Precambrian Research 296 (2017) 62–77

Contents lists available at ScienceDirect

Precambrian Research

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

The role of deformation in the formation of banded iron formation-hosted high-grade iron ore deposits, Hamersley Province (Australia)

Mathias S. Egglseder[a,*], Alexander R. Cruden[a], Hilke J. Dalstra[b], Leigh Nicholas[c]

[a] School of Earth, Atmosphere and Environment, Monash University, Melbourne, VIC 3800, Australia
[b] Rio Tinto Exploration, 37 Belmont Avenue, Belmont, WA 6104, Australia
[c] Rio Tinto Iron Ore, 152-158 St. Georges Terrace, Perth, WA 6000, Australia

ARTICLE INFO

Article history:
Received 15 December 2016
Revised 13 April 2017
Accepted 26 April 2017
Available online 29 April 2017

Keywords:
Hamersley Province
Banded iron formation
Iron ore
Multilayer deformation
Dissolution–precipitation creep
Sub-simple shear

ABSTRACT

The Hamersley Province (Western Australia) hosts some of the world's largest iron ore deposits but despite decades of research, their genesis is still extensively debated. Many iron ore deposits are hosted in complexly deformed Archean to Paleoproterozoic banded iron formations, comprising thin chert and iron oxide bands interlayered with silicate-rich shales and carbonates. Current iron ore genesis models have identified a strong structural control on ore formation linked to extensive hypogene and supergene fluid circulation along fault structures. These fluid pathways facilitate the removal of vast amounts of gangue minerals, leading to enrichment of the iron oxide residue to iron ore. However, the evolution of the associated structures has not yet been considered as a key element in ore genesis.

Here we show through multiscale structural analyses that deformation not only forms suitable fluid channels, but that folding and shearing also result in significant synkinematic removal of gangue minerals. Our multidisciplinary investigation of the structural evolution of the Mount Tom Price deposit combines microtectonic, field geology and 3D implicit modelling techniques to establish a link between deformation structures at various scales. Microscale shear bands and outcrop-scale asymmetric parasitic folds share striking similarities in their evolution and their controlling mechanisms. Both features record substantial non-coaxial deformation accompanied by volume changes due to stress-induced silica remobilisation. The closely spaced layering of rheologically different lithologies within Hamersley Province strata plays a crucial role in complex multilayer deformation, which resulted in extensive strain partitioning.

Our study suggests that deformation was of major significance in the upgrading of banded iron formation to iron ore and was active from the early stages of banded iron formation during diagenesis. Deformation structures also established a micro- to deposit-scale lateral and vertical fluid network, which enabled infiltration by hypogene and supergene fluids during or after deformation. These new insights have important implications for iron ore genesis models, structural applications in the mine environment, and for understanding complex multilayer deformation with volume loss.

1. Introduction

Banded iron formation (BIF) is an enigmatic (meta-) sedimentary rock type that is the main source of iron ore for the global steel-making industry. BIFs have been found on all continents and are mainly composed of μm- to cm-thick laminae of alternating iron oxides and chert or carbonates (Trendall and Blockley, 1970; Ayres, 1972; Bekker et al., 2010). The Hamersley Province, Western Australia, contains the world's largest region of outcropping BIF. Since these Precambrian rocks have only been weakly metamorphosed (Fig. 1; Smith et al., 1982), they have been pivotal for many, often controversial studies, on the global rise of oxygen and the evolution of the Precambrian atmosphere and hydrosphere (see review by Bekker et al., 2010). Some of the world's largest iron ore deposits are also hosted in Hamersley Province BIF and multiple ore genesis models have been proposed since their discovery in the 1960s (see reviews by Morris, 1985; Morris and Kneeshaw, 2011). Synorogenic ore formation has been suggested (Powell et al., 1999), but the most recent ore genesis model emphasises structural controls on high-grade iron ore deposits by passive, fault-controlled fluid pathways during post-deformational hypogene and supergene fluid overprints (Taylor et al., 2001; Dalstra, 2006, 2014). However, the formation of these structures is poorly

