HAMERSLEY IRON PROVINCE, WESTERN AUSTRALIA

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INTRODUCTION

The Hamersley Iron Province of the central Pilbara Craton contains extensive areas of regolith cover. This regolith has traditionally been regarded as an impediment to exploration for primary bedded iron ore deposits, but locally there are sufficient concentrations of ferruginous deposits to form commercial resources. This research was carried out to determine which, if any, of three different theories for the origin of the ferruginised sediments most closely fits the evidence. The theories were: i) erosion and deposition of a ferruginised "laterite" zone which previously blanketed the landscape (e.g., Twidale *et al*., 1985); ii) that the material was eroded and deposited as siliceous BIF fragments and subsequently mineralised; and iii) that the sediments were directly derived from primary bedded deposits, whose location could be traced by developing an understanding of the transport processes involved.

The landscape model presented here is based on observations made at 144 locations and on numerous traverses over a 4 125 km^2 area (Figure 1).

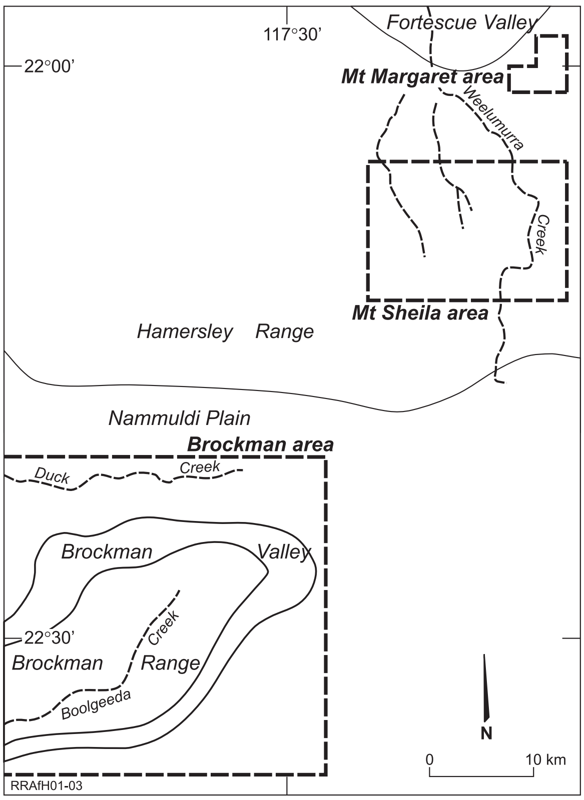

Figure 1. Location map for part of the Hamersley Iron Province, Western Australia.

PHYSICAL SETTING

Geology

The rocks of the area comprise late Archaean metasediments and metavolcanics of the Fortescue Group, unconformably overlain by Early Proterozoic metasediments of the Hamersley Group (Figure 2). In the northern part of the study area (Mt Sheila, Mt Margaret), Hamersley Group rocks are essentially sub-horizontally bedded. In the southern part of the study area (Brockman Range), the Hamersley Group has been faulted and folded into a ~10 km wide anticline, plunging to the east. The northern and southern areas are separated by the Nammuldi Plain, a broad low valley of Fortescue Group outcrop.

Geomorphology

Hamersley Group banded iron-formation (BIF) is highly resistant to erosion, and is preserved as the dominant lithology at high levels of the landscape. The less resistant of the Hamersley Group rocks, and the Fortescue Group rocks, are typically exposed on valley flanks and floors. Where the Hamersley Group is sub-horizontally bedded, the landscape is characterised by flat topped hills and plateaux, typically bounded by scarps and incised by deep dendritic valleys and gorges. In the folded areas, valleys

