The Amadeus Basin in Western Australia: a forgotten corner of the Centralian Superbasin

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Abstract

Recent fieldwork by the Geological Survey of Western Australia indicates the need for substantial revision of the stratigraphy of the Amadeus Basin in Western Australia. This is because a more complete Neoproterozoic succession, with closer similarities to the established stratigraphy within the Northern Territory than previously realised, appears to be present. The thick Boord Formation, previously interpreted as a correlative of only the glacigene Areyonga Formation of the Northern Territory Amadeus Basin, actually contains two discrete glacial successions, and greater thicknesses of non-glacial strata. This succession contains several disconformities and closely resembles the entire interval between the Bitter Springs Formation and the Arumbera Sandstone of the northeastern Amadeus Basin. The lithostratigraphic similarities are strongly supported by stromatolite biostratigraphy, which can also be used to subdivide the underlying Bitter Springs Formation into correlatives of existing members in the Northern Territory. There is no compelling evidence of the previously postulated interdigitation of the entire Boord and Carnegie Formations. Instead, the thick siliciclastic package comprising the Carnegie Formation, Sir Frederick Conglomerate, Ellis Sandstone, and Maurice Formation are probably synorogenic (Petermann Orogeny) and thus are likely correlatives of the Neoproterozoic to Early Cambrian Arumbera Sandstone – Mount Currie Conglomerate package of the eastern Amadeus Basin. The recognition in Western Australia of the same stratigraphic intervals that have demonstrated or possible source potential in the Northern Territory, increases the petroleum prospectivity of the Amadeus Basin in Western Australia.

KEYWORDS: Amadeus Basin, Centralian Superbasin, Neoproterozoic, lithostratigraphy, stromatolite biostratigraphy, petroleum

The Amadeus Basin (Wells et al., 1970; Korsch and Kennard, 1991) is a thick package of Neoproterozoic to Paleozoic sedimentary rocks exposed over about 170 000 km^2 in central Australia (Fig. 1), mainly within the Northern Territory (NT), although a significant portion extends across the border into Western Australia (WA). The present Amadeus Basin is interpreted as a relic of the former Centralian Superbasin (Walter et al., 1995), which was fragmented during the late Neoproterozoic to earliest Paleozoic Petermann Orogeny, and mid-late Paleozoic Alice Springs Orogeny (Haines et al., 2001). The northern and southern boundaries of the present Amadeus Basin are thus mainly of tectonic origin, produced by uplift and erosion of basin strata to expose Paleo–Mesoproterozoic metasedimentary and igneous rocks of the Arunta Orogen and Musgrave Province, respectively. The basin continues westward and eastward beneath younger basins, such as the Canning Basin to the west.

Basin tectonics are complex, being the result of halotectonics (Dyson and Marshall, 2007) and the superimposed effects of the two orogenies. The latter were accompanied by deposition of coarse clastic foreland deposits, thickest near tectonically controlled basin margins (Wells et al., 1970; Haines et al., 2001). The basin is extensively folded and faulted, but generally unmetamorphosed, with local exceptions associated with basin margin tectonism. Compared with the Amadeus Basin in the NT, where the Neoproterozoic succession is overlain by thick Paleozoic successions, the WA component appears to be mainly of Neoproterozoic to possibly Cambrian age, with only small local outliers of confirmed later Paleozoic rocks. Superficial Permian deposits are considered part of the overlying Canning Basin, and are not discussed further.

Previous work

In contrast to the NT portion of the Amadeus Basin, which has undergone multiple phases of study by Government organizations, universities, and exploration companies, the WA part of the basin is poorly known and has only been mapped at reconnaissance level. The main area of outcrop (MacDonald[*] and Rawlinson) was mapped by the Bureau of Mineral Resources (BMR, now Geoscience Australia) in 1960 (Wells et al., 1961, 1964, 1970). Peripheral areas were mapped by joint BMR and Geological Survey of Western Australia (GSWA) parties in the early 1970s. A review of the stratigraphy, based on comparisons with the stratigraphy of the eastern Amadeus Basin, was published by Grey (1990). However, most areas have not been re-visited by Government geologists since first-pass mapping, with the exception of recent and current GSWA programs, and there has been limited exploration for petroleum or mineral resources. Reasons for this lack of activity have included poor access due to remoteness and a perception of low prospectivity.

