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Facies analysis of the Neoproterozoic to Late Cambrian Amadeus Basin, Central Australia

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ABSTRACT

The study aims to fill research gaps in sedimentology by presenting a sedimentological study of the Neoproterozoic to Late Cambrian section in the Eastern MacDonnell Ranges to the east of Alice Springs, northeastern area of the Amadeus Basin. This study used the facies analysis in order to improve the current understanding of lithofacies which assists in clarifying depositional environments interpretation in the northeast of the Amadeus Basin. This study recognised six lithofacies types (massive claystone, trough cross-stratification sandstone, hummocky cross-stratification sandstone, wave ripple lamination sandstone, massive siltstone, ripple cross-lamination sandstone) from the sedimentological log section. The Arumbera Sandstone and Shannon Formation were interpreted as deltaic settings. The Todd River Dolomite and Giles Creek Dolomite are possibly transitional marine to deltaic-peritidal setting. Sedimentological analysis in this study classified the Arumbera Sandstone and Todd River as arkoses and the Shannon Formation as dolostone.

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1. Introduction

The Amadeus Basin is one of the largest basins located in central Australia. It is an integral part of the Centralian Superbasin which also includes the Officer Basin, Ngalia Basin and Georgina Basin (Fig. 1). These basins have similar depositional successions that represent the upper part of Precambrian (Neoproterozoic) to Paleozoic (Walter et al., 1995; Hill & Walter, 2000).

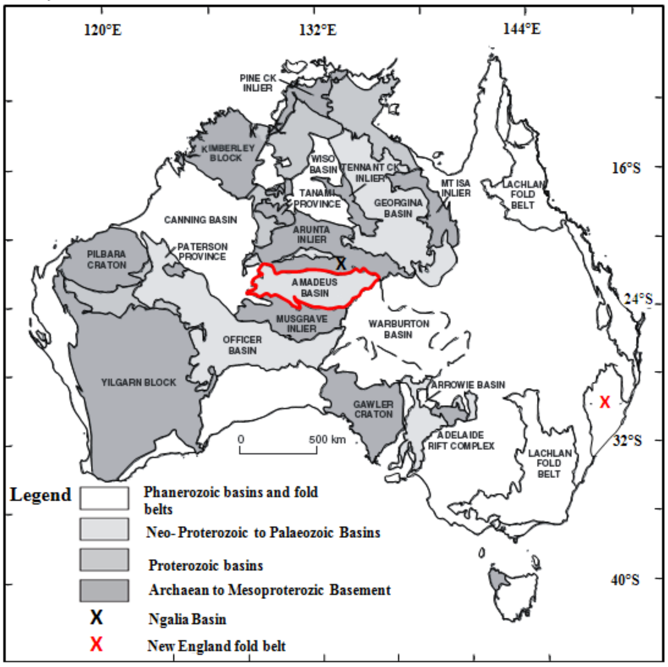

Fig. 1: Map of the intracratonic basins in Australia which include the Amadeus Basin (red outline), Officer Basin, Ngalia Basin and Georgina Basin (modified: Maidment et al., 2007).

Most available data of Neoproterozoic provenance suggest that the source of sediments in the Amadeus Basin was local and sediments were derived from Musgrave Province, Arunta Region and Gawler Craton after uplifting and erosion (Maidment et al., 2007). Previous studies investigating sedimentary provenance in the Amadeus Basin in central Australia have focused on isotope analysis, geochemistry and detrital zircon (Zhao et al., 1992; Maidment et al., 2007). These studies confirm the Amadeus Basin was controlled by local source regions, but also suggest that there is uncertainty because there is a limited isotopic work in the Amadeus Basin. The lack of isotope elements in these formations revealed doubt in some previous provenance studies outcomes in the Amadeus Basin (Maidment et al., 2007). Those depositional units covered significant geological time and therefore different depositional environments, so a change in provenance is possible (Deckelman, 1991).

The focus of this study is to interpret the depositional environments of the northeastern Amadeus Basin by providing a sedimentological study. It is hoped that outcomes of this study will enable better and more detailed comparison between similar depositional units in the different basins of the Centralian Super basin. Investigating the depositional environment of sediments in the northeast of the Amadeus Basin is important because it attempts to determine the provenance generation, transportation, deposition and early diagenesis. It also clarifies the relations between sediment composition, texture and grain size provides indications to the early state of the rock quality before burial with depth in subsurface. Provenance investigation could assist in understanding the tectonic setting, mapping depositional systems and paleogeography reconstruction. This study is also important for enabling a better comprehension of the exploration possibilities within the northeastern Amadeus basin.

2. Aim of this study

The aim of this study is enable a more detailed depositional environment and a more accurate lithofacies interpretations for the Neoproterozoic to late Cambrian than has previously been conducted for this section in the Eastern MacDonnell Ranges to the east of Alice Springs, northeastern area of the Amadeus Basin.

