy wall, and gently convex laminae that transition gradually from gently to steeply curved in profile, and in which the light laminae are considerably thicker than the dark laminae. By contrast, *T. inna* is characterized by its gnarled, tuberous, widely divergent, randomly oriented branches.

?Linella munyallina Preiss, 1974

Figures 13, 14

Material

See Preiss (1974) for described material. No new collected material, tentatively identified from outcrop observations at NTRA 068 and NTRA 069, NT, Amadeus Basin.

Diagnosis

For diagnosis, see Preiss (1974).

Remarks

A stromatolite Form, tentatively identified as *Linella munyallina* and comparable to specimens from the Enorama Shale of the Adelaide Rift Complex, is interspersed between the bioherms of *T. inna* in the Ringwood area at NTRA 068 and NTRA 069.

It is distinguished from the widely divergent randomly oriented branches of *T. inna* by dominantly parallel branching with a near-vertical growth habit, a wall that is partly discontinuous, bumpy column margins and subordinate pointed projections, and highly variable lamina profiles. More extensive sampling and laboratory examination is needed to confirm the identification.

RECORD 2018/11

THE CRYOGENIAN ARALKA FORMATION, AMADEUS BASIN: A BASINWIDE BIOSTRATIGRAPHIC CORRELATION

Allen et al.

This Record is published in digital format (PDF) and is available as a free download from the DMIRS website at <www.dmp.wa.gov.au/GSWApublications>.

Further details of geological products produced by the Geological Survey of Western Australia can be obtained by contacting:

Information Centre
Department of Mines, Industry Regulation and Safety
100 Plain Street
EAST PERTH WESTERN AUSTRALIA 6004
Phone: +61 8 9222 3459   Fax: +61 8 9222 3444
www.dmp.wa.gov.au/GSWApublications