Palaeoproterozoic terrestrial sedimentation in the Beasley River Quartzite, lower Wyloo Group, Western Australia

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ABSTRACT

Pre-2.2 Ga aeolianite deposits are relatively rare in the geological record, due to reworking of aeolianites either by fluvial systems, transgression or non-recognition. Here, we present high resolution sedimentary facies analysis of a section through the 2.2 Ga Beasley River Quartzite, lower Wyloo Group, Western Australia. The unambiguous presence of terrestrial (fluvial-aeolian) deposition is documented in the form of fluvial architectural elements (channel, bar, lateral accretion and overbank deposits) and aeolian features (dune, pin-stripe lamination, wind streaks, and adhesion features). These observations strongly contrast with a previous interpretation of marine deposition, which is discounted. Our data is consistent with the dominantly terrestrial depositional mode of the rest of the lower Wyloo Group, including the basal Three Corners Conglomerate Member and the subaerial Cheela Springs Basalt. We conclude that the lower Wyloo succession formed in a terrestrial regime during continental rifting.

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1. Introduction

The deposition of aeolian deposits in arid subtropical regions lacking vegetation on Recent Earth has been used to imply that pre-vegetational Precambrian sedimentary successions should be replete with aeolian deposits (Eriksson and Simpson, 1998). Although aeolian deposits are well documented from the late Palaeoproterozoic to the Neoproterozoic (Table 1 in Eriksson and Simpson, 1998), early Palaeoproterozoic to Archaean aeolinites are rare (cf. Simpson et al., 2004, 2012; Chakraborty and Sensarma, 2008). This rarity is enigmatic, as the facies commonly associated with aeolian deposits—such as braided fluvial and coastal successions—are generally well preserved in modern environments. The rarity of pre-2.2 Ga aeolianites has been explained as a consequence of reworking, either by braided rivers across non-vegetated floodplains or transgression, or their non-recognition (Eriksson and Simpson, 1998; Eriksson et al., 1998).

The Beasley River Quartzite (BRQ) of the lower Wyloo Group, Western Australia (Trendall, 1979; Martin et al., 2000) is a thick succession of clastic sedimentary rocks that unconformably overlies the 2.4–2.3 Ga Turee Creek Group and is conformably overlain by the 2.2 Ga Cheela Springs Basalt (Martin et al., 1998; Müller et al.,

2005). The BRQ has been interpreted as largely shallow marine (Thorne and Seymour, 1991), or fluvio-marine with offshore tidal channel and sandbar facies (Martin et al., 2000).

However, a problem with previous models of BRQ deposition is that no detailed facies analysis was undertaken and inferences regarding the depositional environment was solely based on the petrography of the clastic rocks and statistical analysis of palaeocurrent data (Martin et al., 2000; their Table 1 and references therein). Furthermore, the interpreted marine environment contrasts with a demonstrably subaerial mode of eruption of the conformably overlying Cheela Springs Basalt (a 4 km thick succession of stacked, amygdaloidal flows), and a clearly fluvial depositional environment of the lowermost member of the BRQ, the Three Corners Conglomerate Member (cf. Trendall, 1979).

The lower Wyloo Group outcrops around the Hardey Syncline (Fig. 1) and presents an ideal and unique opportunity to reconstruct the fluvial and aeolian depositional systems. Detail stratigraphic analysis of the lower Wyloo Group over a broad area is under progress. In this paper, we present sedimentary facies analysis of a section through the BRQ in the Hardey Syncline area (Fig. 1), where the sedimentary succession is well preserved. In significant contrast to the existing interpretation, our sedimentary facies analysis reveals that the Baesley River Quartzite includes at least a component of terrestrial deposition. This finding suggests that pre-2.2 Ga aeolianties may not be as rare as previously considered, but unreported due to non-recognition (see also Simpson et al., 2012).

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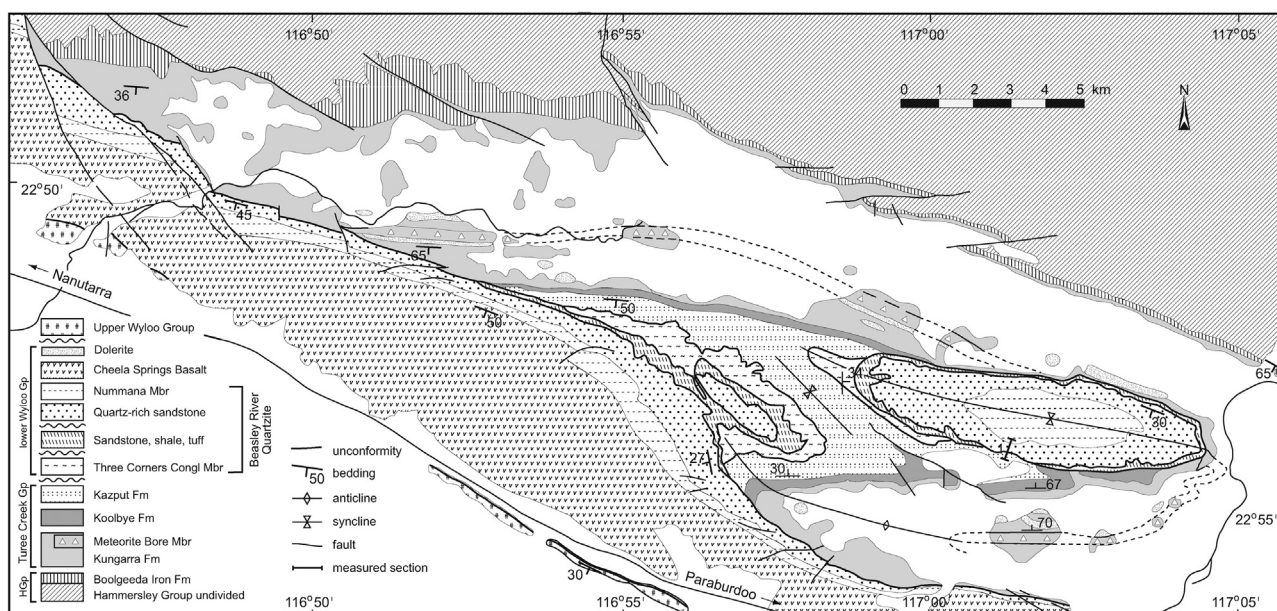(R. Mazumder).

Fig. 1. Geological map of the study area, showing the disposition of the Beasley River Quartzite and bounding units.

