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IRON-FORMATIONS: A MINERAL SYSTEMS ANALYSIS

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P Duuring

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Cover image: Wave and wind sculpted stromatolites at Flagpole Landing, Hamelin Pool in the world heritage site of Shark Bay, Western Australia (photo courtesy of Heidi Allen, DMIRS)

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Abstract

Iron-formations (banded iron-formations and granular iron-formations) are the main source of iron for the world's economy. Major iron-formation districts include those in the Hamersley Basin, Yilgarn Craton and Pilbara Craton of Western Australia; as well as the Quadrilátero Ferrífero and Carajás Mineral Provinces of Brazil; the Sishen and Thabazimbi districts of South Africa; and the Krivoy Rog deposits in the Ukraine. A mineral systems analysis has been performed to define critical and constituent processes controlling their genesis, as well as mappable proxies for these processes. Critical processes include: i) formation of fertile iron-formations as a source of iron; ii) transport of hydrothermal fluids within structures; iii) reaction of silica-dissolving (supergene or hypogene) fluids that results in the removal of primary quartz and the concentration of iron oxides; and iv) preservation of deposits through erosion and uplift of the iron-formation and orebodies. The constructed Mineral System Tree for iron-formations demonstrates the link between geological processes and their recommended geographic information system map layers for exploration.

KEYWORDS: banded iron-formation, goethite, hematite, hypogene, iron ores, magnetite, supergene

Introduction

This Record describes the iron-formation mineral system in the Geological Survey of Western Australia (GSWA) Mineral Systems Atlas (MSA). Mineral systems models exist for iron deposits hosted by banded iron-formations; the first model was constructed by Angerer et al. (2015) and is based on a comparison of iron deposits in the Yilgarn Craton and Hamersley Basin of Western Australia. This model was later revised and expanded by Hagemann et al. (2016) to include iron deposits from around the world, such as those in the Quadrilátero Ferrífero and Carajás Mineral Provinces of Brazil, the Sishen and Thabazimbi districts of South Africa, and the Krivoy Rog deposits in the Ukraine. The present study builds upon their work by using their recommended critical processes that control iron mineralization to define a list of mappable proxies, and then developing corresponding geographic information system (GIS) map layers in the MSA.

In this GSWA Record, a brief description is first given of iron-formations, their iron ore types and the critical processes for mineralization. A mineral systems model is summarized in graphic form as a Mineral System Tree. Further information about GIS map layers constructed for the iron-formation mineral system may be found in the online Guide to the Mineral Systems Atlas (www.dmp.wa.gov.au/msa). The information in the Guide and Atlas is likely to evolve and be updated, based on improvements in our understanding about this mineral system and additions of related geoscience data to the GSWA databases.

GSWA Mineral Systems Atlas

The MSA is an interactive GIS-based platform that collates and delivers map-based geoscience data layers filtered to be specifically relevant to understanding and exploring for mineral deposits in Western Australia (www.dmp.wa.gov.au/MineralSystemsAtlas). MSA content is systematically defined by applying the mineral systems concept advocated by Wyborn et al. (1994) and McCuaig et al. (2010). The premise of this concept is that mineral deposits will only form and remain preserved where there has been a spatial and temporal coincidence of critical earth processes (geodynamic setting, lithosphere architecture, fluid, ligand and ore component reservoir(s), fluid flow drivers and pathways, depositional mechanisms, post-depositional processes), and that the occurrence of these critical processes might be recognized from mappable geological features expected to result from them. It is these geological features ('targeting elements' or 'geological proxies') that can be extracted as digital map layers from geoscience datasets and may be used in GIS-based prospectivity studies.

Different mineral systems (Fraser et al., 2007) are analysed to define mappable geological proxies for critical mineralizing processes. Such analyses draw on in-house knowledge, existing literature and collaborations with subject-matter experts. Structured queries are then used to extract relevant data from one or more statewide GSWA geoscience databases, for those proxies that can be practicably produced. These queries operate directly on, and are dynamically linked to, primary GSWA geoscience data sources. No new data are acquired or created, although some information may be reformatted to meet the internal requirements of particular map layers. Furthermore, the queries are scheduled to automatically update the derived proxy map layers whenever new data are added to the primary databases. Users may therefore be confident that the data layers portrayed in the MSA are always current.