3. Geological setting

The Amadeus Basin is one of the largest intracratonic sedimentary basins located in the central part of Australia. It is approximately 170,000 km^2, extending to the southern part of the Northern Territory and west into Western Australia (Preiss & Forbes, 1981; Walter et al., 1995; Hill & Walter, 2000; Skotnicki et al., 2008; Fig. 2). There is evidence for more than 14 km thick deposits of marine and non-marine sedimentary rocks from Neoproterozoic to late Paleozoic, a period of ~550 Ma (Wade et al., 2005).

It is located near other sedimentary basins which have the same geological age as the Amadeus Basin, in particular, Ngalia Basin lying within southern Northern Territory, Georgina Basin between Northern Territory and Queensland and Officer Basin that extends between South Australia and Western Australia (Lindsay & Korsch, 1991; Fig. 2). These basins have become one part of the geological hypothetical Centralian Superbasin (Kaufman & Knoll, 1995; Maidment et al., 2007). The Centralian Superbasin is now a series of separate sedimentary basins, but was believed to be a massive basin area before separation (Maidment et al., 2007).

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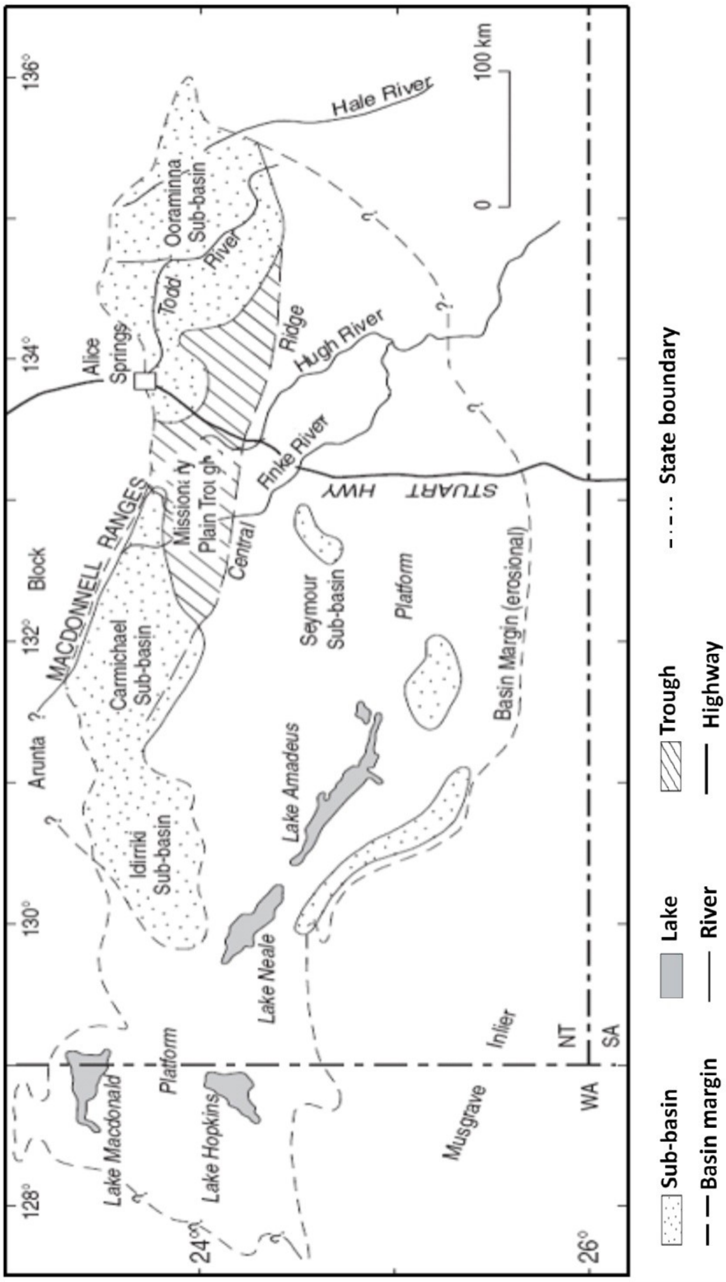

Fig. 2: Major morphological features of the Amadeus Basin, focus area in red square refers to Fig. 3 (from: Lindsay & Korsch, 1991).

4. Materials and methods

The samples were all collected in the Eastern MacDonnell Ranges, to the east of Alice Springs in the northeast of the Amadeus Basin. Most of them are from a section that was logged through about 700 m of stratigraphy, exposed along the Ross River in the northeast of the Amadeus Basin (Fig. 3). The sedimentological log data were used to interpret the depositional processes and likely depositional environments for the Arumbera Sandstone, Todd River Dolomite, Giles Creek Dolomite and Shannon Formation. These depositional units were analysed by using the facies analysis based on sedimentary structures, grain size and fossils content in combination with vertical trends. This analysis involved interpreting the facies by looking for lithofacies and facies associations (Tucker, 1982; Collinson & Lewin, 1983; Ghazi & Mountney, 2009; Ghazi & Mountney, 2010). Lithofacies are characterised by sedimentary features, such as grain size, fossils content or sedimentary structures (Reading, 1986). Facies associations contain genetically and environmentally related groups of facies (Boggs, 1995). The facies analysis in this study is likely to be crucial for understanding the depositional environment, which could possibly provide a framework for future exploration work as it can help in predicting the paleogeographic distribution and continuity of each facies association (Ainsworth et al., 2011).