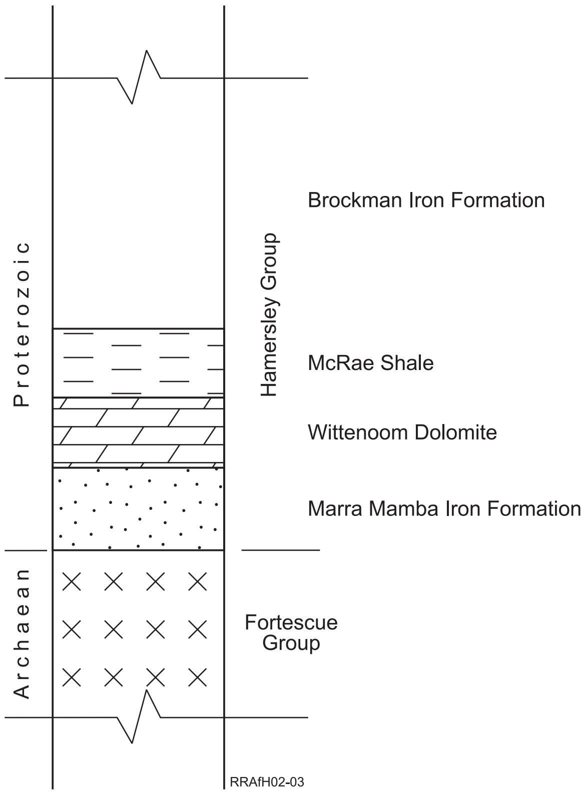

Figure 2. Schematic section showing upper Fortescue Group and lower part of the Hamersley Group, as exposed in the study area.

have developed where the more easily eroded lithologies have been removed. The resultant curvilinear ridges and valleys follow strike.

Climate and vegetation

The area is situated north of the tropic of Capricorn. Average annual rainfall of between 200–300mm/yr occurs mainly in the summer months. Rainfall is irregular, being subject to the extremes of cyclone and summer thunderstorm variability. The vegetation is dominated by spinifex grasses (*Triodia* spp.), with snappy gum (*Eucalyptus brevifolia*) and mulga variably present.

REGOLITH–LANDFORM RELATIONSHIPS

The regolith–landform relationships are controlled by a combination of basement lithology, structure and the position of the relevant unit with respect to local relief. Essentially, the landforms of the area are pre-Tertiary, with Tertiary to recent modification. Prior to modification, most of the study area was capped by a deeply weathered crust. Modification was a process of erosion of the weathered mantle in areas of greatest potential, and deposition in areas of least potential. Thus the area may be characterised as having hill tops and upper slopes stripped to fresh rock. Valley floors, lower slopes and most areas of low relief retain some or all of their weathered zones, which are typically preserved under a blanket of sediments. The sediments of the area record a continuum of depositional processes. These evolve from (proximal) rock fall and avalanche, through alluvial fans to (distal) alluvial plains, braided fluvial systems and lake/clay pans with increasing distance from the ranges.

Further modifications to this basic pattern of distribution have occurred where local or regional base levels have been lowered. This has resulted in the erosion and removal of sediment, weathered mantle and basement. Local base levels have fallen where lithological barriers such as basement steps have been breached. Regional controls on base level were outside geographic the scope of this study.

Areas of high erosional potential

Hill tops and upper slopes and scarps of BIF are dominated by outcropping fresh rock (Figure 3), with variable amounts of unweathered and weathered colluvium trapped in surface depressions and fractures. Ferruginised zones and massive silcretes may be preserved where basement faults have served as conduits for groundwater flow. Where siliciclastic formations are exposed in these locations, they rarely preserve much evidence of weathering.

Areas of low erosional potential

Flat lying upland areas, lowlands and the lower slopes of valleys generally preserve well-developed zones of weathered *in situ* material overlain and preserved by sediments (Figure 3). Alluvial fans are preserved at the break in slope where gullies and channels have delivered sediment from the hills to the valleys. These fans grade into and interfinger with alluvial sediments deposited on the valley floors.

Where developed on BIF, the most completely preserved weathered sections comprise a 2–3 m thick hematite/goethite zone overlying a variable thickness of more goethitic and siliceous BIF, grading down into unweathered rock. Massive silcretes are patchily preserved and exposed under areas of weathered BIF. Weathered profiles in siliciclastic formations consist of a ferruginous duricrust overlying bleached saprolite, grading down into mottled and less altered bedrock.