2. Geological setting

Western Australia is one of the few places in the world that document a near-continuous record of early Earth history (Trendall and Blockley, 1970; Trendall, 1979; Van Krandendonk, 2010 and references therein; Hickman and Van Kranendonk, 2012). From the beginning of the Neoarchean, the terrestrial to marine Fortescue Group (2.78–2.63 Ga), marine Hamersley (2.63 to <2.45 Ga), and Turee Creek (<2.45 to >2.22 Ga) groups record almost continuous deposition for nearly 600 Ma, across the rise of atmospheric oxygen (Van Kranendonk, 2010; Williford et al., 2011). The Turee Creek Group is unconformably overlain by the Wyloo Group of the Ashburton Basin, which consists of low-grade sedimentary and volcanic rocks with a thickness of about 12 km (Thorne, 1990; Thorne and Seymour, 1991). The Wyloo Group has been informally divided into a lower Wyloo Group and an upper Wyloo Group (Fig. 1: Powell and Horwitz, 1994). The upper Wyloo Group unconformably overlies the lower Wyloo Group and these are unconformably overlain by the younger sequences of the Blair basin or the Breshnahan, Edmud, and Collier basins (Cawood and Tyler, 2004).

Age constraints for the lower Wyloo Group include a 2209 ± 15 Ma date for a tuffaceous component within the lower part of the Cheela Springs Basalt (Martin et al., 1998). This date is in excellent agreement with two identical dates of 2208 ± 10 Ma from the associated subvolcanic dolerite sills that were emplaced into the underlying rocks of the Beasley River Quartzite and the Turee Creek Group (Martin et al., 1998; Müller et al., 2005; Martin and Morris, 2010). Age data from detrital zircons from the Beasley River Quartzite indicate a maximum depositional age of 2446 ± 6 Ma, although the youngest individual zircon analysis is 2420 ± 18 Ma (Nelson, 2004). The upper Wyloo Group is constrained by an age of c. 1790 Ma from the June Hill Volcanics (Evans et al., 2003; Wilson et al., 2010).

The Beasley River Quartzite constitutes the lower unit of the lower Wyloo Group and consists of the basal Three Corners Conglomerate Member of conglomerate and sandstone, medium- to fine-grained quartz-rich sandstones, and an upper unit of siltstone, mudstone, and fine- to coarse-grained sandstone (Nummana Member). The quartz-rich sandstone member is characterized by large to small scale cross-bedding, low angle stratification, asymmetric current ripples and planar bedding. The basal Three Corners

Conglomerate Member consists of sandstone and conglomerate, the latter with abundant, rounded to subrounded clasts (pebbles to cobbles) of banded-iron-formation (BIF) and chert within a sandy matrix rich in secondary magnetite. The Beasley River Quartzite is conformably overlain by the Cheela Springs Basalts, a 4 km thick succession of subaerial lavas.

3. Sedimentary facies

A detailed section through the main quartz-rich sandstone of the BRQ was measured on the southern limb of the Hardey Syncline (Fig. 1). Here, the Beasley River Quartzite is predominantly composed of medium- to fine-grained quartz-rich sandstone. In the measured section, two facies associations are stacked in a repetitive succession, tens-of-meters thick (Fig. 2). The facies associations include a braided fluvial facies association and inter bedded aeolian dune and inter dune facies association (Fig. 2).

3.1. Braided fluvial facies associations

The braided fluvial deposits are developed at the meter scale. Quartz-rich sandstones of this facies are poorly sorted with angular to sub-angular grains (Fig. 3A). This facies association is almost devoid of mud. The sandstones are characterized by planar, as well as trough cross-bedding. As paleocurrent determination from planar cross-beds is often problematic (High and Picard, 1974 and references therein), we have collected paleocurrent data (trough axis azimuth) from three-dimensional bedding plane exposures with spectacular trough cross-beds. Paleocurrent analysis has been done following the methodology prescribed by Dott (1974) and High and Picard (1974). As the dip of bedding is <25°, no tilt correction has been done (cf. Ramsay, 1961; Dott, 1974). Eight facies constitutes the braided fluvial association and differ from each other in type, scale and associated primary sedimentary structures. Individual sedimentary facies with Miall's facies and architectural element nomenclature (Miall, 1985) are described below.

3.1.1. Thick, lenticular, medium-grained trough cross-stratified sandstone (CH)

This facies is characterized by lenticular, medium-grained sandstone with trough cross-beds (Fig. 3B). The thickness of trough

cross-bed sets decreases upward within a coset. The coset and cross-set thicknesses vary generally between 45 and 70 cm, and 5 and 15 cm, respectively. Cross-strata orientation is unimodal (Fig. 2). This facies invariably occurs on major erosion surfaces and is associated with facies B.

This facies is attributed to dune migration along the channel floor under the hydrodynamic conditions of the upper part of the lower flow regime (Miall, 1985; Mazumder and Sarkar, 2004; Sambrook Smith et al., 2006).

