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Microplaty hematite ore in the Yilgarn Province of Western Australia: The geology and genesis of the Wiluna West iron ore deposits

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ABSTRACT

The Wiluna West small (~130 Mt) high-grade bedded hematite ore deposits, consisting of anhedral hematite mesobands interbedded with porous layers of acicular hematite, show similar textural and mineralogical properties to the premium high-grade low-phosphorous direct-shipping ore from Pilbara sites such as Mt Tom Price, Mt Whaleback, etc., in the Hamersley Province and Goldsworthy, Shay Gap and Yarrie on the northern margin of the Pilbara craton. Both margins of the Pilbara Craton and the northern margin of the Yilgarn craton were subjected to sub-aerial erosion in the Paleoproterozoic era followed by marine transgressions but unlike the Hamersley Basin, the JFGB was covered by comparatively thin epeirogenic sediments and not subjected to Proterozoic deformation or burial metamorphism. The Joyner's Find greenstone belt (JFGB) in the Yilgarn region of Western Australia was exhumed by middle to late Cenozoic erosion of a cover of unmetamorphosed and relatively undeformed Paleoproterozoic epeirogenic sedimentary rocks that preserved the JFGB unaltered for nearly 2 Ga; thus providing a unique snapshot of the early Proterozoic environment.

Acicular hematite, pseudomorphous after acicular iron silicate, is only found in iron ore and BIF that was exposed to subaerial deep-weathering in early Paleoproterozoic times (pre 2.2 Ga) and in the overlying unconformable Paleoproterozoic conglomerate derived from these rocks and is absent from unweathered rocks (Lascelles, 2002). High-grade ore and BIF weathered during later subaerial erosion cycles contain anhedral hematite and acicular pseudomorphous goethite. The acicular hematite was formed from goethite pseudomorphs of silicate minerals by dehydration in the vadose zone under extreme aridity during early Paleoproterozoic subaerial weathering. The principal high-grade hematite deposits at Wiluna West are interpreted as bedded ore bodies that formed from BIF by loss of chert bands during diagenesis and have been locally enriched to massive hematite by the introduction of hydrothermal specular hematite. No trace of chert bands are present in the deep saprolitic hematite and hematite–goethite ore in direct contrast to shallow supergene ore in which the trace of chert bands is clearly defined by goethite replacement, voids and detrital fill. Abundant hydrothermal microplaty hematite at Wiluna West is readily distinguished by its crystallinity.

The genesis of the premium ore from the Pilbara Region has been much discussed in the literature and the discovery at Wiluna West provides a unique opportunity to compare the features that are common to both districts and to test genetic models.

1. Introduction

Banded iron formation (BIF) hosted iron ore deposits are the major source of high-grade iron ore both in quantity and quality of ore compared to sources such as magmatic iron deposits, magnetite skarns, magnetite veins, and other sedimentary ores (Beukes et al., 2003; Dalstra and Rosière, 2008). Currently widely accepted genetic models for BIF-derived high-grade iron ore are combinations of mesothermal (hypogene and supergene-modified hypogene models) and supergene enrichment (Beukes et al., 2002). These models ultimately involve the removal of microquartz (meta-chert) bands from BIF to leave a residue of iron oxides and have convincing supporting evidence from some localities, but large parts of the deposits at these localities and many other ore deposits show no evidence to support either model (Lascelles, 2002, 2006a,b, 2012). The hypogene model involves hydrothermal precipitation of magnetite or specular hematite without necessarily upgrading the adjacent BIF (Angerer and Hagemann, 2010; Mukhopadhyay et al., 2008). The two stage hypogene supergene-modified model involves heated saline to alkaline fluids replacing microquartz chert bands with carbonates that are subsequently leached as bicarbonate by supergene fluids (Barley et al., 1999; Lascelles, 2006a,

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2007a; Powell et al., 1999; Taylor et al., 2001; Thorne et al., 2004) whereas the supergene model proposes residual accumulation of iron oxide after the selective solution of microquartz by groundwater (Lascelles, 2012; Leith, 1903; Morris, 1980, 1983, 1985, 2012; Morris and Kneeshaw, 2011; Ramanaidou, 2009). Specific structural features are considered to be essential controls on mineralization (Angerer and Hagemann, 2010; Dalstra, 2005; Dalstra and Rosière, 2008; Morris, 1985; Morris et al., 1980). Other models suggesting enrichment during deformation (Angerer and Hagemann, 2010; Findlay, 1994) are less widely accepted.

An additional model suggesting loss of chert during diagenesis as the major source of large bedded iron ore deposits and thus predating structural, hypogene and supergene processes has been proposed (Lascelles, 2006a, 2007b) based on the occurrence of unweathered and unaltered BIF without chert bands and the absence of any evidence of chert bands being present prior to weathering in the major saprolitic high-grade ore deposits. It is also pointed out that the presence of hypogene or supergene alteration and intense structural deformation is not proof that they were the cause of the upgrading of BIF to high-grade ore without further evidence, as all these processes can affect BIF without selectively removing chert bands (Lascelles, 2012).

The Joyner's Find greenstone belt (JFGB) containing the Wiluna West iron ore deposit is situated on the northern margin of the Yilgarn Craton, 30 km west of the town of Wiluna and about 700 km northeast of Perth in Western Australia (Fig. 1A). The Neoarchean JFGB trends in a southerly direction from the north-eastern margin of the Yilgarn craton beneath the Yerrida Basin that overlies the craton margin. Magnetometry indicates that the JFGB extends for approximately 40 km beneath younger sedimentary rocks (Cooper and Flint, 2007) before the magnetic signature fades due to either increased depth of burial or truncation at the craton margin (Fig. 1b). The exposed JFGB is approximately 45 km long and in excess of 10 km wide in the north, but narrows to approximately 2 km wide in the south.