Iron-formation mineral system

The iron-formation mineral system as defined by this study includes iron deposits hosted by banded iron-formations and granular iron-formations. Banded iron-formations (commonly referred to as BIF, with iron contents of 20–45 wt% Fe_{total}) are the major source (>50%) of iron for the world economy, with their enriched higher grade iron ore bodies (58–69 wt% Fe_{total}) representing preferred targets for exploration and mining (Angerer et al., 2015). Major BIF-hosted iron ore districts are mostly constrained to Archean cratons and Proterozoic mobile belts, located in Western Australia, Brazil, West Africa, South Africa, India, Ukraine, North America and China (Hagemann et al., 2016). Banded iron-formations span the Precambrian; they include Archean and Paleoproterozoic Algoma-type BIF (e.g. in the Yilgarn Craton of Western Australia and the Carajás Mineral Province of Brazil), Proterozoic Lake Superior-type BIF (e.g. iron deposits in the Hamersley Basin) and Neoproterozoic Rapitan-type BIF (e.g. in the Urucum iron ore district) (see Bekker et al., 2014 for a more detailed description of banded iron-formation characteristics and their origins).

Granular iron-formations (GIF) are well-sorted iron-rich chemical sands that lack continuous bedding (Boggs, 2006). A Western Australian example includes intervals of Fe-rich and Si-rich GIF that alternate with siltstone in the c. 1.89 Ga Frere Formation in the Earaheedy Basin (Pirajno et al., 2009; Akin et al., 2013). GIF in the Frere Formation are comparable to iron-formations within the Gunflint Formation in the Lake Superior region of North America (Walter et al., 1976; Tobin, 1990).

Iron deposit types that are not included in GSWA's iron-formation mineral system model are ooidal ironstones (i.e. channel iron deposits, also known as CID), detrital iron deposits and orthomagmatic Fe–Ti–V deposits. CID and detrital iron deposits are derived from the physical transport and reworking of primary and/or enriched iron-formations; they are omitted from the model because their critical processes involve significant transport of materials away from their primary iron-formation. Orthomagmatic Fe–Ti–V deposits are excluded because they form as a result of igneous rather than sedimentary processes.

Iron ore types in the iron-formation mineral system

Iron ores hosted by iron-formations include primary and enriched varieties (Fig. 1). Primary ores are BIF that have not been enriched by secondary processes. They comprise alternating quartz and magnetite bands, with the latter often at least partly oxidized and pseudomorphed by hematite (often referred to as martite). Although primary ores have lower iron grades (<40 wt% Fe_{total}) than enriched ores, they are still considered to be exploration targets in some parts of the world because of their large combined resources and reserves. For example, BIF in China are the main local source of iron, representing more than 58% of known iron ore resources (Zhang et al., 2012). These ores are mostly lower grade (<50 wt%), with only 1% of their total iron ore resources sourced from the higher grade, enriched ores (Zhang et al., 2014). The most economic primary ores are generally thick and laterally extensive occurrences of primary BIF that are uncontaminated by endogenetic siliclastic or pyroclastic material, and are therefore depleted in most major elements except iron and silica (Beukes and Gutzmer, 2008).

Enriched ores are generally preferred exploration targets throughout the world because of their higher iron contents and lower costs of production. These ores can be divided into hypogene (magnetite, crystalline hematite) and supergene (goethite–hematite) ore types according to their mineralogy and the interpreted source of their mineralizing fluids. Facies architecture of the iron-formations determines to a large extent the texture and composition of the higher grade iron ores hosted by them (e.g. Beukes and Gutzmer, 2008), including the deleterious elements Al and P. Specific occurrences of iron-formations may host any, or all, of these iron ore types in a single district or deposit. Examples of primary and enriched iron-formation deposits in Western Australia include those in the Hamersley Basin (e.g. Thorne et al., 2008), Pilbara Craton (Duuring et al., 2017a) and Yilgarn Craton (Duuring et al., 2017b).