3.1.2. Compound cross-stratified medium-grained sandstone (SB)

This facies is characterized by compound cross-stratification (Fig. 3C: Bose and Chakraborty, 1994; Mazumder and Sarkar, 2004) and is confined to the basal part of the facies
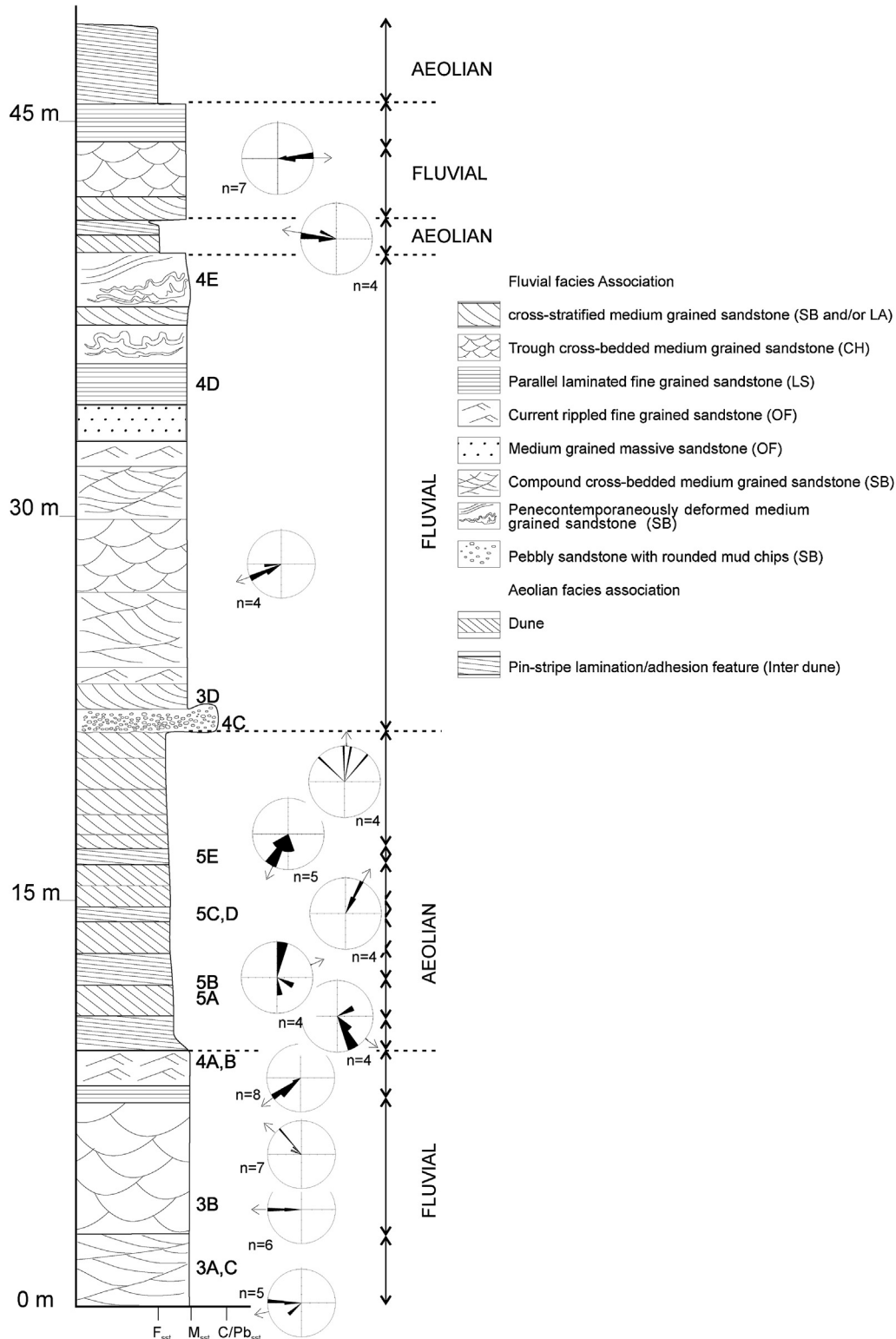

Fig. 2. Detailed measured section through the quartz-rich sandstone of the Beasley River Quartzite on the southern limb of the Hardey Syncline (see Fig. 1 for location of the section). Stratigraphic position of various sedimentary facies constituents are also indicated by their respective figure numbers. Miall's code (Miall, 1985) of fluvial architectural element nomenclature for individual facies has been shown in the legend.
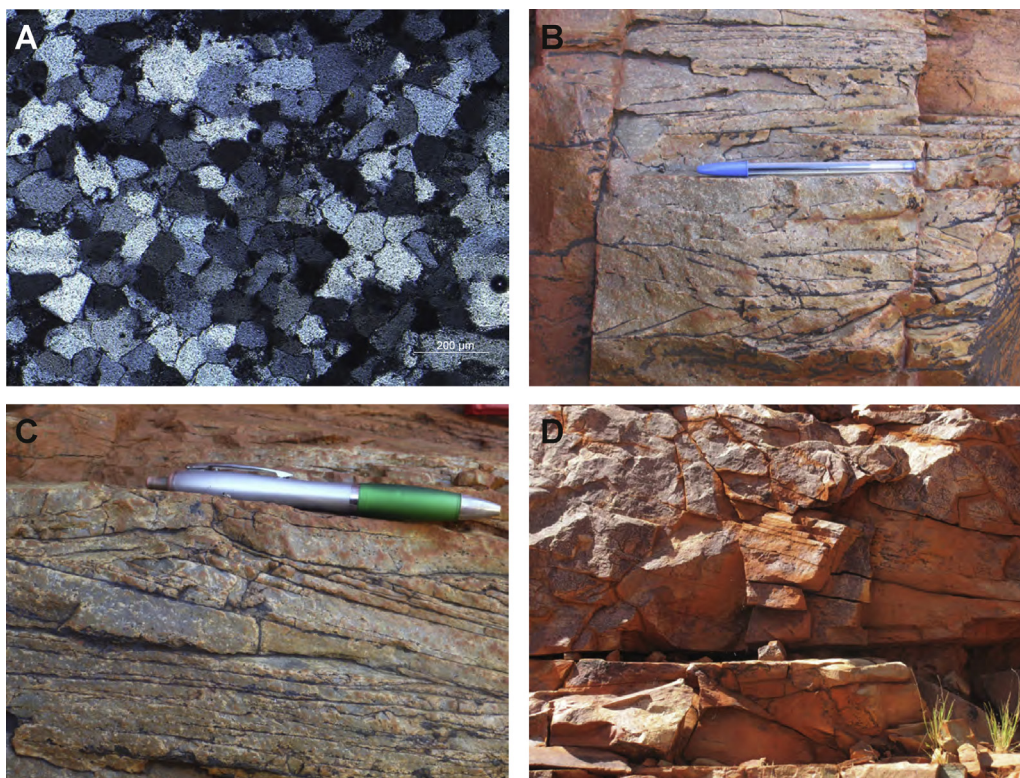
Fig. 3. Fluvial facies constituents of the Beasley River Quartzite: (A) Photomicrograph of medium-grained quartz-rich sandstone; note the angularity of the grains and poor sorting; (B) Trough cross-stratified sandstone facies (pen 13 cm); (C) Compound cross-stratified sandstone facies (pen 10 cm); (D) Tabular cross-stratified sandstone; note decrease in foreset dip in the down current direction.

association (Fig. 2). Whereas the major cross-strata dips around 5–7°, the smaller internal planar cross-laminae make an angle of about 15° with the larger sets, broadly in the same direction (Fig. 2). The set thickness of the larger and smaller cross-strata varies from 15 to 20 cm and 8 to 10 cm, respectively.

This facies is associated with facies A and represents bars on the channel floor. Small dunes, migrating on the stoss of the bars, crossed the bar crest and migrated further downstream (Best et al., 2003; Mazumder and Sarkar, 2004; Sarkar et al., 2012).