The current resource at Wiluna West is estimated at 130.3 Mt at 60.0 wt.% Fe; 0.06 wt.% P; 7.4 wt.% SiO_2; 2.4 wt.% Al_2O_3; and 3.6 wt.% LOI. The cut-off grade of 50 wt.% Fe reflects the high values of the principal ore types of >68 wt.% Fe; phosphorous and sulfur are typically low and were not used for cut-off definition. A detailed description of the resource is provided in the Appendix. The Wiluna West iron ore prospect is small in terms of iron ore resource but large in terms of diversity and new insights and constraints on the origin of high-grade iron ore deposits. The 130 Mt is distributed over 29 separate ore bodies, with a variety of ore types for each of which the genesis can be deduced from the environment and geological history. The small dimensions of the individual ore deposits and the great distance from ports makes them challenging for exploitation but the high grade (66–68 wt.% Fe) and quality of the ore makes the effort enticing.

The most significant Wiluna West iron ore typically consists of M-mplh (Morris, 1980) ore that is much sought after owing to its excellent metallurgical properties but its nature and genesis is still debated (Barley et al., 1999; Brown et al., 2004; Dalstra, 2011; Lascelles, 2002, 2012; McLellan et al., 2004; Morris, 2002, 2011, 2012; Morris and Kneeshaw, 2011; Müller et al., 2005; Powell et al., 1999; Taylor et al., 2001; Thorne et al., 2004; Webb et al., 2003). The occurrence at Wiluna West of abundant high-grade bedded hematite ore petrographically similar to M-mplh ore provides a new opportunity for defining the genesis of the important deposits from the Hamersley Province and other areas.

This study records the first observation of M-mplh ore in the Yilgarn Province and also the first observation of granular iron formation (GIF) in the Archean rocks of Australia with the only other record of GIF being the 1.8 Ga Frere Iron Formation in the Earaheedy Basin (Hall and Goode, 1978). The study also details a very complex redox history for the JFGB and although most of the samples have gone through multiple stages of reduction and oxidation, and are from highly weathered and oxidized diamond core and outcrops, remnants and textural traces of earlier stages are fairly common and the mineralization history may be deduced from pseudomorphic textures. The relatively simple tectonic, structural and metamorphic history of the JFGB has been preserved unaltered, by a cover of undeformed and unmetamorphosed Paleoproterozoic rocks, until erosion of the cover commencing in the Mid-Cenozoic era, providing a unique window into the state of the JFGB at ~2 Ga. The small scale of the numerous ore bodies makes it possible to distinguish the factors influencing the formation of the various ore types. This paper is based on detailed surface mapping and petrography during exploration of the ore deposits and aims to describe the geology of the Wiluna West high-grade iron ore deposits and to evaluate the evidence for the genesis of the variety of different ore types present. It is proposed that comparison of the features at Wiluna West that are common to the M-mplh deposits of the Hamersley Province and elsewhere will assist in the formulation of a more robust model of their genesis.

2. Methods

Five major magnetic bands labeled A to E were identified from aerial magnetometry (Cowan Geodata Services, 2005, unpublished company report) of the JFGB (Fig. 1B, C) but only B and C bands were found to contain BIF with magnetite-bearing mafic volcanic rocks forming the others (Fig. 1C). The high-grade (>60 wt.% Fe) iron ore deposits consist of a series of strata bound lenses associated with the BIF units that crop out on two prominent, mulga (*Acacia* sp.) covered, flat-topped ridges (B and C Ridges, Fig. 1D). Minor bands of BIF outcropping between the ridges also contain areas of high-grade ore. An extensive program of RC percussion drilling of B and C bands, including a number of parallel diamond drill cores, was carried out to test grade and tonnage of the ore deposits. All holes were drilled at an angle of 60° to the east with a maximum drilling depth of 200 m that caused some holes to bottom in high-grade ore. Detailed lithological field mapping was carried out at a scale of 1:2000 (Appendix Fig. A1a, b, c, d). After mapping of the main BIF outcrops more detailed mapping of intervening and adjacent areas to the east was conducted but was not extended to the west of C Ridge as there did not appear to be any BIF units in that direction (Fig. 1).

Due to the deep weathering (>200 m), apart from chip samples from a deep percussion drill hole, unweathered BIF and ore were not available for study. Polished thin sections were made from 174 samples (Table A1) collected from the area included in the Wiluna West exploration tenement and examined by transmitted and reflected polarized light. Thirty-four samples were collected from diamond drill core, two samples from percussion drill chips and the remaining samples were collected from outcrops. Four samples of the conglomerate and one sample of sandstone were collected from the Windplain Group at the base of the overlying Yerrida Basin, and one sample of strongly weathered amphibolite from immediately beneath the conglomerate. Nineteen samples were collected from various Archean sedimentary and igneous rocks and the rest of the samples were collected from BIF bands on Units B and C covering the major ore bodies and intervening BIF north of the C1 deposit (Fig. 1D); with an additional six samples from the extreme south of the leases (South 2) for comparison. Apart from the percussion drill chips, one core sample of chlorite schist and one amphibolite outcrop, all samples were highly weathered, with varying degrees of goethitization and no remaining primary carbonate or silicate minerals.

3. The Joyner's Find greenstone belt

3.1. Previous work

A brief description of the stratigraphy and structure of the JFGB by Elias et al. (1982) referred to work by Mabbutt (1963) and Sofoulis and Mabbutt (1963), and a fuller description was given by Ferdinando (2002). The JFGB is assigned to the Southern Cross Domain (Cassidy et al., 2006) due to the large volumes of BIF and clastic sedimentary