* Corresponding author.
E-mail address: egglseder.mathias@gmail.com (M.S. Egglseder).

http://dx.doi.org/10.1016/j.precamres.2017.04.034
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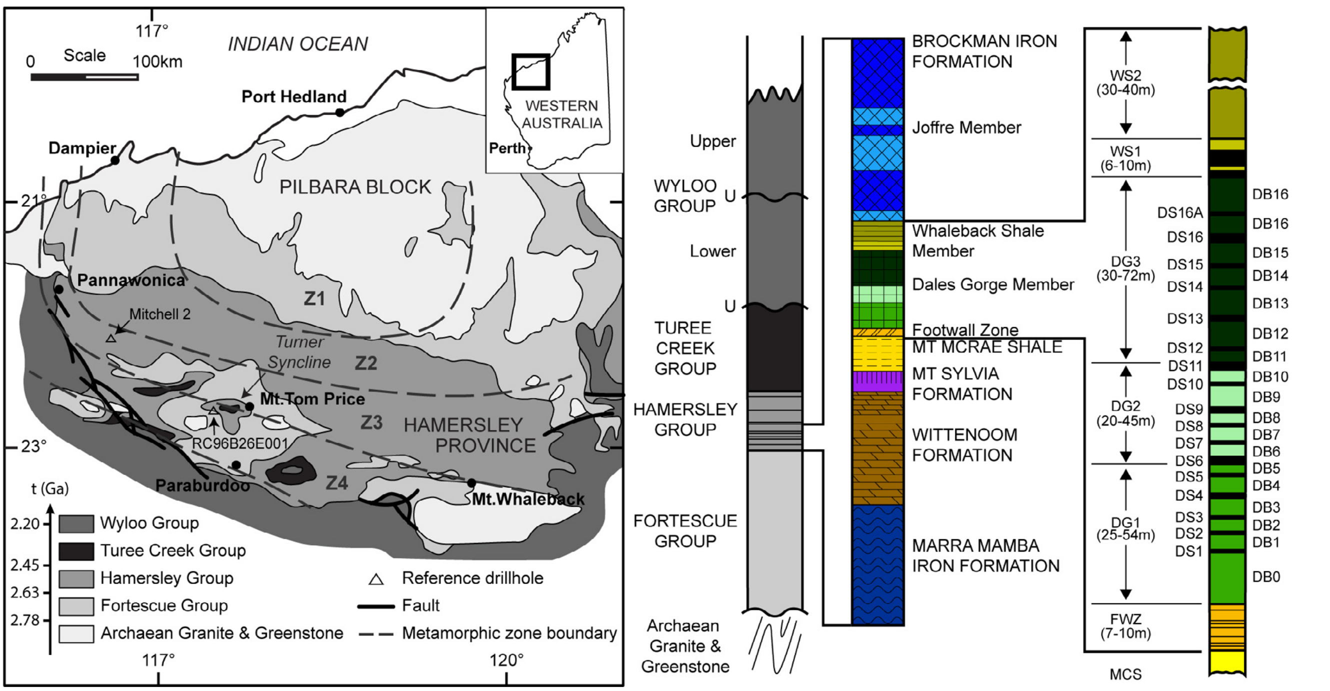

Fig. 1. Geological overview of the Hamersley Province. The central and western part of the Province is characterised by complex fold interference patterns and the Mount Tom Price deposit is located at the eastern end of the Turner Syncline (box; modified after Taylor et al., 2001). East-west trending, open dome-and-basin folds are the main regional-scale structural elements (D2). Ages (t) are based on Trendall et al. (2004) and metamorphic zones are identified as Z1: prehnite-pumpellyite facies, high zeolite facies; Z2: prehnite-pumpellyite facies; Z3: pumpellyite-actinolite facies; Z4: greenschist zone (Smith et al., 1982).

understood, and neither microscale nor macroscale deformation has so far been considered to have played an active role in the in situ upgrading of BIF to iron ore.

