Tools for discovering BIF-hosted iron ore deposits in the Pilbara Craton

by

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A consequence of the mostly upward trajectory of iron ore prices from 2007 to 2011 was a broadening of the exploration and research scope in Western Australia, from a historical focus on the mining centres of the Hamersley Basin, to the inclusion of smaller but high-grade (>55 wt% Fe) iron ore deposits in the Yilgarn and Pilbara Cratons. Genetic models for banded iron-formation (BIF)-hosted iron ore deposits were initially influenced by the synthesis of detailed studies completed in the Hamersley Basin (e.g. Morris, 1980; Barley et al., 1999; Taylor et al., 2001), but later evolved to incorporate results from district-scale studies in the Yilgarn Craton (e.g. Angerer et al., 2015). Only recently have iron ore deposits of the Pilbara Craton been examined in order to develop a statewide understanding of iron ore styles and genesis for these deposits. This contribution summarizes the main outcomes of a collaborative project coordinated by the Minerals Research Institute of Western Australia (MRIWA), involving Atlas Iron Ltd Pty, the Centre for Exploration Targeting (CET) at The University of Western Australia, RWTH Aachen University, and the Geological Survey of Western Australia (GSWA) (recently published as GSWA Report 163; Duuring et al., 2016).

Characteristics of iron ore deposits in the Pilbara Craton

The Pilbara Craton contains Archean granite–greenstone terranes unconformably overlain by the Fortescue and Hamersley Basins (Fig. 1). The Hamersley Basin hosts >76% of Western Australia's reported iron resources (44 962 Mt from a total 58 845 Mt of combined resource and reserve estimates; Department of Mines and Petroleum's (DMP) MINEDEX database, November 2016), whereas the Yilgarn and Pilbara Cratons contain about 12 and 11%, respectively. Greenschist-facies metamorphosed greenstone sequences in the Pilbara Craton comprise mainly volcanic and clastic sedimentary rocks, with minor intervals of Mesoarchean BIF that are thickest and most laterally extensive in the East Pilbara Terrane.

Iron ore deposits in the craton are classified by Cooper (2015) on the basis of their genetic and host-rock associations into primary magnetite-rich BIF (21–37 wt% Fe), high-grade supergene-enriched BIF (>55 wt% Fe), pisolitic/channel-iron deposits (CID) ores formed in paleochannels (52–57 wt% Fe), detrital ores (<58 wt% Fe), and orthomagmatic Fe–V–Ti ore hosted by layered mafic igneous rocks (~44 wt% Fe) (Fig. 1). Primary and supergene-enriched iron deposits are the main source of iron ore, representing >96 % of all iron resources in terms of their contained Fe (i.e. 6173 Mt from a total 6401 Mt Fe of combined resources plus reserves; DMP MINEDEX database, November 2016). However, the higher costs of refining primary magnetite-rich BIF ores have so far prevented their development into producing mines (e.g. the Maitland River, Mt Marie, and Mt Oscar deposits; Fig. 1). Instead, high-grade supergene-enriched BIF occurrences remain the primary target and have been mined from various camps throughout the Pilbara Craton, including McPhee Creek (136 Mt Fe; combined resource and reserve estimates), Goldsworthy (122 Mt Fe; comprising the satellite deposits of Mt Goldsworthy, Nimingarra, Shay Gap, Sunrise Hill and Yarrie), Mt Webber (39 Mt Fe), Corunna Downs (37 Mt Fe), Wodgina (18 Mt Fe), Abydos (11 Mt Fe), and Pardoo (6 Mt Fe). Pisolitic, detrital, and orthomagmatic Fe–V–Ti iron ore prospects in the Pilbara Craton are generally too small for mining.

BIF of the 3022–3016 Ma Cleaverville Formation are the main host to high-grade iron ore deposits, with only minor iron ore hosted by older BIF units of the Kangaroo Caves and Paddy Market Formations. BIF within the Cleaverville Formation are thicker (up to 1 km) and generally more iron rich (31–39 wt% Fe). Iron orebodies are mostly centred on kilometre-scale fold hinges that are intersected by shear zones or fault zones (e.g. Corunna Downs, Wodgina, and Pardoo camps), demonstrating the importance of secondary thickening of BIF units and their coincidence with broad damage zones. The enhanced permeability of these zones promotes hydrothermal fluid flow and chemical exchange with BIF, resulting in intense alteration and upgrade to high-grade orebodies (e.g. the ALX pit at Pardoo, Fig. 2a).