3.1.3. Tabular cross-stratified medium-grained sandstone (SB and/or LA)

This facies is characterized by medium-grained sandstones with tabular cross-strata. The cross strata are steeper in the up-current direction but the inclination decreases in the down-current direction, with an asymptotic toe (Fig. 3D). Average cross-set thickness is 18 cm.

This facies either represents a transverse bank-attached bar (Todd and Went, 1991; Mazumder and Sarkar, 2004) or lateral accretion on a bank-attached or mid-channel bar (Sarkar et al., 2012).

3.1.4. Ripple laminated fine grained sandstone (OF)

This facies is associated with the parallel laminated sandstone (facies E) or facies B (Fig. 2) and is characterized by fine-grained sandstone with linguoid ripples (Fig. 4A). The palaeocurrent is southwestward and is broadly similar to that in facies B. Sand volcanoes are present, at places, on the bedding plane (Fig. 4B).

This facies is interpreted as a river floodplain deposit (Miall, 1985, 1996; Collinson, 1996). The presence of sand volcanoes indicates rapid loading, possibly related to contemporary basin tectonism and/or seismicity in a distant place (Van Loon and Maulik, 2011).

3.1.5. Parallel laminated sandstone (LS)

This facies consists of fine grained sandstone with parallel lamination. It has sheet like geometry and is generally overlain by ripple laminated fine-grained sandstone (facies D). In the upper part of the section, this facies overlies massive sandstones (Fig. 2).

This facies is interpreted as sheet flood, deposited from sediment-charged flood water (Collinson, 1996 and references therein).

3.1.6. Pebbly sandstone with rounded mud chips (SB)

This facies is characterized by relatively coarse-grained pebbly sandstone with thin chips of mudstone or fine siltstone (Fig. 4C). This facies overlies aeolian dunes with erosional contact and is overlain by facies C of the fluvial association (Fig. 2).

This facies possibly represents a fluvial channel lag (Miall, 1996; Collinson, 1996) and its association with the tabular cross-stratified sandstone (facies C) supports this interpretation.

3.1.7. Massive sandstone (OF)

This facies is characterized by medium-grained massive sandstone (Fig. 4D) with local traces of cross-stratification. The facies body geometry is wedge-shaped. This facies is associated with relatively finer-grained units of facies D and E (Fig. 2).

This facies is formed as a result of rapid deposition from heavily suspended flow, possibly of flash flood origin (cf. Sarkar et al., 2012).

3.1.8. Penecontemporaneously deformed sandstone (SB)

This facies is confined to the upper part of the succession and is characterized by medium-grained sandstone with penecontemporaneously deformed cross-stratification, consisting of overturned cross-beds or recumbently folded cross beds (Fig. 4E: Allen and Banks, 1972).
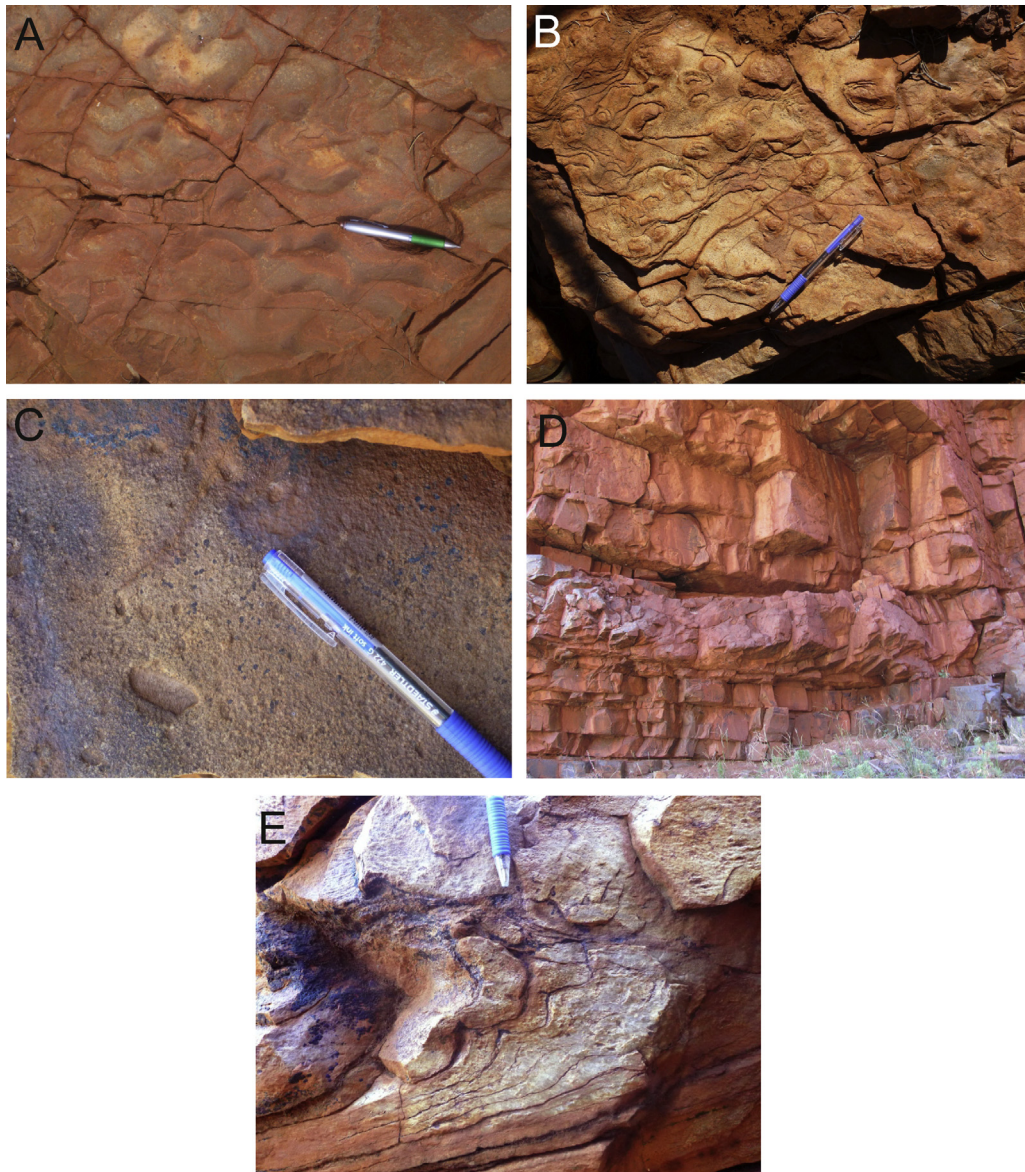
Fig. 4. Fluvial facies constituents of the Beasley River Quartzite: (A) Sinuous crested current ripples on floodplain; (B) Sand volcanos on a bedding plane (pen 12 cm); see text for details; (C) Pebbly sandstone with rounded mud chips; (D) Massive sandstone facies (note wedge-shaped geometry of the facies units); (E) Penecontemporaneously deformed recumbently folded cross-stratified sandstone facies.