[*] Capitalized names refer to standard 1:250 000 map sheets

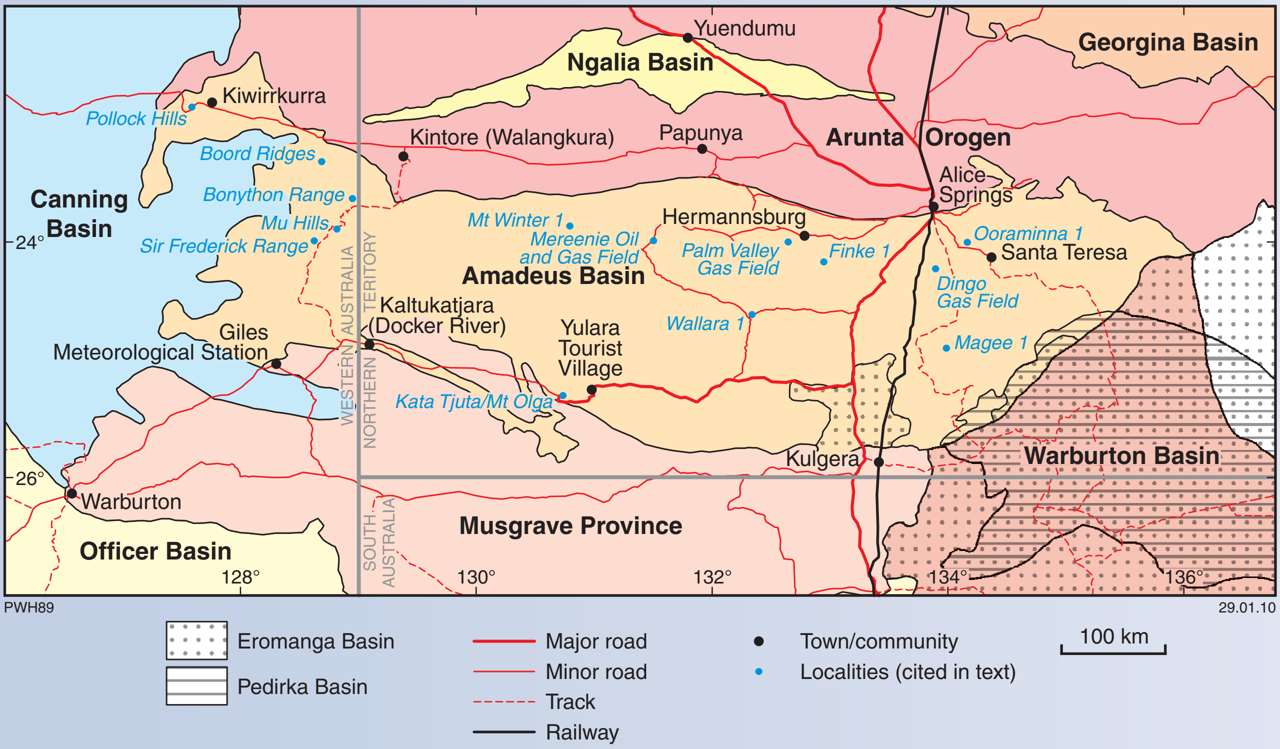

Figure 1. Locality map showing Amadeus Basin and adjacent tectonic units, and localities referred to in the text.

The western extremities of the Amadeus Basin are largely covered by surficial deposits. Consequently there is little continuity of outcrop and, coupled with the perception of significant facies changes from east to west (now seen as largely an artefact of miscorrelation), a mostly separate stratigraphic nomenclature was set up for the portion of the basin near and west of the WA state border (Fig. 2). The basin-wide Neoproterozoic stratigraphic nomenclature and correlation scheme of Wells et al. (1970) has undergone significant modification in the NT (Weste, 1989; Korsch and Kennard, 1991), particularly in the better exposed northeastern part of the basin, but correlations between far west and east have not been reassessed through field examination until now. Only the Heavitree Quartzite and its equivalent the Dean Quartzite, and the overlying Bitter Springs Formation were previously recognized in both areas.

