Comparison of supergene mimetic and supergene lateritic iron ore deposits

E. R. Ramanaidou and R. C. Morris

Erick Raymond Ramanaidou
CSIRO Earth Science & Resource Engineering
Minerals Down Under Flagship
CSIRO ARRC PO Box 1130 Bentley WA 6102 Australia
Erick.Ramanaidou@csiro.au

Richard Cecil Morris
CSIRO Earth Science & Resource Engineering
CSIRO ARRC PO Box 1130 Bentley WA 6102 Australia
Richard.Morris@csiro.au
ABSTRACT

Supergene lateritic iron ores are uncommon compared to the vast tonnage of BIF-hosted microplaty hematite ores or the dominant supergene mimetic martite-goethite ores of the Hamersley area.

In Australia and to a minor extent in India and South America, mimetic replacement of gangue minerals by iron hydroxyoxides is a major factor in forming supergene iron ore from banded iron-formation (BIF) and results in the superb preservation of the original BIF features. This includes primary banding down to the finest inclusions, as is a result of pseudomorphing of the BIF gangue at depth by goethite. The enrichment as a whole is an absolute accumulation of Fe at depth, dissolved from the surface BIF, with a removal of the gangue elements without loss of the original BIF mineral textures. Thus the ores grow upward to meet the downward destruction of the surface BIF by erosion.

In contrast the supergene lateritic ores including the ‘blue dust ores’ are residual ores resulting from the relative accumulation of Fe. In the supergene lateritic ores derived from BIF, removal of the gangue is accompanied by repetitive solution and precipitation by secondary hematite and goethite. The final product of lateritisation of BIF and BIF-derived ores is typically complex due to successive overprinting of earlier stages of alteration during the process and because of the different precursors. This progressive lateritic modification tends to produce a varied surface complex including massive, vermiciform, and botryoidal, or nodular aluminous/siliceous goethite and hematite, variously known as ferricrete, duricrust, canga, or hydrated zone hardcap. The significant difference between these ores and the supergene mimetic
martite-goethite ores is that they grow downward, with the total destruction of any of the parent BIF or BIF-ore textures.
INTRODUCTION

The goal of this paper is to clarify the definition and understanding of ‘supergene iron ore’ since confusion still exists in the literature and in the common usage of the term. Most workers in the field of iron ore equate the term ‘supergene iron ore’ with lateritic iron ore. Both these ore types are supergene but their end products are vastly different.

Broadly the term supergene means genesis from above, in contrast to hypogene, meaning genesis from below which by implication is related to hydrothermal processes.

The original American Geological Institute (AGI) Glossary (1972) offered:
“Supergene - said of a mineral deposit, weathering or alteration formed by descending solutions”; the most recent (2005), states
“Supergene - said of a mineral deposit or enrichment formed near the surface commonly by descending solutions”.

In the new AGI definition the term has lost its general status and has become specifically related to shallow “ore”. We believe the early wording that includes weathering and alteration but no depth restrictions, has greater validity. Supergene processes affect all surface rocks without necessarily producing ‘ore’.

Supergene processes have affected banded iron-formations (BIF) to considerable depth (Morris 1980, 1983, 1985) and to more than 200 m (Ramanaidou, 1989, 2009). The apparently anomalous depths of supergene alteration and enrichment found in BIF-hosted iron deposits reflect the marked electron conductive properties of magnetite-rich BIF (Morris et al. 1980; Morris 1985). It is this lithology that enables
surface atmospheric-driven chemical reactions to occur at depths well below the normal ‘near-surface’ weathering zone implied by the AGI Glossary (2005). The following is modified from Morris (1985).

“There is a profound difference between the mechanisms and products of prolonged weathering and those of deep-seated, supergene mimetic enrichment in BIF, even though both are related to supergene processes.

- Supergene (mimetic) enrichment typically occurs well below the water table. This happens only when structure and topography combine with atmospheric conditions to produce hydrodynamic groundwater flow systems that can drive large electrochemical cells for millions to tens of millions of years. Supergene enrichment preserves most of the textures of the parent BIF, until metamorphism or lateritisation intervenes.