In contrast to research on BIF of the Quadrilátero Ferrífero in Brazil (Rosiere et al., 2001; Rosière et al., 2008, 2013), no study to date has linked the microstructural to the macroscale structural evolution of BIF in the Hamersley Province. Here, we describe the physicochemical processes that occurred during the deformation of BIF and associated rocks during their multiphase deformation history. Our goal is to examine the geometrical similarities and differences between microstructures and deposit-scale structures of the Mount Tom Price deposit. We have combined microtectonics principles and 3D implicit modelling to gain new insights on deformation mechanisms and the complex evolution of the structural framework that was available to all fluids related to iron ore formation.

2. Regional geology

The stratigraphic record in the Hamersley basin commenced at ca. 2.78 Ga with unconformable deposition of thick mafic flood basalts interbedded with sandstones and shales of the Fortescue Group onto granitoids and greenstones of the Archean Pilbara craton (Fig. 1; Trendall and Morris, 1983). The development of a relatively stable passive margin at 2.63 Ga led to the deposition of the Hamersley Group with BIF intercalated with shales, dolomites as well as mafic and felsic volcanics (Trendall et al., 2004; Trendall and Blockley, 1970). These sediments are commonly associated with early deformation structures (D1) such as chert pods, slump folds and isoclinal folds that formed by vertical loading, diagenesis and soft-sediment deformation (Dalstra, 2006, 2014).

The lower half of the Hamersley Group (Fig. 1), is of particular economic significance and comprises three major BIF units, the Marra Mamba Iron Formation, Dales Gorge Member (DG1 to DG3) and Joffre Member (J1 to J6). The Dales Gorge Member consists of metre to tens of metre thick macrobands of alternating BIF, which are divided by cm- to m-thick 'shale' macrobands composed of iron silicates (e.g., stilpnomelane, minnesotaite), chert, and siderite, that were derived from reworked tuffs and volcaniclastic sediments (Fig. 1; MacLeod, 1966; Trendall and Blockley, 1970; Blockley et al., 1993; Barley et al., 1997; Pickard, 2002). BIF macrobands are composed of cm-thick mesobands and μm- to mm-thick microbands of mainly chert and iron oxides (magnetite, hematite), with minor bands of siderite and stilpnomelane (Trendall and Blockley, 1970). In contrast, the Joffre Member and the Marra Mamba Iron Formation do not show all forms of Dales Gorge Member banding and are dominated bymesobanding; macrobanding is absent from the Joffre Member and microbands are missing in the Marra Mamba Iron Formation (Trendall and Blockley, 1970; Blockley et al., 1993). These major iron formations are separated by dolomites, argillites and shales of the Wittenoom Formation (WD), the chert and shale-dominated units of the Mount Sylvia Formation (MTS), the Mount McRae Shale Formation (MCS), with its BIF-rich top section, the Footwall Zone (FWZ), and the Whaleback Shale Member (WS1, WS2; Fig. 1). The less economic upper half of the Hamersley Group does not crop out in the Mount Tom Price study area; it comprises the Yandicoogina Shale Member, the BIF-containing Weeli Wooli Formation, the Woongarra Volcanics and the Boolgeeda Iron Formation (Trendall and Blockley, 1970).

Deposition of the Hamersley Group and BIF ceased with the closure of the Hamersley basin at ca. 2.45 Ga, which is marked by a major transgression and sedimentation of the clastic Turee Creek Group (Trendall and Morris, 1983). Peak burial metamorphic conditions were reached after deposition of the Turee Creek Group sediments, with very low metamorphic grades (Fig. 1: Z1) occurring in the north to maximum greenschist-facies conditions in the south (Fig. 1: Z4; Smith et al., 1982). Consecutive shortening during the Ophthalmian orogeny at ca. 2.2 Ga under similar