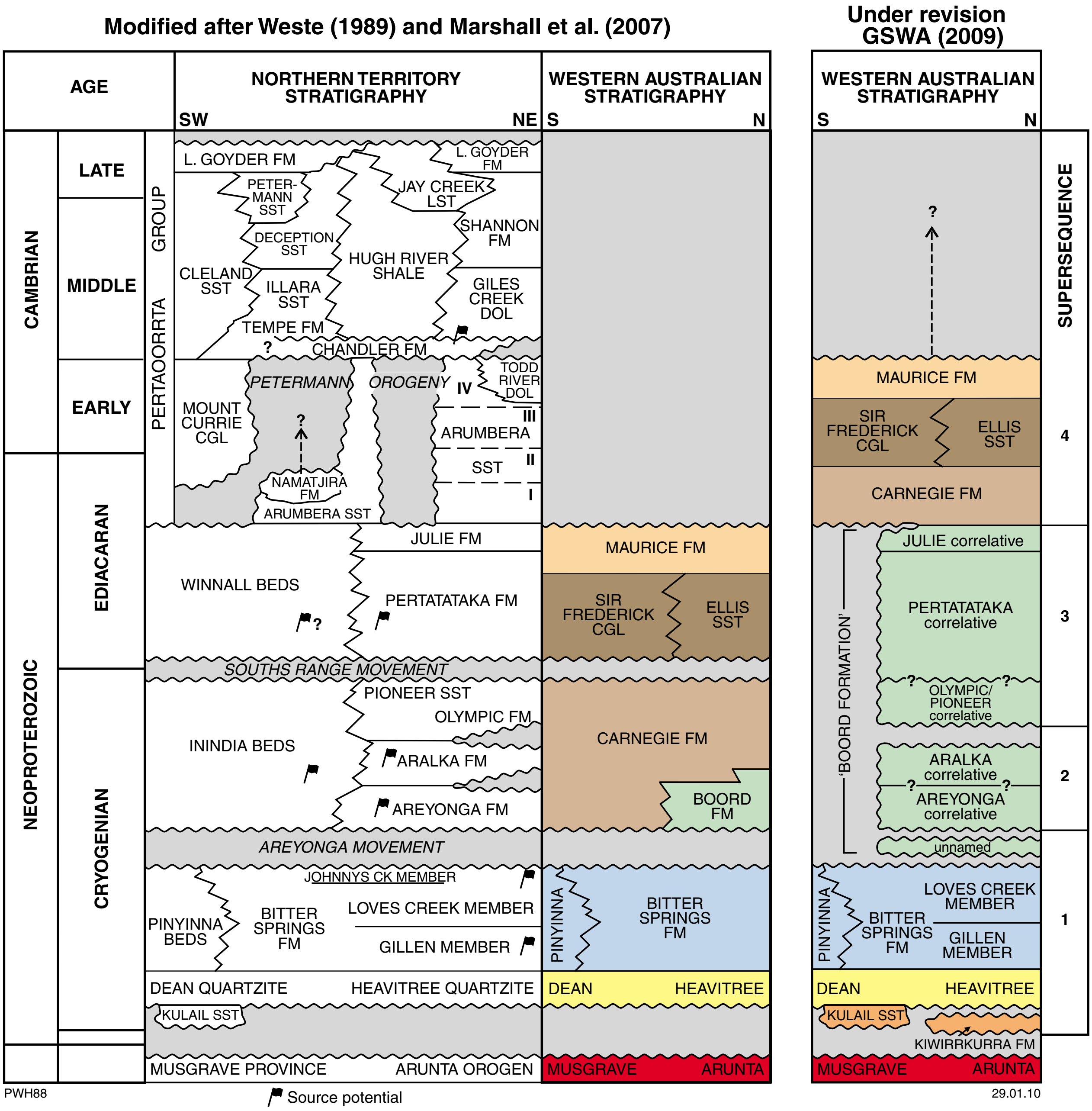

Figure 2. Stratigraphy of the Northern Territory and Western Australian Amadeus Basin, comparing the most commonly used current scheme on left with our revisions in progress at right. The supersequence scheme of Walter et al. (1995) is shown at far right.

Progress towards revised stratigraphy and correlations

Basal clastic units

The basal unit of the Amadeus Basin along almost the full length of the northern margin is the Heavitree Quartzite (Fig. 3a). In WA this unit is typically thinner, less heavily silicified, and its lower part more conglomeratic than in the NT. In the Pollock Hills area, the Heavitree Quartzite is underlain by a unit of coarse red-brown lithic and pebbly sandstone that was previously mapped as part of the Paleoproterozoic Pollock Hills Formation of the basement Arunta Orogen (Blake, 1977). However, this unit is separated from the main volcanic and volcaniclastic succession of the Pollock Hills Formation by a marked angular unconformity, while having similar structural attitude to the Heavitree Quartzite, although the contact is covered. Recently named the Kiwirrkurra Formation (Geological Survey of Western Australia, 2008), this unit tentatively is considered as part of the Amadeus Basin succession. The Dean Quartzite is the assumed equivalent of the Heavitree Quartzite on the southern margin of the Amadeus Basin. In the NT, the original Dean Quartzite has been recently subdivided to differentiate a local basal lithic and felspathic unit, the Kulail Sandstone (Close et al., 2003), a possible correlative of the Kiwirrkurra Formation. The Kulail Sandstone has been mapped westward to the state border, and clearly extends into WA, but has yet to be delineated further west.