- Supergene lateritic weathering in contrast, produces iron-enrichment in BIF, as in most rocks, by dissolution of rock components and the precipitation of iron in the vadose zone. The parental textures are usually obliterated in these residues by repeated solution and deposition of aluminous goethite.

The present ridge topography of iron-ore deposits is a result of the chemical and physical resistance of the ores to erosion: the ores are not the result of the present topography. Thus, in considering the origin of the deep ores it is necessary to project their structural systems back into the past, sometimes as far as the Proterozoic.”

The creation of supergene mimetic ore in BIF requires the transfer of iron from the near surface, possibly by biogenically-aided dissolution, into the reacting zone at depth. If, as some suggest, the ore bodies grew from the surface downward, then ore
genesis must have been significantly faster than surface erosion in order to generate the great depths of ore typically observed. A more realistic appraisal indicates growth upward as the surface BIF erodes. Calculations based on analyses of the Dales Gorge Member BIF and its varied ore types suggest that the iron from at about 1½ to 2 stratigraphic units of BIF is needed to produce 1 equivalent unit of iron ore (Morris, 1985).

**SUPPERGENE MIMETIC ENRICHMENT OF BIF**

Most of the deep-seated BIF-derived mimetic supergene iron ores extend to depths well beyond the likely reach of oxygenated water. Fe$^{3+}$ is effectively insoluble under most natural conditions. Thus, to have concentrated in its present position by mimetic goethite replacement of the BIF matrix, it must have been transported in the soluble Fe$^{2+}$ form, followed by oxidation to Fe$^{2+}$ and precipitation as Fe$^{3+}$ hydroxyoxides (by hydrolysis) at depth.

Because magnetite and its kenomagnetite-maghemite (Morris, 1980) derivatives are excellent conductors of electrons, atmospheric effects in the sub-outcrop can drive large electrochemical cells in BIF (Figure 1). Solution of iron from surface BIF leaves a residue of friable silica, locally known as ‘denatured BIF’ (Figure 1). This readily erodes, exposing more BIF for reaction. Fe$^{2+}$ is transferred in groundwater through pores and fractures to the reacting zone at depth and precipitated as Fe$^{3+}$, pseudomorphing chert (Morris and Fletcher, 1987), carbonates, and silicates by goethite, with oxidation of magnetite to martite (Morris 1980, 1985; and Figure 2, 3, 4). This process is by electron exchange and does not require the presence of O$_2$ in the
reacting zone. Ionic exchange via groundwater completes the reaction. Thus, the ore body grows upward, as erosion removes the surface, forming a topographic low.

**SUPERGENE LATERITIC IRON ORE**

Some iron ore deposits are produced by supergene lateritic process and have developed in itabirite, i.e., banded iron formation or BIF (Dorr, 1973; Melfi et al., 1988; Ramanaidou, 1989; Ramanaidou et al., 1996; Wegen and Valeton, 1990; Chicarino et al., 1997; Taylor et al., 2001; Spier et al., 2003; Beukes et al., 2003; Freyssinet et al., 2005; Roy and Venkatesh, 2009. For instance, in the Capanema mine in Brazil (Ramanaidou, 1989; Ramanaidou, 2009) the tropical climatic conditions producing this ore have led to a lateritic mantle consisting of a succession of weathering horizons that are from bottom to top (1) a desilicified horizon, (2) a friable hematite-rich horizon and (3) a goethite-rich cemented horizon capped by (4) ferruginous duricrust or canga. The first stages of the weathering process, in the desilicified horizon, include the dissolution of the gangue minerals (as opposed to the replacement of the gangue as seen in the supergene mimetic ores). The dissolution of the quartz grains has been well documented (Ramanaidou, 1989; Ramanaidou, 2009) commencing from the edges and working toward the centres (Figure 5). The corroded quartz grains are partially isolated in dissolution voids with a similar size to those of the original quartz. The quartz corrosion may continue until the mineral is totally dissolved.