Critical mineralization processes

Of the many different iron ore types, goethite–hematite ores are the most simply explained in that they are the product of near-surface supergene enrichment processes related to the circulation of oxidized meteoric fluids through iron-formations (Morris, 1985; Ramanaidou and Morris, 2010). In contrast, the deeper and older magnetite and hematite ores have a more controversial origin. Rival models include: i) early diagenetic desilicification of BIF with corresponding iron enrichment (Lascelles, 2006); ii) ancient near-surface supergene enrichment of BIF followed by recrystallization of microplaty hematite during burial metamorphism (Harmsworth et al., 1990; Morris, 1985); or iii) a supergene-modified hypogene fluid model that involves hot externally derived fluids that upgrade iron in BIF through replacement of primary quartz bands by hypogene carbonate minerals, followed by carbonate dissolution and concentration of residual iron oxide minerals (e.g. Taylor et al., 2001; Angerer et al., 2015; Hagemann et al., 2016).

Despite these identified differences between the iron ore types (i.e. their iron oxide mineral assemblages, relative timing, hydrothermal fluid properties and sources), the proposed iron-formation mineral system presents a unifying model for iron deposits worldwide. Their critical processes include: i) genesis of a fertile iron-formation (one that is thick and with low contamination by deleterious elements such as Si, Al, Ti or P); ii) transport of hydrothermal fluids within structures; iii) reaction of silica-dissolving fluids with iron-formations that result in removal of quartz and concentration of iron oxides; and iv) preservation of iron ore deposits (Table 1). Details about their constituent processes, mappable proxies and GIS layers are presented in a Mineral System Tree in Figure 2. The layers are useful at specific scales; for example, a map showing the distribution of paleocratonic boundaries is likely to only be of use to exploration targeting at terrane scale. In contrast, a map that shows the location of structurally thickened iron-formations (as a result of folding or tectonic stacking) is more useful at a district scale. These distinctions are illustrated in the Mineral System Tree (Fig. 2).

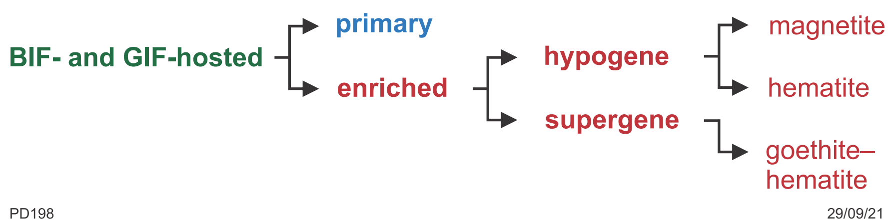

Figure 1. Iron ore types — categorized by their relative timing with respect to their host iron-formation, mineralizing fluids and ore mineral associations. Individual iron deposits may comprise combinations of these ore types

Conclusions

This manuscript summarizes the mineral systems model for iron-formations, which includes iron deposits hosted by banded and granular iron-formations. The objective is to demonstrate links between geological processes involved in their genesis and GIS map layers that may be useful for iron exploration. Critical processes include: i) formation of fertile iron-formations as a source of iron; ii) transport of hydrothermal fluids within structures; iii) reaction of silica-dissolving fluids that remove gangue minerals such as quartz and carbonate, and concentrate iron oxides; and iv) preservation of deposits through erosion and uplift of the iron-formation and orebodies. The constructed Mineral System Tree for iron-formations presents a list of recommended GIS map layers for exploration.