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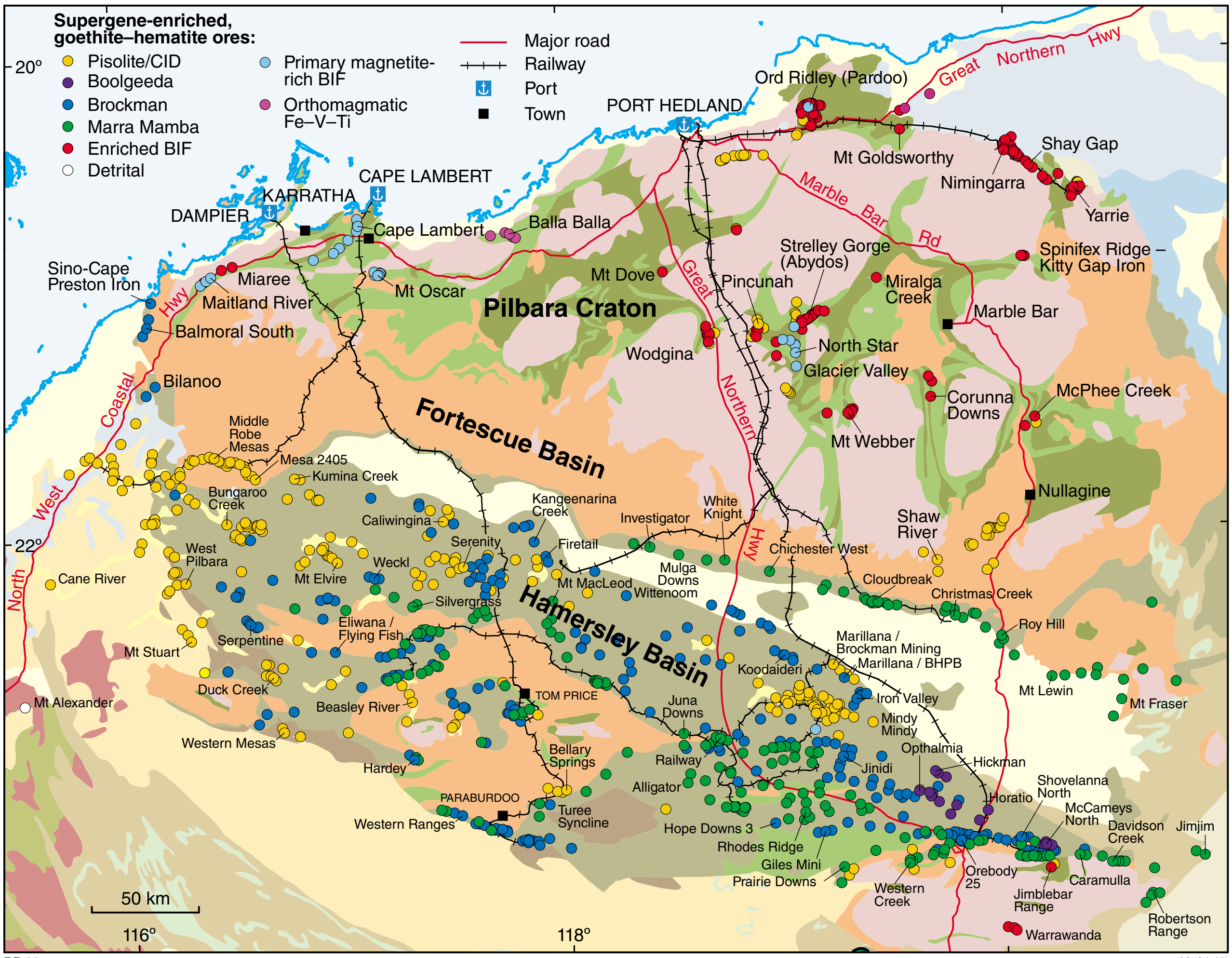

Figure 1. Comparison of iron ore occurrences in the northern half of the Pilbara Craton (the focus of this study) with those in the Hamersley Basin. In the Pilbara Craton, green polygons represent greenstone belts and pink polygons indicate granites. Other colours represent Proterozoic and Phanerozoic rocks that surround the Pilbara Craton. Iron ore occurrences are sourced from DMP's MINEDEX database, June 2016; the geology is sourced from the Geological map of Western Australia, 1:2 500 000, 2015.

Common to all studied deposits is their complex deformation and fluid alteration histories, which include early folding and multistage hypogene fluid alteration events, followed by supergene alteration by meteoric fluids along fault zones (e.g. the Wodgina camp; Teitler et al., 2016). Hypogene magnetite ± hematite ± quartz ore zones are steeply dipping and extend to depths of >200 m, but are narrow (<10 m wide) and low to moderate grade (37–55 wt% Fe). Overprinting supergene goethite ± martite ores are broader and high grade, and they extend from surface to depths of about 100 m (Figs 2b,c).

Hypogene-altered BIF is depleted in Si and enriched in Fe compared with unweathered least-altered BIF. At the Pardoo camp, hypogene-altered BIF are commonly enriched in W. Supergene goethite ± martite ores are depleted in Si and enriched in Fe, P, and volatile (loss on ignition) components, and commonly enriched in Mn, Ni, Co, As, Zn, and Cu, and more locally in U, Ca, Mg, Pb, and Ba compared with unweathered least-altered BIF. The variable enrichment patterns in supergene-altered BIF between iron ore camps are likely the product of chemical exchange between BIF and country rocks with diverse compositions.