Bitter Springs Formation

In the eastern Amadeus Basin the Bitter Springs Formation is a mixed carbonate, siliciclastic, and evaporite succession that has been subdivided into the Gillen, Loves Creek, and Johnnys Creek Members, in ascending order. It contains a regional disconformity at the base of the Loves Creek Member (Ambrose, 2006). The Gillen Member typically contains a halite unit in the subsurface responsible for widespread halotectonic deformation (Dyson and Marshall, 2007). In WA the Bitter Springs Formation has not been previously divided into members. Such subdivision is difficult on purely lithostratigraphic grounds because of structural complications, incomplete sections, and generally poor outcrop, but is desirable because of implications for petroleum prospectivity. Stromatolite biostratigraphy appears to be the best approach for outcrop sections, because the members have distinct stromatolite assemblages (Walter, 1972). Most stromatolite localities thus far identified in the Bitter Springs Formation in WA contain elements of the *Acaciella australica* Stromatolite Assemblage (Stevens and Grey, 1995; Fig. 3c), implying correlation with the Loves Creek Member and with similar successions in other Australian Neoproterozoic Basins. However, *Tungussia erecta* (Fig. 3b) has been found at a lower stratigraphic position, just above the top of the Heavitree Quartzite in the Pollock Hills area, confirming the presence of a correlative of the Gillen Member in WA. Complexly folded outcrops of Bitter Springs Formation, particularly in the Bonython Range (Fig. 3d) are suggestive of halotectonics and the presence of subsurface halite within the Bitter Springs Formation in WA, presumably within the Gillen Member. Dentith and Cowan (2009) interpreted salt withdrawal basins from geophysical data over the WA Amadeus Basin.

Boord Formation

Over most of the NT Amadeus Basin, the Bitter Springs Formation is overlain disconformably by the glacigenic Areyonga Formation or the partly laterally equivalent Inindia beds (Wells et al., 1970; Weste, 1989; Grey, 1990). Under the WA stratigraphic scheme of Wells et al. (1964), the Bitter Springs Formation is overlain, also with disconformity, by the mixed carbonate–siliciclastic Boord Formation or the siliciclastic Carnegie Formation. Wells et al. (1970) correlated the Boord Formation with the Areyonga Formation because both contain glacial diamictite. The lower Carnegie Formation was also correlated with the Areyonga Formation, despite there being no recognized glacigene strata, because of its perceived stratigraphic relationships, including inferred interdigitation with the entire Boord Formation. Grey (1990) preferred to correlate the Boord–Carnegie package with the younger glacigene Olympic Formation and Pioneer Sandstone of the northeast Amadeus Basin. Recent fieldwork has led to the recognition that the Boord Formation is a composite unit that contains disconformities and correlates with several northeastern Amadeus Basin formations, with considerable time spread. We also found no compelling evidence for the inferred lateral equivalence of the Boord and Carnegie Formations. While there may be some interdigitation of facies between the top of the Boord Formation and the basal Carnegie Formation, most of the latter appears to be younger. We propose eventual abandonment

