Precambrian Research 256 (2015) 314–343

Contents lists available at ScienceDirect

Precambrian Research

journal homepage: www.elsevier.com/locate/precamres

Sedimentology of the Paleoproterozoic Kungarra Formation, Turee Creek Group, Western Australia: A conformable record of the transition from early to modern Earth

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ARTICLE INFO

Article history:
Received 11 December 2013
Received in revised form 1 September 2014
Accepted 15 September 2014
Available online 30 September 2014

Keywords:
Paleoproterozoic
Sedimentology
Glacio-marine succession
Turee Creek Group
Western Australia

ABSTRACT

This paper presents the first, detailed sedimentological analysis of the Paleoproterozoic Kungarra Formation, the lowermost of three formations comprising the Turee Creek Group in Western Australia, which was deposited across the rise in atmospheric oxygen (the Great Oxidation Event, or GOE) and the transition from early to modern Earth.

The data show that the Kungarra Formation has a gradational, conformable lower contact with underlying banded iron-formation of the Hamersley Group and predominantly comprises an upward-shallowing succession from deepwater shales and siltstones, through rippled fine-grained sandstones and stromatolitic carbonates, to tidal flat deposits that immediately underlie coastal–fluvial deposits of the overlying Koolbye Formation.

At the base of the Kungarra Formation is a gradual transition from alternating units of magnetic green shale and thin units of banded iron-formation that pass upsection to units of non-magnetic shale and ferruginous chert and grey chert, reflecting a gradual loss of iron from the world's oceans accompanying the rise of atmospheric oxygen. A falling stage systems *tract* is recognised above this transition in the Hardey Syncline area, capped by stromatolitic carbonates and a period of exposure marked by an erosional unconformity and carbonate beachrock. Two glacio-eustatic cycles are recognised within the middle to upper parts of the Kungarra Formation, each of which is marked by the rapid onset of falling systems tracts and characterised by falling systems tracts during and following diamictite deposition.

Stratigraphic data are used to infer a depobasin filled by a sediment wedge prograding from southeast to northwest, in contrast to previous models of a north-northeastward deepening foreland basin. The lack of seismites or internal unconformities within the formation precludes a foredeep setting. Rather, deposition is interpreted as having occurred within an intracratonic basin, with detritus sourced from erosion of uplifted bedrock to the southeast.

1. Introduction

Earth experienced a fundamental revolution across the Archaean–Proterozoic transition, when the rate and style of continental crust formation changed rapidly, the biosphere was thrown out of equilibrium, and the composition of the atmosphere changed dramatically from one with little, or no, free atmospheric oxygen to one with $>10^{-5}$ present atmospheric level (PAL) O_2 during the Great Oxidation Event (GOE) at 2.45–2.22 billion years (Ga) ago (Kirschvink et al., 2000; Farquhar et al., 2000; Holland, 2002;

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http://dx.doi.org/10.1016/j.precamres.2014.09.015

Bekker et al., 2004; Hannah et al., 2004; Johnson et al., 2008; Van Kranendonk et al., 2012). This transition was marked by the onset of global glaciations and the development of unconformities and terrestrial successions, and led, ultimately, to the development and flourishing of eukaryotic life (Horodyski and Knauth, 1994; Eriksson et al., 1999; Kirschvink et al., 2000; Prave, 2002; Condie et al., 2009; Konhauser et al., 2011; Van Kranendonk, 2010; Eriksson and Condie, 2014; Mazumder and Van Kranendonk, 2013).

A question remains, however, as to the extent and significance of the Paleoproterozoic glaciations. Suggested to be global in nature (including low-latitude glaciations: Evans et al., 1997; Williams and Schmidt, 1997; Kirschvink et al., 2000; Kopp et al., 2005) and similar to the better-documented 'Snowball Earth' events of the Neoproterozoic (Hoffman et al., 1998; Bekker et al., 2005), the true extent and significance of Paleoproterozoic glaciations remains unsubstantiated due to different numbers of glacial units on different continents (one in Western Australia, two in South Africa, three in North America), the predominantly terrestrial, rift-related, nature of many glacial units, and uncertainty regarding the veracity of paleomagnetic data (Martin, 1999; Bekker et al., 2001; Young et al., 2001; Hilburn et al., 2005; Eyles, 2008; Melezhik et al., 2012). Significantly, the transition from early Earth (warm, anoxic atmosphere) to more modern Earth (cool, oxygenated atmosphere) across the GOE is plagued by successions with internal unconformities, particularly at the base of glaciogenic successions, thereby precluding a thorough understanding of the nature of the rise in atmospheric oxygen and the response of the biosphere to this revolution.