This facies represents penecontemporaneously deformed fluvial mid-channel or bank-attached bar (Bose and Chakraborty, 1994). The sharp change in palaeocurrent pattern of the fluvial system across this facies indicates tectonic tilting of the basin and/or rapid basin subsidence during deposition (cf. Jones and Rust, 1983; Bose and Chakraborty, 1994; Mazumder and Sarkar, 2004). Alternatively, penecontemporaneous deformation of the bedding could be due to seismogenic shocks (Allen and Banks, 1972; Bose et al., 1997; Bhattacharya and Bandyopadhaya, 1998; Mazumder and Altermann, 2007). However, the lack of lateral continuity of this facies, coupled with the sharp change in palaeocurrent direction, indicates this facies is a product of tilting associated with basin subsidence (see Jones and Rust, 1983; Bose and Chakraborty, 1994).

3.2. Aeolian facies association

The aeolian facies association is interbedded with braided fluvial deposits (Fig. 2). Three facies constitute this facies association.

3.2.1. Tabular cross-stratified fine-grained sandstone

This facies is characterized by large-scale, planar and tabular cross-stratified fine-grained sandstone (Fig. 5A) containing cross-sets of variable thickness, the maximum being 2 m. Foresets are downslope-wedging and, in places, constitute two sublaminae, having lighter and darker color, respectively. Windstreaks (Fig. 5B) are well-preserved on the bedding planes.

These cross-stratified sandstones are either the products of lateral accretion of linguoid bars in fluvial systems (Cant, 1978; Cant and Walker, 1978; Miall, 1988, 1996; Collinson, 1996) or migration of aeolian dunes (Boothroyd and Nummedal, 1978; Bose and Chakraborty, 1994; Kocurek, 1996; Eriksson and Simpson, 1998; Simpson et al., 2004). However, the very well sorted nature of the sands and their association with units that contain wind streaks, pin-stripe lamination and adhesion-structure-bearing sandstones (inter dune deposits; Fig. 2) clearly support an aeolian origin of these deposits (see below; Kocurek, 1991, 1996; Simpson et al., 2004).
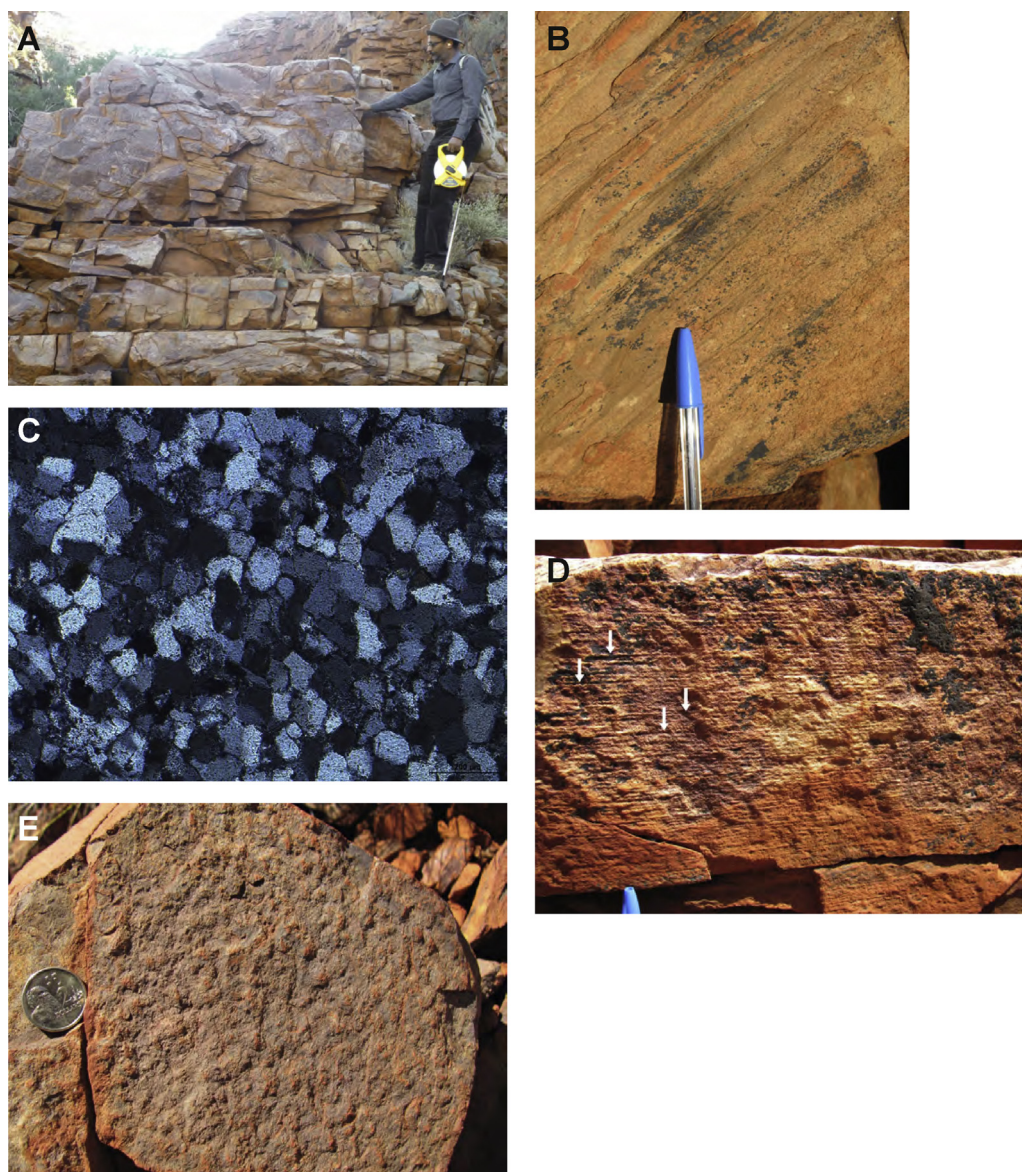
Fig. 5. Aeolian facies association: (A) Large scale aeolian dune facies; (B) Wind streaks preserved on the bedding plane of the aeolian dune facies; (C) Photomicrograph of fine-grained quartz-rich sandstone with pin-stripe lamination; note rounded to well rounded grains; (D) Fine-grained sandstone with spectacular pin-stripe lamination; arrows indicate dark colored, fine-grained laminae; see text for details; (E) Adhesion feature preserved on the bedding plane of the fine grained sandstone.