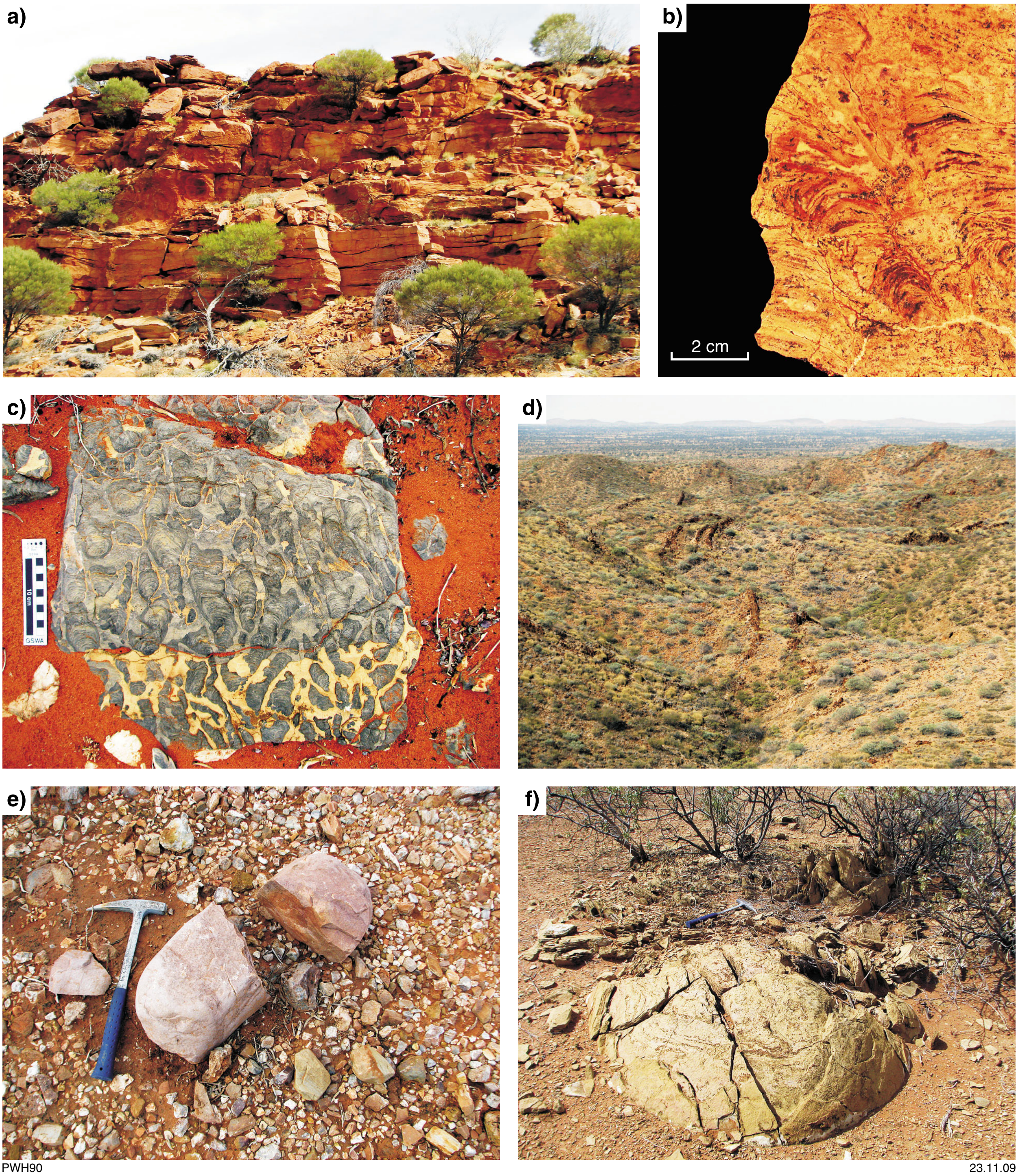

Figure 3. Field and hand specimen photographs: a) Heavitree Quartzite, Pollock Hills; b) Stromatolite Tungussia erecta*, Gillen Member, Pollock Hills; c) Columnar stromatolites, Loves Creek Member, Boord Ridges; d) Complexly folded outcrop of Bitter Springs Formation, Bonython Range; e) Large rounded quartzite clast, Areyonga Formation correlative, Boord Ridges; f) Large isolated domical stromatolite, Aralka Formation correlative, Boord Ridges*

of the term 'Boord Formation', but until a new stratigraphy is finalized we will use this term informally for the composite package (Fig. 2).

Lower 'Boord Formation'

At the type section in the Boord Ridges the base of the 'Boord Formation' was defined by a poorly exposed zone of chert rubble overlying the Bitter Springs Formation (Wells et al., 1964). The contact was inferred to be a disconformity because the chert was considered to have been reworked from the silicified top of the Bitter Springs Formation. We found that where it is best exposed this chert-dominated zone can be resolved into two discrete stratigraphic units, the lower comprising in situ stromatolitic and ooid chert (silicified carbonate) about 150 m thick with rare preservation of non-silicified stromatolitic carbonate. This as yet unnamed unit has a poorly preserved basal lithic (chert-bearing) sandstone suggesting a disconformity separates it from the Bitter Springs Formation. Identification of the stromatolite *Baicalia burra* also suggests that it is significantly younger than the Bitter Springs Formation, and implies correlation with the informally named 'Finke beds' intersected above the Bitter Springs Formation in petroleum exploration wells Finke 1 and Wallara 1 in the NT (Grey et al., in press), and the upper Buldya Group of the Officer Basin and the Burra Group of the Adelaide Rift Complex. The upper part contains no exposures of in situ chert, but, in rare outcrops, the angular chert clasts are shown to be embedded in a grey mudstone matrix. It appears that in this case the chert rubble at the surface represents a lag deposit over chert-bearing diamictite. The chert rubble is also associated with sparse quartzite and sandstone pebbles and cobbles (Fig. 3e) displaying facets and rare striations suggestive of a glacigene origin; glacigene influence at this level in the 'Boord Formation' was not previously recognized. We infer that this basal unit, which is estimated to be about 150 m thick and appears to have an irregular lower boundary suggestive of a disconformity, is most likely a correlative of the Areyonga Formation, rather than the previously recognized diamictite, which lies stratigraphically higher in the succession.