Western Australia is one of the few places in the world that document a near-continuous record of deposition across the rise of atmospheric oxygen within a conformable succession of marine sedimentary rocks known as the Turee Creek Group (Trendall and Blockley, 1970; Trendall, 1979; Thorne and Tyler, 1996). A single glacial diamictite unit has been described previously in Western Australia by Trendall (1981) and Martin (1999) from the Meteorite Bore Member (MBM) of the Kungarra Formation, the lowermost formation of the 2.45–2.22 Ga Turee Creek Group. The Meteorite Bore Member has been described as a glacio-marine deposit, however no detailed sedimentary facies analysis has been undertaken and inferences regarding the depositional environment are solely based on the petrography of the clastic rocks and lithofacies characteristics (Martin, 1999; Martin et al., 2000). Recently, however, a second unit of glaciogenic diamictite has been described from the type area of the Turee Creek Group (Van Kranendonk and Mazumder, 2014), so in order to better understand the full succession of events recorded across the rise of atmospheric oxygen in the Western Australian succession, we here describe the sedimentology of the Kungarra Formation and its transition from the underlying Hamersley Group.

Detailed sedimentological analysis of the Kungarra Formation documents a lateral and vertical shift in sedimentary facies across the Turee Creek basin. Sedimentary facies analysis shows that the Kungarra Formation consists of an overall shallowing-upward succession, with a sediment source to the southeast. Prior to glaciation, the basin experienced relative base-level rise, leading to periodic exposure. The two glacial episodes were each initiated by a falling stage systems tract prior to diamictite deposition, and accompanied by a transgressive systems tract during, and immediately following, diamictite deposition: these changes are attributed to drawdown by developing glaciers and recharge by glacial melting, respectively. Basin fill was via the development of a northwesterly prograding sediment wedge, but sedimentological and geochronological evidence does not support deposition in an active foreland basin, as previously proposed. Rather, the depositional environment is interpreted to have been an intracratonic basin, with an uplifted source terrain to the southwest that may have accompanied an episode of failed rifting and/or re-activation of basement domes.

2. Regional geology and previous work

The Turee Creek Group crops out in the hinges of large-scale folds along the southern part of the Hamersley Range in Western Australia (Fig. 1). Trendall (1981) and Thorne and Tyler 1996 defined the clastic sedimentary rock succession of the c. 3.9 km thick Turee Creek Group as comprising the lower Kungarra, middle Koolbye, and upper Kazput formations (Fig. 2).

Geochronological constraints for the Kungarra Formation are provided by the 2449 ± 3 Ma Woongarra Rhyolite that lies

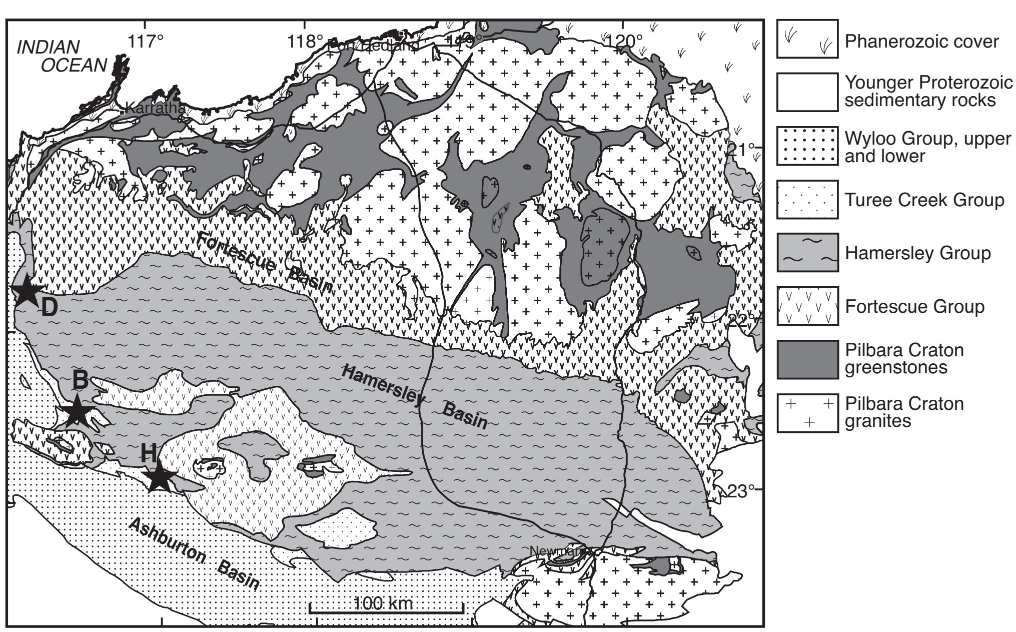

Fig. 1. Regional geological map of the Pilbara, northwestern Australia, showing the distribution of the Turee Creek Group and study localities with measured sections: B = Boundary Ridge; D = Deepdale; H = Horseshoe Creek.