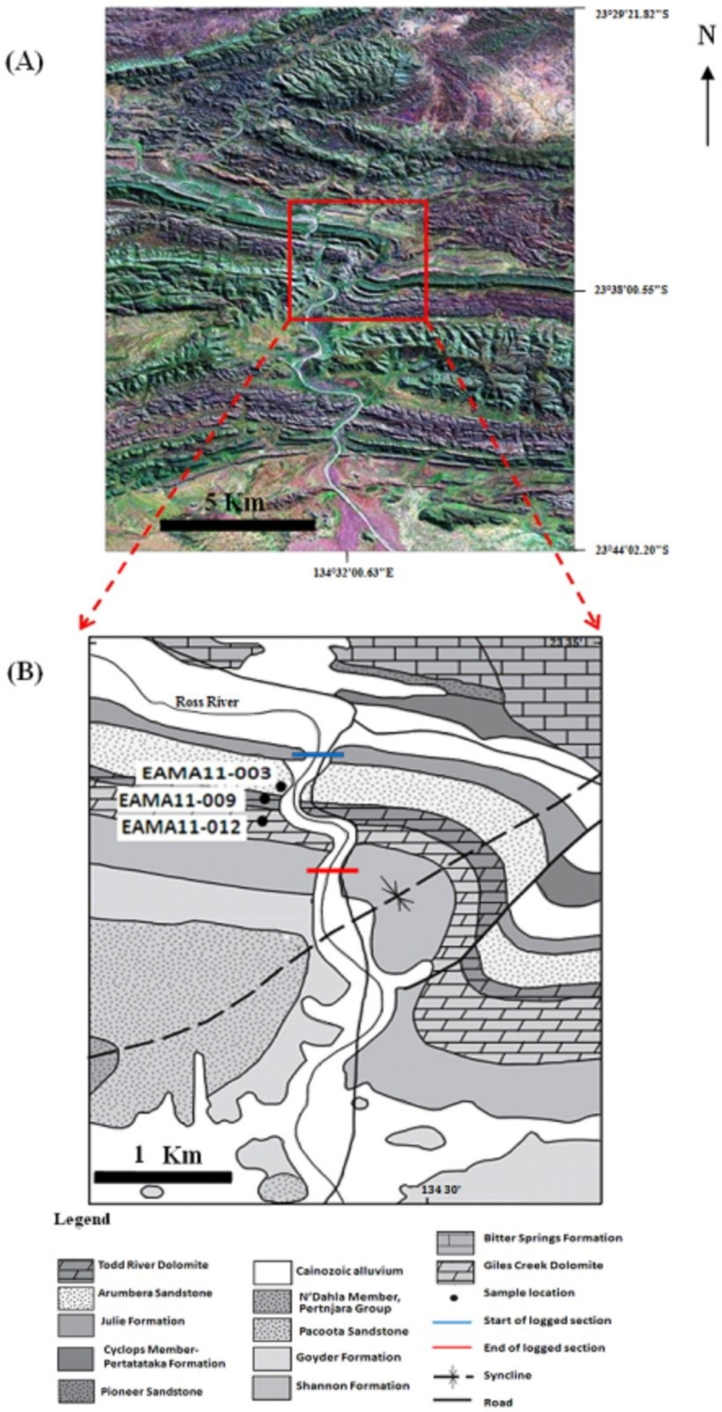

Fig. 3: (A) Landsat image of the Ross River and (B) some sample localities and geology of the Ross River focus area of the Amadeus Basin, (sample locations are highlighted by black dots and stratigraphic section is highlighted by blue line start section and red line end section)(B modified: Maidment et al., 2007).

5. Lithofacies Analysis

5.1. Lithofacies

This study has identified six lithofacies (Cm, St, Sh, Sw, Sm, Sr) which occur in a predictable stratigraphic order. These lithofacies are presented in Table 1, Fig. 5 and annotated on sedimentological log in Fig. 4b.

Massive Claystone (Cm)

Description

This is the most abundant facies type in nearly all cycles, representing 15 % of total succession (Fig. 4b). It consists of interbedded mudstone and siltstone and is generally massive (Fig. 5a). The lower contact of this facies is sharp with facies St and Sw, while the upper contact is gradational with facies Sh (Fig. 4b).