The probable correlative of the Areyonga Formation is overlain by a thick (approximately 450 m) — and mostly covered or very poorly exposed — interval that appears to be mainly dominated by siltstone and shale, with increasing carbonate at the top. The basal contact is not exposed. Multiple horizons of isolated domical stromatolites (Fig. 3f), often nucleated on intraclastic debris, are present in the upper part, and are very similar to undescribed stromatolites in the eastern Amadeus Basin that are probably older than the Pioneer Sandstone (Grey, 2005, p. 93). The siltstone unit is capped by a ridge-forming intraclastic, microbial, and stromatolitic limestone unit. Based on lithology, stratigraphic constraints, and stromatolites this combined interval is a likely correlative of the Aralka Formation of the northeast Amadeus Basin and the central Inindia beds to the south.

Upper 'Boord Formation'

A second and better exposed interval of glacigene diamictite lies with angular erosional contact over the Aralka Formation correlate, locally removing the upper ridge-forming limestone. This is the glacial unit noted by earlier workers (Wells et al., 1961, 1964), and contains pebble- to boulder-sized clasts of limestone, dolomite, sandstone, quartzite, and chert, and rarer granite and volcanic and metamorphic rocks. The largest clasts, several metres in size are clearly derived from the nearby underlying stratigraphy, most notably the ridge-forming limestone unit. Many of the smaller clasts, particularly well-indurated sandstone and quartzite, are rounded, faceted, and striated (Fig. 4a). The matrix, where preserved, is brown to grey, sandy mudstone. The diamictite is interbedded with lenticular sandstone and conglomerate beds, and where significantly incised into underlying stratigraphy is commonly underlain by a basal pebbly and cross-bedded sandstone unit tens of metres thick. We interpret this second glacigene interval, which averages about 100 m in thickness, as a correlative of the Olympic Formation and laterally equivalent Pioneer Sandstone of the northeastern Amadeus Basin.

The upper glacial unit is overlain by a unit about 300 m thick. Local poor exposures suggest that it is dominated by red-brown siltstone and shale, with thin interbeds of fine- to medium- and rarely coarse-grained sandstone, mainly in the upper third. The basal contact is not exposed. Lithologically, it closely resembles the Pertatataka Formation, which overlies the Olympic Formation and Pioneer Sandstone in the northeastern Amadeus Basin. This unit grades up into a succession of limestone and dolomite interbedded with recessive intervals that are either entirely covered or display poor exposure of siltstone, and weathered silty to sandy carbonate (Fig. 4b). The facies association is typical of shallowing-upward cycles in shallow-water carbonate successions. The ridge-forming carbonates often comprise ooid and other grainstones, and stromatolites are diverse and abundant. Significantly, the presence of the stromatolite *Tungussia julia* (Fig. 4c) provides a biostratigraphic link with the Julie Formation (Walter et al., 1979), a carbonate unit overlying the Pertatataka Formation in the northeast part of the basin. The same stromatolite is present in other Australian Neoproterozoic basins at the same stratigraphic level (Grey, 2008). At the Boord Ridges, the Julie Formation correlative is estimated to be at least 550 m thick (top not exposed), whereas an isolated occurrence about 35 km to the south-southeast is estimated to be about 800 m thick.

Latest Neoproterozoic–Cambrian

The red-brown sandstone and siltstone of the Carnegie Formation, averaging about 1700 m in thickness, is lithologically very similar to the Arumbera Sandstone of the northeastern Amadeus Basin, a deltaic succession overlying the Julie Formation and coeval with the latest Neoproterozoic to Early Cambrian Petermann Orogeny. This correlation is further supported by the common presence of *Arumberia* (Glaessner and Walter, 1975; Fig. 4d), a problematic Ediacaran fossil first reported from the lower Arumbera Sandstone but known from other Ediacaran to Early Cambrian successions worldwide. The presence of the Carnegie Formation directly over probable Bitter Springs Formation in the southern part of the WA Amadeus Basin suggests that uplift during an early phase of the Petermann Orogeny led to erosion of the 'Boord Formation' in that area.