Table 1. Critical processes for the iron-formation mineral system

Critical process	*Description*
Source	Fertility of iron-formations — resulting in a thick, Fe-rich unit with low contamination by other elements (e.g. Si, Al, Ti or P)
Pathway	High-permeability zones that direct fluid flow and iron enrichment in BIF and GIF
Fluids	Silica-dissolving fluid that removes primary quartz and concentrates iron oxides
Exhumation and Preservation	Erosion and uplift of iron orebodies

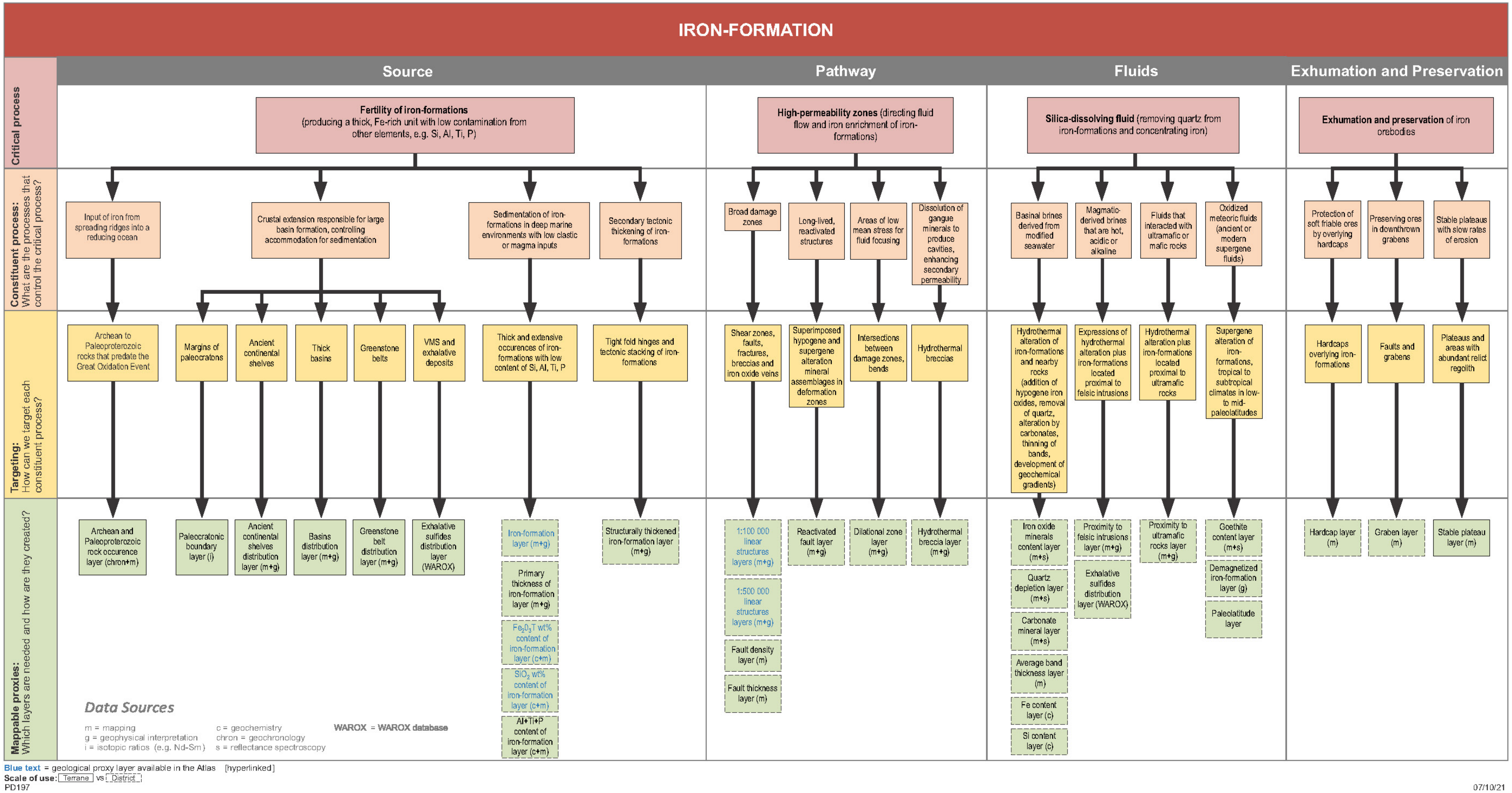

Figure 2. The Mineral System Tree for the iron-formation mineral system shows the links between the critical and constituent processes, and how these processes relate to their mappable proxies and GIS layers

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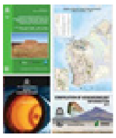

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