3.2.2. Well sorted, fine-grained sandstone with pin-stripe lamination

This facies is characterized by fine-grained, well sorted, almost horizontal sheet like sandstones with rounded to sub-rounded grains and very low angle stratification (Fig. 5C and D). Very fine-grained sand to silt forms the bases of each stratum, evident from distinct color variation. At places, sediments with the coarsest grain size are concentrated on top of each layer, giving rise to inverse grading locally. In places, internal cross-lamination is preserved. Individual facies units have an average thickness of 10 cm. Maximum outcrop width is about 12 m.

The low-angle inclined stratifications in well-sorted fine sand are very similar to the pin-stripe lamination (Hunter, 1981; Hunter and Rubin, 1983; Fryberger and Schenk, 1988; Kocurek, 1991, 1996) and are attributed to aeolian action. Such laminations are one of the characteristic features of modern, as well as ancient, aeolian inter dune deposits (Kocurek, 1991, 1996; Eriksson and Simpson, 1998; Simpson et al., 2012). The color contrast (Fig. 5D) defining the pin-stripe lamination is a consequence of differential permeability caused by differential diagenesis due to the sediments accumulating in wind-ripple troughs and being relatively less sorted than the wind ripple deposits (Fryberger and Schenk, 1988; Simpson et al., 2012).

3.2.3. Crinkly laminated, fine-grained sandstone

This facies is characterized by laterally impersistent, sheet like, fine-grained sandstone with minor irregular wrinkles (Fig. 5E). This facies is predominantly associated with the pin-stripe lamination bearing fine-grained, well sorted sandstone (Facies J) that, together, constitute an aeolian inter dune deposit (Fig. 2).

This facies is interpreted as adhesion feature formed by adherence of wind deflated sand on moist surfaces (Kocurek, 1991, 1996; Simpson et al., 2012).

4. Discussion

Sedimentary facies analyses of a section through the Beasley River Quartzite indicate deposition under terrestrial

(fluvial-aeolian) conditions. The fluvial and aeolian units exhibit different sediment dispersal patterns, as indicated by paleocurrent data (Fig. 2); whereas the fluvial units indicate a broadly south-westerly to northwesterly paleocurrent direction in the lower part of the succession and subsequent change in paleocurrent direction to the east, the aeolian units indicate a highly variable wind dispersal pattern (Fig. 2). This paleocurrent pattern contrasts sharply with the offshore tidal channel and sandbar model of deposition advocated by Martin et al. (2000).

The terrestrial (fluvial-aeolian) section of the Beasley River Quartzite described here is consistent with the dominantly terrestrial depositional nature of the rest of the lower Wyloo Group, including the basal Three Corners Conglomerate Member (fluviatile conglomerates and sandstones) and the subaerial Cheela Springs Basalt (Martin et al., 2000; Van Kranendonk, 2010). Morris (1980, 1985) interpreted a prolonged subaerial exposure of the depositional surface between the deposition and deformation of the marine Turee Creek Group and deposition of the Wyloo Group, which is supported by the angular unconformity at the base of the lower Wyloo Group and by the clearly terrestrial nature of the basal Three Corners Conglomerate Member with its pebbles and cobbles of BIF and chert derived from the immediately underlying Hamersley Group. The terrestrial origin of the Beasley River Quartzite described here confirms that the erosional surface at the base of the lower Wyloo Group was indeed exposed to the atmosphere and thus represents a significant erosional unconformity (sequence boundary, Posamantier et al., 1988; Catuneanu, 2006). A previous interpretation of the lower Wyloo Group having been deposited gradationally up from the Turee Creek Group is inconsistent with this data and will be discussed in more detail in a separate paper that details the regional stratigraphy of this area.

The preservation of a terrestrial succession in the lower Wyloo Group is interpreted to have been the result of basin subsidence during the onset of rifting. Such subsidence may occur in intracontinental or continental margin rifts, or back-arc, or transtensional settings within an orogen. Martin and Morris (2010) suggested a continental magmatic arc setting for the Cheela Plains Basalt, based on geochemical data, but these authors also noted that the composition of these rocks can also be explained through crustal contamination. As there is no evidence of a contemporaneous arc nor of an orogen during lower Wyloo Group deposition, we suggest a continental rift setting for the whole of the lower Wyloo Group.

It is interesting to note that a predicted consequence of a 2.45–2.2 Ga global magmatic shutdown (Condie et al., 2009) and widespread (or global) glaciation (Kirschvink et al., 2000) is a relative fall in sea level, accompanied by extensive erosion on the continents that would have led to widespread unconformities in the stratigraphic record. Significantly, major unconformities indicating marine to terrestrial facies transitions do occur on cratonic nuclei in South Africa and India during this time interval (the Pretoria Group and the Singhbhum Group respectively, Eriksson et al., 1999, 2006; Mazumder et al., 2012). The present study indicates a similar event in Western Australia. Although aeolian deposits are also known from the ∼2.2 Ga Singhbhum Group, India (Simpson et al., 2004; Mazumder, 2005; Mazumder et al., 2012), aeolianites are hitherto unreported from the 2.32–2.05 Ga Pretoria Group, South Africa. As aeolianites are generally interbedded with fluvial and/or shallow marine deposits (Kocurek, 1996; Eriksson et al., 1998 and references therein), the fluvial and/or shallow marine deposits of the Pretoria Group should be critically re-examined for the presence of aeolianites.

Acknowledgements

References

Allen, J.R.L., Banks, N.L., 1972. An interpretation and analysis of recumbent-folded deformed cross-bedding. Sedimentology 19, 257–283.

Best, J.L., Ashworth, P.J., Bristow, C.S., Roden, J., 2003. Three-dimensional sedimentary architecture of a large, mid-channel Sand Braid Bar, Jamuna River, Bangladesh. Journal of Sedimentary Research 73 (4), 516–530.