Lithofacies	Lithology	Sedimentary structures	Fossils	Contacts	% succession	Environmental interpretation
Cm	Interbedded mudstone & siltstone	None	None	Lower boundary sharp&upper boundary gradational	15 %	Pro-delta
St	Fine to medium sandstone with granules, pale pink-yellow colour	Trough cross-stratification, hummocky cross-stratification, contorted bed, and wave ripple lamination	Intraclasts	Lower boundary gradational & upper boundary sharp	15 %	Delta front
Sh	Fine to medium sandstone interbedded with shale	Trough cross-stratification, hummocky cross-stratification with contorted bed	None	Lower & upper boundaries are sharp	12 %	Pro-delta to delta front
Sw	Clay and very fine to fine sandstone interbedded with shale and dolomite graduating up into blocky dolomite	Wave ripple lamination, ripple cross lamination, concretions, planar cross-stratification and planar lamination	Shell fragments and intraclasts	Lower boundary gradational &upper boundary sharp	20%	Transitional marine to deltaic
Sm	Massive siltstone interbedded with dolomite	Ripple cross lamination, planar lamination, planar cross-stratification, wave ripple lamination and hummocky cross-stratification with bioturbation	None	Lower boundary sharp & upper boundary gradational	8%	Pro-delta

Table 1: Summary and identification of six lithofacies occur in a predictable stratigraphy order with their depositional environment interpretations

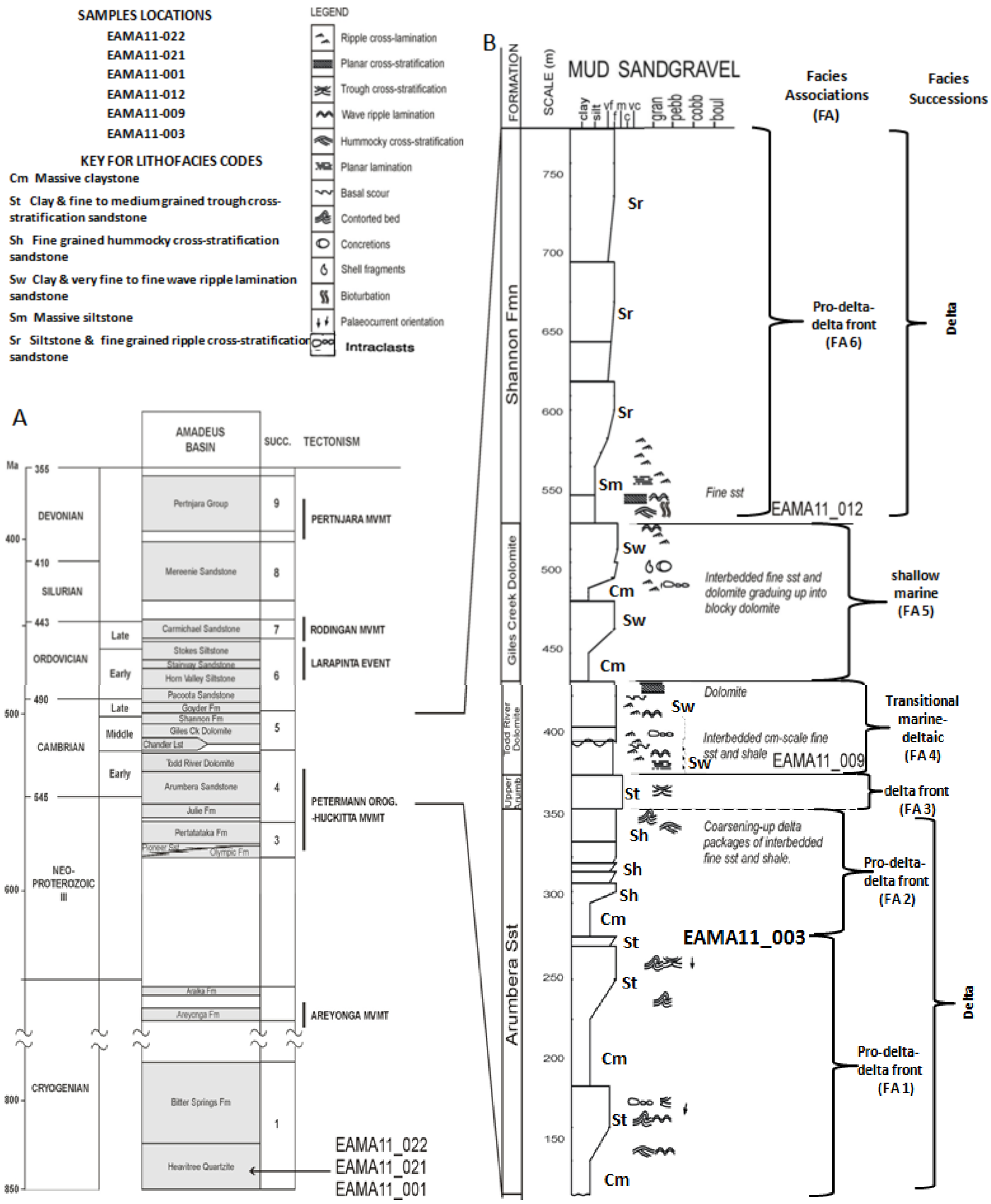

Fig. 4: (A) stratigraphy of the northeastern Amadeus basin, modified from: (Maidment et al., 2007) and (B) sedimentologic log of the Neoproterozoic to late Cambrian stratigraphy exposed along the Ross River to the south of Ross River Resort shows the main lithofacies and facies associations.

Interpretation

According to grain size facies Cm is interpreted to represent pro-delta. The grain size ranges from mud to silt size. The presence of gradational boundaries between the coarsens-upwards cycles indicates that this facies is a pro-delta depositional environment.