Exploration for BIF-hosted iron ore in the Pilbara

Craton-wide predictive exploration strategies are ideally based on a synthesis of detailed deposit- and camp-scale studies obtained from diverse geographical and geological settings. A mineral systems analysis (sensu Wyborn et al., 1994) of enriched BIF-hosted iron ore deposits in the Pilbara Craton identifies the following critical elements for their genesis: (i) the presence of thick BIF; (ii) broad, interconnected damage zones that act as fluid pathways; (iii) a large volume of silica-undersaturated fluid; (iv) exhumation and surficial modification of BIF; and (v) the preservation of orebodies. The occurrence of all critical elements in a locality is required for it to be prospective.

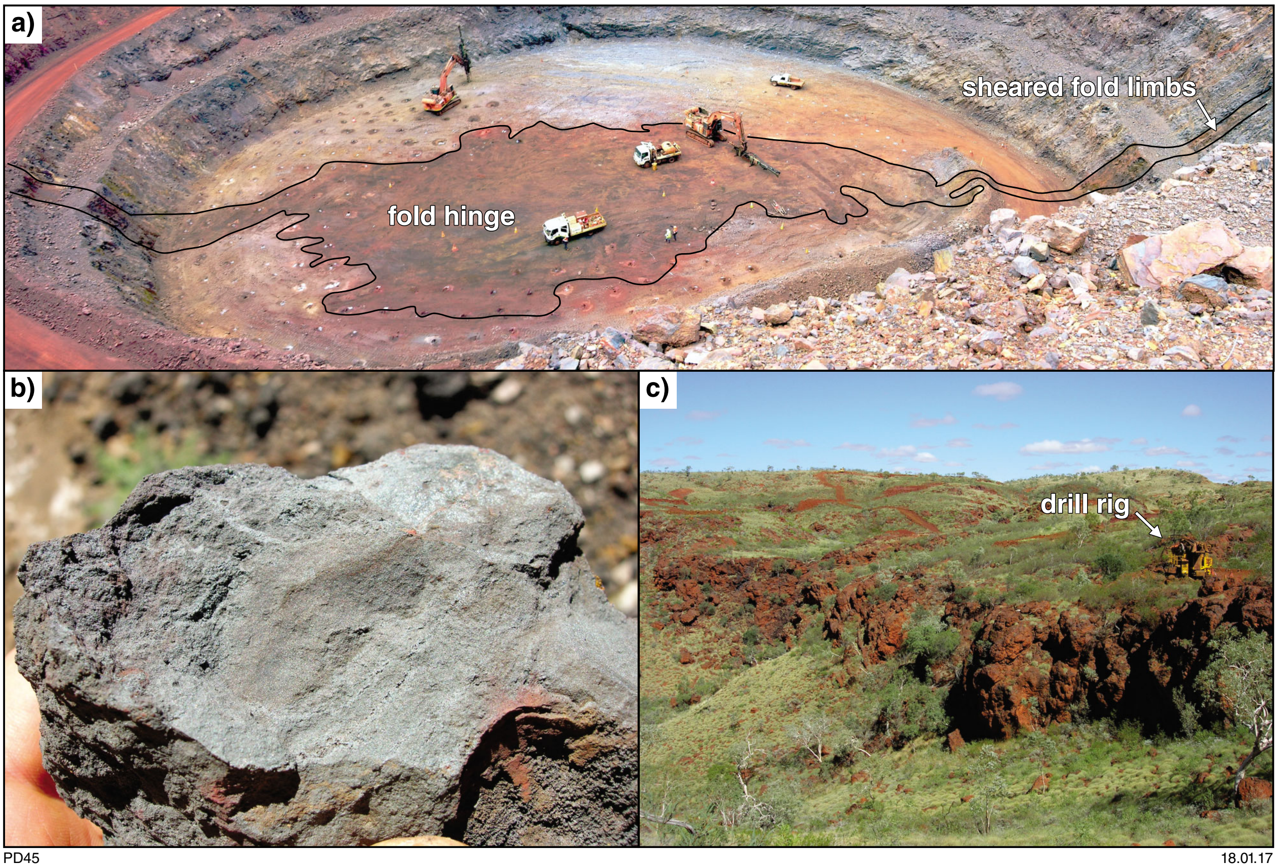

Figure 2. Examples of supergene-modified hypogene ore and supergene ore in the Pilbara Craton: a) Alice Extension pit in the Pardoo camp showing a folded hypogene magnetite-rich orebody that is overprinted by supergene goethite–martite alteration; b) hand specimen of supergene goethite ± martite ore from the Anson pit in the Wodgina camp; c) near-surface, >20 m-thick, subhorizontal layer of high-grade supergene goethite ± martite ore at the Corunna Downs prospect

Concept-driven orebody targeting is best conducted initially at a greenstone belt scale, but requires subsequent testing of specific detection criteria. For example, there is significant geochemical variability in pathfinder element suites for high-grade iron orebodies between camps, illustrating the need to establish baseline petrochemical trends within a camp rather than applying a craton-wide exploration formula. Pathfinder anomalies must be explained in terms of ore-forming processes, and their limitations understood. The greatest potential for the discovery of new iron ore deposits in the Pilbara Craton arguably lies in detecting supergene or hypogene orebodies concealed beneath transported sediment and surface veneers of weathered BIF.

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