Bhattacharya, H.N., Bandyopadhaya, S., 1998. Seismites in a Proterozoic tidal succession, Singhbhum, Bihar, India. Sedimentary Geology 119, 239–252.

Bose, P.K., Chakraborty, P.P., 1994. Marine to fluvial transition: Proterozoic Upper Rewa Sandstone, Maihar, India. Sedimentary Geology 89, 285–302.

Bose, P.K., Mazumder, R., Sarkar, S., 1997. Tidal sandwaves and related storm deposits in the transgressive Protoproterozoic Chaibasa Formation, India. Precambrian Research 84, 63–81.

Boothroyd, J.C., Nummedal, D., 1978. Proglacial braided outwash: a model for humid fan deposits. In: Miall, A.D. (Ed.), Fluvial Sedimentology, vol. 5. Canadian Society of Petroleum Geologist Memoir, pp. 641–668.

Cant, D.J., 1978. Bedforms and bar types in the South Saskatchewan River. Journal of Sedimentary Petrology 48, 1321–1350.

Cant, D.J., Walker, R.G., 1978. Fluvial processes and facies sequences in the sandy braided South Saskatchewan River, Canada. Sedimentology 25, 625–648.

Catuneanu, O., 2006. Principles of Sequence Stratigraphy. Elsevier, Amsterdam, 375–379.

Cawood, P.A., Tyler, I.M., 2004. Assembling and reactivating the Proterozoic Capricorn orogen: lithotectonic elements, orogenies, and significance. Precambrian Research 128, 201–218.

Chakraborty, T., Sensarma, S., 2008. Shallow marine and coastal eolian quartz arenites in the Neoarchean-Palaeoproterozoic Karutola Formation, Dongargarh Volcano-sedimentary succession, central India. Precambrian Research 162, 284–301.

Collinson, J.D., 1996. Alluvial sediments. In: Reading, H.G. (Ed.), Sedimentary Environments: Process, Facies and Stratigraphy. , 3rd ed. Blackwell Science, Oxford, pp. 37–82.

Condie, K.C., O'Neill, C., Aster, R.C., 2009. Evidence and implications for a widespread magmatic shutdown for 250 My on Earth. Earth and Planetary Science Letters 282, 294–298.

Dott, R.H., 1974. Paleocurrent analysis of severely deformed flysch-type strata; a case study from South Georgia Island. Journal of Sedimentary Petrology 44, 1166–1173.

Eriksson, P.G., Condie, K.C., Tirsgaard, H., Muller, W.U., Altermann, W., Catuneanu, O., 1998. Precambrian clastic sedimentation systems. Sedimentary Geology 120, 5–53.

Eriksson, K.A., Simpson, E.L., 1998. Controls on spatial and temporal distribution of Precambrian eolianites. Sedimentary Geology 120, 275–294.

Eriksson, P.G., Mazumder, R., Sarkar, S., Bose, P.K., Altermann, W., Van Der Merwee, R., 1999. The 2.7–2.0 Ga volcano-sedimentary record of Africa, India and Australia: evidence for global and local changes in sea level and continental freeboard. Precambrian Research 97, 269–302.

Eriksson, P.G., Mazumder, R., Catuneanu, O., Bumby, A.J., Ountsch Ilondo, B., 2006. Precambrian continental freeboard and geological evolution: a time perspective. Earth Science Reviews 79, 165–204.

Evans, D.A.D., Sircombe, K., Wingate, M.T.D., Doyle, M., McCarthy, M., Pidgeon, R.T., Van Niekirk, H.S., 2003. Revised geochronology of magmatism in the western Capricorn Orogen at 1805–1785 Ma: diachroneity of the Pilbara–Yilgarn collision. Australian Journal of Earth Sciences 50, 853–864.

Fryberger, S.G., Schenk, C.J., 1988. Pin stripe lamination: a distinctive feature of modern and ancient eolian sediments. Sedimentary Geology 55, 1–15.

Hickman, A.H., Van Kranendonk, M.J., 2012. Early Earth evolution: evidence from the 3.5–1.8 Ga geological history of the Pilbara region of Western Australia. Episodes 35, 283–297.

High Jr., L.R., Picard, M.D., 1974. Reliability of cross-stratification types as paleocurrent indicators in fluvial rocks. Journal of Sedimentary Petrology 44, 158–168.

Hunter, R.E., 1981. Stratification style in eolian sandstones: some Pennsylvanian to Jurassic examples from the western interior USA. In: Etridge, F.G., Flores, R.M. (Eds.), Recent and Ancient Nonmarine Depositional Environments: Models for Exploration, vol. 31. Society of Economic Palaeontologists and Mineralogists, Special Publication, pp. 315–329.

Hunter, R.E., Rubin, D.M., 1983. Interpreting cyclic cross-bedding, with an example from the Navajo Sandstone. In: Brookfield, M.E., Ahlbrandt, T.S. (Eds.), Developments in Sedimentology, vol. 38. Elsevier, Amsterdam, pp. 429–454.

Jones, B.J., Rust, B.R., 1983. Massive sandstone facies in Hawkesbury Sandstone, a Triassic fluvial deposit near Sydney, Australia. Journal of Sedimentary Petrology 53, 1249–1259.

Kirschvink, J.L., Gaidos, E.J., Bertani, L.E., Beukes, N., Gutzmer, J., Maepa, J., Steinberger, L.N.R.E., 2000. Palaeoproterozoic Snowball Earth: extreme climatic and Geochemical global change and its biological consequences. Proceedings National Academy of Science of the United States of America 97, 1400–2140.

Kocurek, G., 1991. Interpretation of ancient eolian sand dunes. Annual Reviews Earth and Planetary Science 19, 43–75.

Kocurek, G., 1996. Desert aeolian systems. In: Reading, H.G. (Ed.), Sedimentary Environments: Process, Facies and Stratigraphy. , 3rd ed. Blackwell Science, Oxford, England, pp. 125–153.

Martin, D.M., Morris, P., 2010. Tectonic setting and regional implications of ca. 2.2 Ga mafic magmatism in the southern Hamersley province, Western Australia. Australian Journal of Earth Sciences 57, 911–931.

Martin, D.M., Li, Z.X., Nemchin, A.A., Powell, C.M., 1998. A pre-2.2 Ga age for giant hematite ores of the Hamersley province, Australia. Economic Geology 93, 1084–1090.

Martin, D.M., Powell, C.M., George, A.D., 2000. Stratigraphic architecture and evolution of the early Paleoproterozoic McGrath Trough, Western Australia. Precambrian Research 99, 33–64.