Trough cross-stratification sandstone (St)

Description

This facies represents 15 % of the total succession and most commonly overlies facies Cm (Fig. 4b). It consists of fine to medium sandstone with pink-yellow granules, which gradually coarsens-upwards (Fig. 5b). Facies St also contains trough cross-stratification, hummocky cross-stratification, contorted bed, wave ripple lamination and intraclasts. The lower contact of this facies is gradational with facies Cm, while the upper contact is sharp with facies Sw (Fig. 4b).

Interpretation

According to grain size and sedimentary structures facies St is interpreted to represent delta front. The gradational boundaries between facies St and Cm represent coarsens-upwards cycles, which indicate, that facies St is delta front. Trough cross-stratification was formed in the lower flow regime. Facies St is wave-dominated because wave is responsible for forming trough and hummocky cross-stratification. The presence of intraclasts at the bottom of facies St indicates that facies Cm is pro-delta (Fig. 4b), while facies St is delta front (Fig. 4b).

Hummocky cross-stratification sandstone (Sh)

Description

This facies represents 12% of the total succession and consists of fine to medium sandstone interbedded with shale, the sandstone represents coarsens-upwards (Figs. 4b & 5c). It also contains hummocky cross-stratification and trough cross-stratification with contorted bed. The lower and upper contacts of this facies are sharp with facies Cm and St (Fig. 4b).

Interpretation

According to grain size and sedimentary structures facies Sh is interpreted to represent pro-delta to delta front. The presence of coarsens-upwards delta packages of interbedded fine sandstone and shale indicate transition between pro-delta to delta front. Hummocky cross-stratification was formed in the lower flow regime. Facies Sh is wave dominated because storm action is responsible for forming hummocky cross-stratification (Tucker, 1991).

Wave ripple lamination sandstone (Sw)

Description

This facies represents 20 % of the total succession and most commonly overlies facies Cm (Fig. 4b). It consists of very fine to fine sandstone with minor clay laminae interbedded with shale and dolomite graduating up into blocky dolomite (Fig. 5d). The sandstone gradually coarsens- upwards. Facies Sw also contains wave ripple lamination with shell fragments and intraclasts of very fine-to-fine sandstone. The lower boundary is gradational with facies Cm, the upper boundaries of this facies are sharp with facies Cm and Sm (Fig. 4b).

Interpretation

According to grain size, sedimentary structures and fossil contents facies Sw is interpreted to represent transitional marine to deltaic. The presence of coarsens-upwards sandstone within the facies Sw indicates deltaic process. While the presences of wave ripple lamination, shell fragments and intraclasts indicate a shallow marine depositional process (Fig. 4b).

Massive siltstone (Sm)

Description

This facies represents 8 % of the total succession and most commonly overlies facies Sw (Fig. 4b). It consists of massive siltstone interbedded with dolomite. Facies Sw also contains ripple cross lamination, planar lamination, planar cross-stratification, wave ripple lamination and hummocky cross-stratification with bioturbation (Figs. 4b & 5e). The lower contact of this facies is sharp with facies Sw, while the upper is gradational with facies Sr (Fig. 4b).

Interpretation

Facies Sm is interpreted to represent fluvially dominated. It is gradually coarsens-upwardssiltstone to fine sandstone (Fig. 4b). Ripple cross lamination and planar cross-stratification propose pro-delta, whereas hummocky cross-stratification suggests wave influenced or formed due to storm actions. Dolomite indicates that possibly formed due to alteration in carbonate rocks in a shallow marine environment.

Ripple cross-lamination sandstone (Sr)

This facies represents 30 % of the total succession. It consists of silty to fine sandstone interbedded with dolomite (Figs. 4b & 5f). Sandstone coarsens-upwards. Facies Sr also contains ripple cross lamination. The lower boundary is gradational with facies Sm, but the upper boundary is sharp (Fig. 4b).

Interpretation

Facies Sr is interpreted as fluvially dominated. It is gradually coarsening-upward siltstone to fine sandstone. Ripple cross lamination suggests pro-delta to delta front. The ripple cross lamination has two dimensional bedform indicating a high flow regime. Dolomite indicates that possibly formed due to alteration in carbonate rocks in a shallow marine environment.

5.2. Facies Association

Facies association 1 (Arumbera Sandstone): Pro-delta to delta front – Massive claystone and trough cross-stratification sandstone (Cm and St)

Description

This facies association shows coarsens-upwards sand succession (clay to fine grain size sandstone). It contains sedimentary structures that encompass trough cross-stratification (St), contorted bed, wave ripple lamination and hummocky cross-stratification (Table 1).

Interpretation

The sedimentary structures indicate that this facies association is wave dominated because wave action is responsible for forming trough and hummocky cross-stratification. The trough and hummocky cross-stratification have a three dimensional bedform which indicates a low flow regime. Coarsens-upwards cycles confirm the same depositional processes which are a part of pro-delta to delta front (Fig. 4b).