The siliciclastic Sir Fredrick Conglomerate, Ellis Sandstone, and Maurice Formation post-date the Carnegie Formation, and are also likely related to the Petermann Orogeny. The Sir Frederick Conglomerate, of uncertain maximum thickness, is composed predominantly of well-rounded quartzite cobbles and boulders, and rarer basement clasts, deposited in a high-energy fluvial environment (Fig. 4e). We suggest approximate correlation with the Mount Currie Conglomerate of the southern NT Amadeus Basin, best developed at Kata Tjuta (Mount Olga). Both units are apparently derived from the Musgrave Province and lower Amadeus Basin to the south and southwest of present outcrops, as indicated by clast composition and imbrication, but distinct differences in clast and matrix assemblages are apparently due to spatial changes in the composition of the exposed rocks. Specifically, the Dean Quartzite is thickly developed and tectonically repeated south of the exposed Sir Frederick Conglomerate, but is poorly developed in the area south of Kata Tjuta. According to Wells et al. (1964, 1970) the Sir Frederick Conglomerate and Ellis Sandstone are lateral equivalents, but this relationship remains to be reassessed. The youngest unit of the main succession of the WA Amadeus Basin is the Maurice Formation (Fig. 4f). Its estimated exposed thickness is at least 3600 m in the south of its range (top not exposed), but its age is poorly constrained, apart from presumed conformity with the underlying units. It may extend into, or be wholly Cambrian in age — if so it could be a whole or part correlative of the Cleland Sandstone in the NT.

Paleozoic or Neoproterozoic

The Angas Hills beds (informal name) comprise a unit of red-brown sandstone and conglomerate exposed within outliers of the Amadeus Basin within the Arunta Complex north of the main basin. Blake (1977) tentatively correlated the Angas Hills beds with the Devonian Pertnjara Group of the NT Amadeus Basin, implying affiliation with the mid-Paleozoic Alice Springs Orogeny. As yet, the age of the Angas Hills beds remains unknown in the absence of biostratigraphic data, but we note that paleocurrents are typically from the south to southwest, similar to those observed for clastic sediments related to the Petermann Orogeny in the WA Amadeus Basin. Clast types are consistent with derivation from older Neoproterozoic units of the Amadeus Basin.

Petroleum prospectivity

Although still under-explored for petroleum, the NT-portion of the Amadeus Basin has had a successful history of petroleum exploration since the first wells were drilled in 1963. The large Mereenie oil and gasfield and the Palm Valley gasfield, which are still producing, were discovered in 1963 and 1965, respectively. Since then, several subeconomic fields have been discovered, and other wells have encountered significant shows from throughout much of the stratigraphic section. Although the Ordovician is considered the most prospective, a number of proven and potential source intervals and play types have been identified within the Neoproterozoic succession (Marshall, 2003, 2005; Marshall et al., 2007). Marshall (2003), revised in Marshall