Mazumder, R., 2005. Proterozoic sedimentation and volcanism in the Singhbhum crustal province, India and their implications. Sedimentary Geology 176, 167–193.

Mazumder, R., Eriksson, P.G., De, S., Bumby, A., Lenhardt, N., 2012. Palaeoproterozoic sedimentation on the Singhbhum craton: global context and comparison with Kaapvaal. In: Mazumder, R., Saha, D. (Eds.), Paleoproterozoic of India, vol. 365. Geological Society of London, Special Publication, pp. 51–76.

Mazumder, R., Altermann, W., 2007. Discussion on New aspects of deformed cross-strata in fluvial sandstones: examples from Neoproterozoic formations in northern Norway by S.L. Roe and M. Hermansen, 2006. Sedimentary Geology 198, 351–353.

Mazumder, R., Sarkar, S., 2004. Sedimentation history of the Palaeoproterozoic Dhanjori Formation, Singhbhum, eastern India. Precambrian Research 130, 267–287.

Miall, A.D., 1996. The Geology of Fluvial Deposits: Sedimentary Facies, Basin Analysis and Petroleum Geology. Springer-Verlag, Heidelberg, 582 pp.

Miall, A.D., 1988. Facies architecture in clastic sedimentary basins. In: Kleinspehn, K., Paola, C. (Eds.), New Perspective in Basin Analysis. Springer, Berlin/Heidelberg/New York, pp. 67–81.

Miall, A.D., 1985. Architectural element analysis: a new method of facies analysis applied to fluvial deposits. Earth Science Reviews 22, 261–308.

Morris, R.C., 1980. A textural and mineralogical study of the relationship of iron ore to banded iron-formation in the Hamersley iron province of Western Australia. Economic Geology 75, 184–209.

Morris, R.C., 1985. Genesis of iron ore in banded iron formation by supergene and supergene-metamorphic processes: a conceptual model. In: Wolf, K.H. (Ed.), Handbook of Strata-Bound and Stratiform Ore Deposits, vol. 13. Elsevier Science Publications, Amsterdam, pp. 73–235.

Müller, S.G., Krapež, B., Fletcher, Barley M.E.I.R., 2005. Giant iron-ore deposits of the Hamersley province related to the breakup of Paleoproterozoic Australia: new insights from in situ SHRIMP dating of baddeleyite from mafic intrusions. Geology 33, 577–580.

Nelson, D.R., 2004. Geological Survey of Western Australia geochronology dataset. GSWA 178042.

Posamantier, H.W., Jervey, M.T., Vail, P.R., 1988. Eustatic controls on clastic depositional Sequence and systems tract models. In: Wilgus, C.K., et al. (Eds.), Sea level changes: an integrated approach. Spec Publ., 42, Tulsa, Oklahoma 7 S.E.P.M. pp. 109–124.

Powell, C.M., Horwitz, R.C., 1994. Late Archaean and Early Proterozoic Tectonics and basin formation of the Hamersley Ranges: Australian Geological Convention, Geological Society of Australia (WA Division), 12th, Perth, 1994, Excursion Guidebook, p. 57.

Ramsay, J.G., 1961. The effects of folding upon the orientation of sedimentary structures. Journal of Geology 69, 84–100.

Sambrook Smith, G.H., Best, J.L., Bristow, C.S., Petts, G.E., 2006. Braided Rivers: Process, Deposits, Ecology and Management. International Association of Sedimentologists. Special Publication 36, Blackwell, Oxford, 396 pp.

Sarkar, S., Samanta, P., Mukhopadhyay, S., Bose, P.K., 2012. Stratigraphic architecture of the Sonia Fluvial interval, India in its Precambrian context. Precambrian Research 214–215, 210–226.

Simpson, E.L., Bose, P.K., Alkmin, F.F., Rainbird, R., Martins-Neto, M., Bumby, A., Eriksson, P.G., Eriksson, K.A., Middleton, L., 2004. Sedimentary dynamics of Precambrian aeolianites. In: Eriksson, P.G., Altermann, W., Nelson, D.R., Mueller, W.U., Catuneanu, O. (Eds.), The Precambrian earth: tempos and events. Developments in Precambrian geology, vol. 12. Elsevier Science, Amsterdam, pp. 642–657.

Simpson, E.L., Eriksson, K.A., Mueller, W., 2012. 3.2 Ga eolian deposits from the Moodies Group, Barberton Greenstone Belt, South Africa: implications for the origin of first-cycle quartz sandstones. Precambrian Research 214–215, 185–191.

Thorne, A.M., 1990. Ashburton Basin, in Geology and mineral resources of Western Australia: Geological Survey of Western Australia. Memoir 3, 210–219.

Thorne, A.M., Seymour, D.B., 1991. Geology of the Ashburton Basin: Geological Survey of Western Australia, Bulletin 139, p. 141.

Trendall, A.F., 1979. A revision of the mount bruce supergroup: geological survey of Western Australia. Annual Report 1978, 63–71.

Trendall, A.F., Blockley, J.G., 1970. The iron formations of the Precambrian Hamersley Group, Western Australia: Geological Survey of Western Australia, Bulletin 119, p. 366.

Todd, S.P., Went, D.J., 1991. Lateral migration of sand-bed rivers: examples from the Devonian Glashabeg Formation, SW Ireland and the Cambrian Alderney Sandstone Formation, Channel Islands. Sedimentology 38, 997–1020.

Van Kranendonk, M.J., 2010. Three and a half billion years of life on Earth: a transect back into deep time. Geological Survey of Western Australia Record 2010/21, p. 93.

Van Loon, A.J., Maulik, P., 2011. Abraded sand volcanoes as a tool for recognizing paleo-earthquakes, with examples from the Cisuralian Talchir Formation near Angul (Orissa, eastern India). Sedimentary Geology 238, 145–155.

Williford, K.H., Van Kranendonk, M.J., Ushikubo, T., Kozdon, R., Valley, J.W., 2011. Contrasting atmospheric oxygen and seawater sulphate concentrations during Palaeoproterozoic glaciations: in situ sulfur three-isotope microanalysis of pyrite from the Turee Creek Group, Western Australia. Geochimica et Cosmochimica Acta 75, 5686–5705.

Wilson, J.P., Fischer, W.W., Johnston, D.T., et al., 2010. Geobiology of the late Paleoproterozoic Duck Creek Formation, Western Australia. Precambrian Research 179, 135–149.