Facies association 2 (Arumbera Sandstone): Pro-delta to delta front – Massive claystone and hummocky cross-stratification (Cm and Sh)

Description

This facies association shows coarsens-upwards delta packages of interbedded fine sandstone and shale succession (Cm). It has sedimentary structures that encompass hummocky cross-stratification (Sh) and contorted bed (Table 1).

Interpretation

The sedimentary structures indicate wave dominated. Wave action is responsible for producing hummocky cross-stratification. The hummocky cross-stratification has three-dimensional bedform and indicates a low flow regime. The grain size of this facies association supports the same depositional processes that are a part of pro-delta to delta front because it is coarsens-upwards packages with interbedded fine sandstone and shale (Fig. 4b).

Facies association 3 (Arumbera Sandstone): Delta front – Hummocky cross-stratification (Sh)

Description

This facies association exposes a clean body of medium sandstone which contains hummocky cross-stratification (Sh) (Table 1).

Interpretation

The sedimentary structures indicate that this facies association is wave dominated, as the wave action is responsible for generating hummocky cross-stratification. The grain size of this facies association supports the same depositional process which is part of a delta front (Fig. 4b).

Facies association 4 (Todd River Dolomite): Transitional marine to deltaic – wave ripple lamination sandstone with dolomite (Sw)

Description

This facies association demonstrates interbedded cm-scale very fine to fine sandstone and shale with dolomite at the top. It encompasses planar lamination, wave ripple lamination (Sw), ripple cross-lamination, basal scour, planar cross-lamination and intraclasts (Table 1).

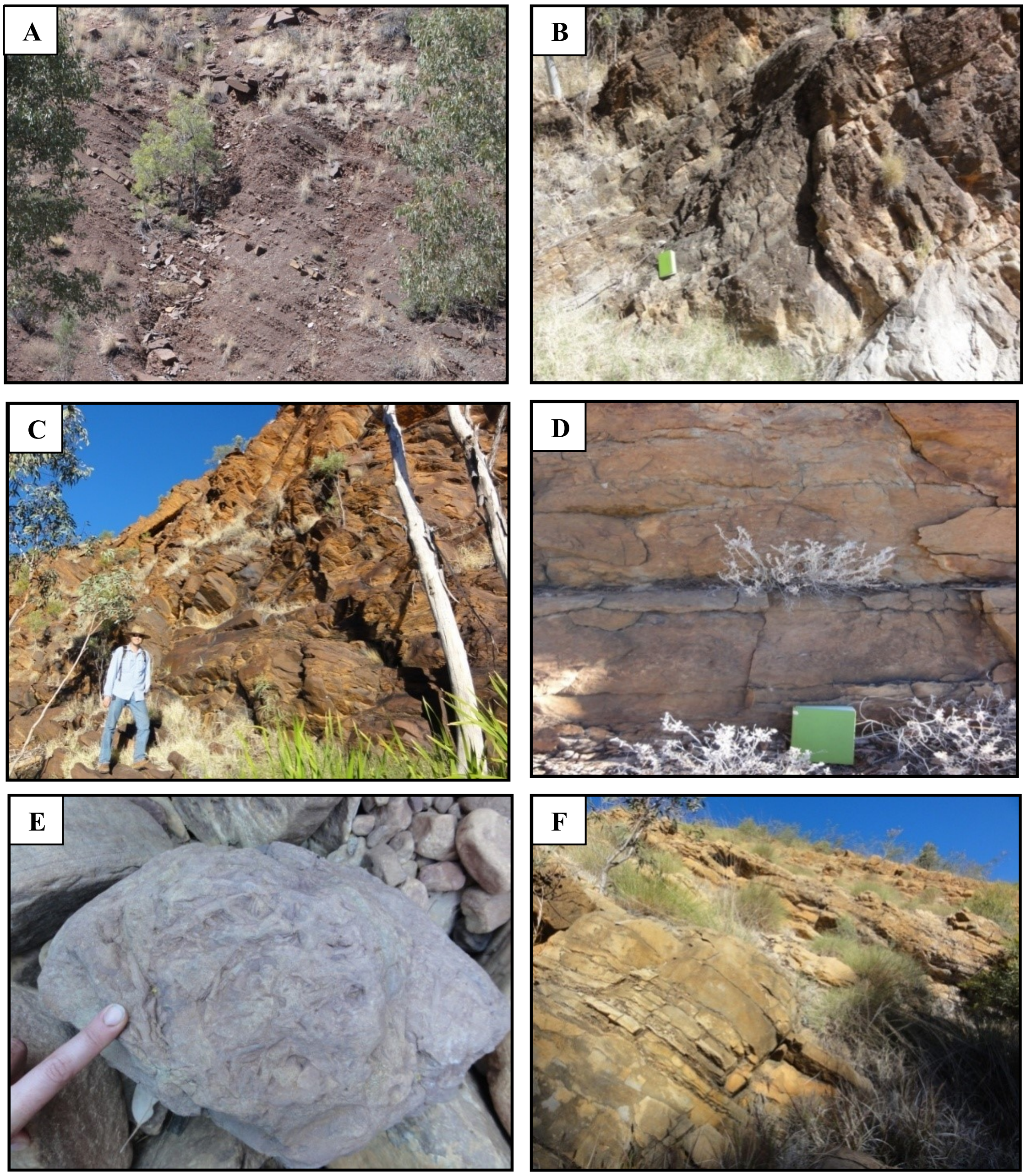

Fig. 5: Characteristic examples of lithofacies within the Arumbera Sandstone, Todd River Dolomite and Shannon Formation, (A) massive claystone facies Cm, (B) clay and fine to medium trough cross-stratification sandstone facies St, (C) hummocky cross-stratification sandstone facies Sh, (D) clay and very fine to fine wave ripple lamination sandstone facies Sw, (E) massive siltstone with bioturbations facies Sm and (F) ripple cross-lamination sandstone facies Sr. Green notebook dimensions; width 15 cm & height 21 cm.