Overall, the process of lateritic iron ore formation is subtractive and the iron enrichment is relative. Although some of the texture is preserved significant loss of texture results from the successive dissolution and precipitation processes taking
place. The end product of the lateritic BIF weathering is a ferruginous duricrust or canga. It can be massive, vermiciform, botryoidal, nodular or ooidal. In Capanema it is sometimes ooidal where nuclei consist of secondary hematite (with varying aluminium substitution) coated by varying aluminous goethitic layers. The ooids are cemented by goethite.

**LATERITIC WEATHERING OF SUPERGENE MIMETIC IRON ORE**

Most of the iron ores deposits in Australia and around the world in Africa, South America, and India have experienced some form of weathering accompanied by textural destruction, dissolution and precipitation processes. In North America and Europe these alteration products have been largely obliterated by the effects of the vast Pleistocene ice sheets that blanketed the BIF areas. This superimposition process can destroy most of the primary features of the deep supergene mimetic iron ore and has led to confusion in understanding iron ore genesis (Taylor et al., 2001).

In the Hamersley Province, the lateritic weathering overprint occurs on all deposits as shown by the early drilling of exploration and mining companies (Morris, 1985). This lateritic mantle includes a carapace (1-2 m) in which the BIF textures are preserved as a hematite-rich association, with a hydrated zone that forms below. As weathering increases, the hydrated zone becomes dominated by vitreous goethite where the original BIF textures can be entirely destroyed as a result of dissolution of hematite and precipitation of aluminous goethite. The final result of this process is a goethite-rich ferricrete with little or no remnant of any original BIF-related textures. In some of the martite-goethite deposits along the Hamersley scarp, such as Marillana and
Kookaiderie, this weathering zone is as much as 75 metres thick, whereas in the martite-microplaty hematite ores of Tom Price and Whaleback it is generally around 20-35 metres thick.

CONCLUSION

Two processes can lead to the formation of supergene iron ores - (1) a deep seated supergene mimetic mechanism where goethite pseudomorphs the primary gangue minerals, an additive process that dominates the ores of the Hamersley area, preserving all the original BIF textures, and (2) a supergene lateritic mechanism that dissolves the BIF components in a destructive and subtractive process that removes the gangue and reprecipitates the iron dominantly as aluminous goethite and hematite with a potential total loss of the original BIF textures.

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REFERENCES


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Figure 1. Simplified model for supergene iron ore growth from below, as erosion removes the surface, from Morris (2002, 2003) based on the electrochemical model of Morris et al. (1980). N.B. Though a fault is shown as the initiating mechanism this could be an intrusive, cross-folding, or axial plane fractures. Silica solubility is increased by up to 10 times as a result of Fe$^{2+}$ - Fe$^{3+}$ reactions (Morris and Fletcher, 1987). M-mpl-H is martite microplaty hematite.

Figure 2. Partially leached mimetic supergene ore (left side) showing goethite pseudomorphs of carbonate (G c) and silicates (G sil) present in a goethite after quartz matrix, now partially leached out. The right side shows the unleached M-G ore (G q sil c) in which the various pseudomorphs are recognisable by slight colour differences due to minor element (Al, Si.) variations. M (white) is martite.

Figure 3. M-G ore showing goethite-replaced coarse prismatic riebeckite(G rieb) in a matrix of goethite-pseudomorphed chert, fine riebeckite, and carbonate (left side). The right side shows the effects of ground water partial leaching of the chert and minnesotaite -goethite emphasising the perfection of the mimetic replacement of the original BIF texture. G c is a pseudomorphed carbonate grain with numerous fine riebeckite inclusions also pseudomorphed. M is a skeletal martite grain. The large upper central void is a leached ex-magnetite raft in which goethite after kenomagnetite has been leached out.

Figure 4. M-G ore showing the partial leaching of goethite after quartz and silicate (lower) revealing the goethite carbonate pseudomorphs. Note that replaced quartz inclusions have been preferentially leached from the former carbonates. White is martite (M) and G sil is replaced silicate.

Figure 5. Dissolution of quartz grains in BIF during supergene lateritic iron ore formation (from Ramanaidou, 2009). 17
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