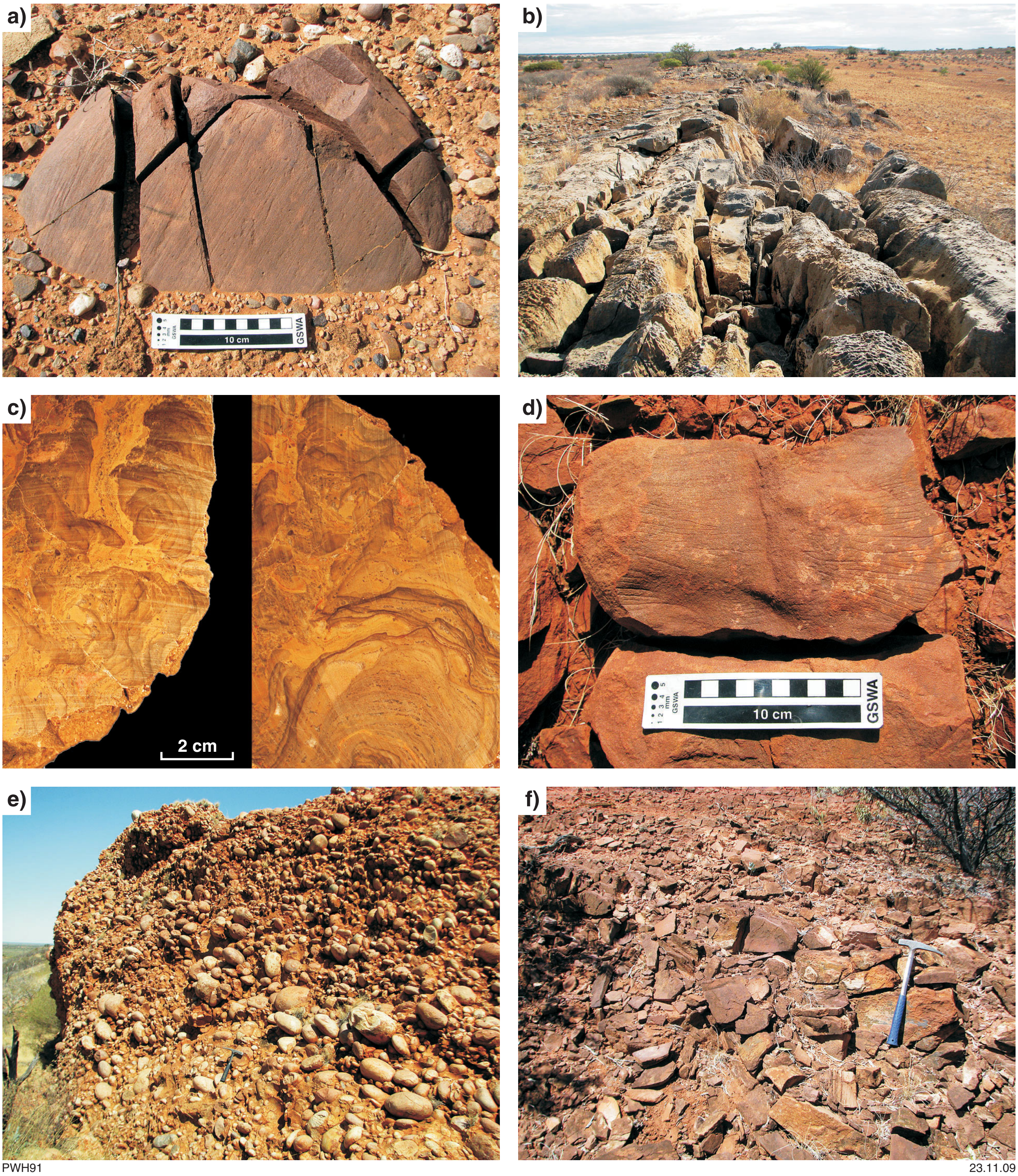

Figure 4. Field and hand specimen photographs: a) Striated quartzite clast, Olympic Formation correlative, Boord Ridges; b) Gently dipping limestone ridge, Julie Formation correlative, Boord Ridges; c) Stromatolite Tungussia julia, *Julie Formation correlative, Boord Ridges; d) Problematic* Arumberia, *Carnegie Formation, Mu Hills; e) Well-rounded quartzite cobbles in sandstone matrix, Sir Frederick Conglomerate, Mu Hills; f) Red-brown lithic and micaceous sandstone, Maurice Formation, southwest of Sir Frederick Range*

et al. (2007), recognized four Neoproterozoic to earliest Cambrian petroleum systems. The oldest, the sub-salt Gillen Member – Heavitree Quartzite play, produced a significant gas flow with high helium content in Magee 1. The second system involves potential source rocks in the upper Bitter Springs, Areyonga, and Aralka Formations and the correlative Inindia beds in the south. This system is most likely responsible for a paleo-oil column in the 'Finke beds' in Finke 1, a measured gas flow in Ooraminna 1, and oil shows in Mount Winter 1. The third system involves potential source rocks in the Pertatataka Formation and correlative Winnall beds, whereas the fourth includes the subeconomic Dingo gasfield, reservoired in the Arumbera Sandstone and probably sourced from lower systems.

In the absence of drill hole information, the source and reservoir potential, and maturity of the WA part of the Amadeus Basin remains speculative. However, recognition that the stratigraphy and facies of the WA Amadeus Basin have much more in common with the eastern succession than previously thought raises the possibility that some of the same petroleum systems and plays may be present.

Conclusions

The Neoproterozoic stratigraphy of the WA Amadeus Basin has much more in common with the NT portion of the basin than previously thought, and correlatives of most stratigraphic intervals can be recognized. Lithostratigraphic correlations are further strengthened by stromatolite biostratigraphic ties. The revised correlations lead to significant changes of inferred age for most units above the Bitter Springs Formation — the 'Boord Formation' as mapped probably spans the interval between and including the Areyonga and Julie Formations; and the Carnegie Formation, Sir Frederick Conglomerate, Ellis Sandstone, and Maurice Formation are probably latest Neoproterozoic to Cambrian synorogenic correlatives of the Arumbera Sandstone and Mount Currie Conglomerate, extending possibly to the Cleland Sandstone. The presence of Western Australian equivalents of units with proven or possible source potential in the NT increases the number of potential petroleum systems that may be present in the WA part of the basin.

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