Interpretation

The sedimentary structures indicate shallow marine and deltaic influence because wave ripple lamination and planar lamination can be formed by both depositional processes. Shallow marine and deltaic fluvial processes might be responsible for making these sedimentary structures, in particular planar cross-lamination. The presence of coarsens-upwards sandstone within the facies Sw indicates deltaic process. While the presences of wave ripple lamination, shell fragments and intraclasts and dolomite indicate a shallow marine depositional process (Fig. 4b). Dolomite indicates that possibly formed due to alteration in carbonate rocks in a shallow marine environment.

Facies association 5 (Giles Creek Dolomite): Shallow marine – Massive claystone and wave ripple lamination (Cm and Sw)

Description

This facies association demonstrates massive claystone at the base (Cm) to interbedded fine sandstone and dolomite grading up into blocky dolomite at the top. It comprises wave ripple lamination (Sw), ripple cross-lamination with shell fragments and concretions (Table 1).

Interpretation

Giles Creek Dolomite facies association may possibly be shallow marine sandstone and peritidal based on sedimentary structures, grain size and fossils content. The presence of wave ripple lamination, shell fragments and concretions indicate shallow marine depositional process. This process might be responsible for creating these sedimentary structures, in particular ripple cross lamination and wave ripple lamination. These sedimentary structures have two-dimensional bedform and indicate a low flow regime. Grain size and fossil fragments of this facies association demonstrate interbedded shallow marine sandstone and dolostone (Fig. 4b). Dolomite indicates that possibly formed due to alteration in carbonate rocks in a shallow marine environment.

Facies association 6 (Shannon Formation): Pro-delta to delta front – Massive siltstone and ripple cross-lamination (Sm and Sr)

Description

This facies association highlights siltstone (Sm) to fine sandstone coarsens-upwards. It encompasses ripple cross-lamination (Sr), planar lamination, planar cross-stratification, wave ripple lamination and hummocky cross-stratification with bioturbation (Table 1).

Interpretation

This facies association may represent cycles of deltaic deposition because it contains coarsens-upwards cycles (pro-delta to delta front) based grain size and vertical trend (Fig. 4b). Ripple cross lamination and planar cross-stratification suggest fluvially dominated, whereas the hummocky cross-stratification suggests wave influenced. These sedimentary structures have two dimensional bedform and indicate a high flow regime, while hummocky cross-stratification has three dimensional bedform that suggests wave influenced, storm and a low flow regime.

5.3. Facies Succession

Based on the above facies associations interpretation, depositional environments of component units of the Arumbera Sandstone and Shannon Formation are likely to be deltaic depositional environments as a part marginal marine depositional environment. The Arumbera Sandstone and Shannon Formation indicate that there are cycles of pro-delta to delta front. The Todd River Dolomite and Giles Creek Dolomite may represent transitional marine to deltaic depositional environments. The presence of wave ripple lamination, ripple cross-lamination, trough cross-stratification and hummocky cross-stratification, planar lamination and fossil fragment with minor bioturbation proposes that these facies associations in the Todd River Dolomite and Giles Creek Dolomite were deposited in a wave-dominated shore face setting.

A new process-based classification for marginal marine systems by Ainsworth et al. (2011) has been utilised in this study according to availability and percentage of sedimentary structures in these facies successions. The facies associations within the Arumbera Sandstone suggest 80 % wave dominated and 20 % fluvially influenced and facies associations within the Shannon Formation suggest 90 % fluvially dominated and 10 % wave influenced (Fig. 6).

The percentage of sedimentary structures in the Arumbera Sandstone was calculated separately based on availability of sedimentary structures in Facies Association 1 that includes Facies Cm and St, Facies Association 2 that includes Facies Sh and Cm and Facies Association 3 that includes Facies St (Fig. 4). Trough cross-stratification and hummocky cross-stratification are the main dominated sedimentary structures in these Facies Associations which represent wave dominated. While wave ripple lamination could represent fluvially dominated. The percentage of sedimentary structures in the Shannon Formation was calculated based on availability of sedimentary structures in Facies Association 6 that includes Facies Sr and Sm (Fig. 4). Ripple cross lamination, planar cross-stratification and wave ripple lamination are the main dominant sedimentary structures in this Facies Association that represent fluvially dominated. Whereas hummocky cross-stratification shows a small percentage referring to wave dominated.

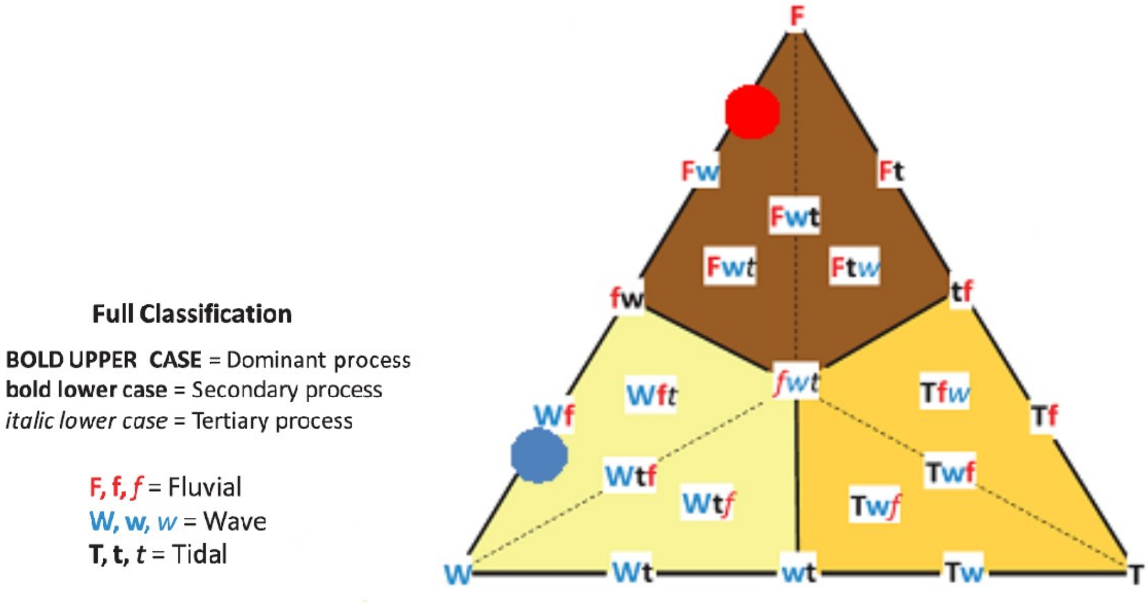

Fig. 6: Facies classification based on percentages of sedimentary structures from sedimentological log data, it suggests that the Arumbera Sandstone is likely to be wave dominated and fluvially influenced (highlighted by blue circle), while the Shannon Formation is likely to be fluvially dominated, wave influenced (highlighted by red circle). Note facies association 1, 2 & 3 were used to calculated percentage sedimentary structures within the Arumbera Sandstone and facies association 6 within the Shannon Formation.

6. Discussion

The results of this study and available data from Conrad (1981) and Lindsay (1987) defined the Arumbera Sandstone as pro-delta to delta front (Lindsay, 1987). Previous publications interpreted the Todd River Dolomite as tidal flat carbonates and transgressive oolitic barrier bars (Lindsay, 1987). This study interpreted the Todd River Dolomite as transitional marine and deltaic based on sedimentary structures, grain size and fossils content in conjunction with vertical trends.

Available data indicate that the depositional environment the Giles Creek Dolomite as shallow marine and peritidal based on silty sandstone, siltstone, conglomerate, arkose, greywacke, and thin beds of fine grey dolomite and fossils content (Deckelman, 1985). The facies analysis in this study supports that the Giles Creek Dolomite is likely to be shallow marine sandstone based on wave ripple lamination. Grain size and fossil fragments of this facies association demonstrates interbedded shallow marine sandstone. Dolomite indicates that possibly formed due to alteration in carbonate rocks in a shallow marine environment.

Previous work in the northeastren Amadeus Basin divided the Shannon Formation into two units (Dee et al., 1984). The lower unit is described as a shale-rich unit with interbedded limestone

(Deckelman, 1985). The upper part of Shannon Formation is described as shallow marine siliciclastic mudrocks and peritidal dolostone (Kennard et al., 1986). The Shannon Formation was mainly interpreted as a shallow marine depositional environment (Dee et al., 1984). Nevertheless, the facies analysis in this study suggests that the Shannon Formation deposited through various cycles of deltaic (pro-delta to delta front). Ripple cross-lamination and planar cross-stratification suggest fluvially dominated, whereas the hummocky cross-stratification suggests wave influenced.

7. Conclusions

Lithofacies analysis in this study has identified six lithofacies (massive claystone, trough cross-stratification sandstone, hummocky cross-stratification sandstone, wave ripple lamination sandstone, massive siltstone, ripple cross-lamination sandstone). The facies associations in the Arumbera Sandstone indicate a pro-delta to delta front. While the facies association within the Todd River Dolomite reveals as transitional marine and deltaic. The Giles Creek Dolomite suggests shallow marine sandstone, whereas the facies associations in the Shannon Formation indicate cycles of deltaic (pro-delta to delta front). Repeated cycles of general coarsens-upwards were very clear through combining the vertical succession of the facies association identified in the sedimentological log.

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