Areas of re-mobilisation

In the open valleys such as Nammuldi Plain (Figure 1), lowering of regional base level has enabled significant erosion of weathered Fortescue Group basement and the overlying channel iron deposits and pisolitic alluvial sediments. This has resulted in a landscape inversion, with the channel and marginal alluvial sediments being preserved on the tops of mesas and ridges which grade up and

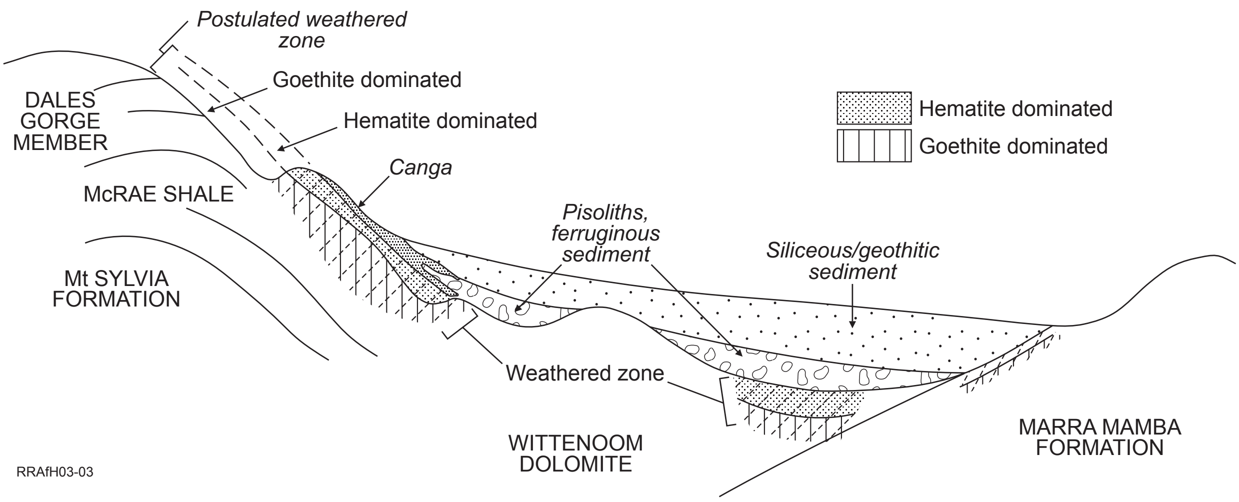

Figure 3. Schematic section showing relationship between areas of fresh rock outcrop (tops of hills), preserved *in situ* weathered materials (valley flanks, floors) and sediment deposits (valley floors).

merge on to the bounding hills (Figure 4).

In the strike valleys of the southern part, and the dendritic valleys of the northern part of the study area, base level lowering has principally led to gullying and dissection of the alluvial fill. Where most fully developed, gullies have eroded valley margins, exposing sections of weathered *in situ* material and their overlying sedimentary sequences. Rarely, significant sections of basement have also been eroded, leaving relict alluvial fans standing proud and isolated from the range fronts.

REGOLITH CHARACTERISATION

In situ regolith

In situ regolith is almost exclusively found in the floors and lower slopes of valleys. Weathered profiles developed in BIF typically have two zones. Where complete, the upper zone comprises 2–3 m of hematite/goethite. The lower zone may consist of up to several tens of metres of goethitic and more siliceous rock, with patchily distributed massive silcrete. Complete profiles have only been recognised in subcrop and have been characterised from drill holes. Exposed sections in the lower slopes of valleys are best preserved under alluvial fan deposits. Hill slope sections have typically had part or all of their upper hematite zones stripped by erosion.

Weathered profiles developed in Fortescue Group and siliciclastic Hamersley Group rocks are significantly different from those developed in BIF. They typically have an indurated ferruginous (goethitic) upper horizon overlying bleached and mottled argillaceous material. This merges at depth with unweathered rock.

Transported regolith

Transported regolith falls into two main classes, distinguished by the dominant presence of either ferruginous or siliceous clasts. The external geometry of sediment units, and their internal structures, indicate that both classes were deposited from a continuum of evolving proximal to distal processes. Alluvial fans are the most proximal deposits. These preserve rock fall, debris flow and fluvial structures. The fans evolve into distal alluvial plains, braided fluvial systems and ephemeral lake/clay pans with increasing distance from the range fronts.

Transported ferruginous regolith

Transported ferruginous regolith generally comprises one of three main types:

i) mineralised BIF (derived from *in situ* weathered BIF)

ii) pisoliths (*sensu stricto*)

iii) fossilised wood fragments (also known as Robe Pisolite or Channel Iron Deposits)

Except at valley margins and mesa tops, transported ferruginised materials are generally overlain by transported siliceous regolith (see below). The transported ferruginised materials are distributed by type. Alluvial fans situated at valley margins are dominated by coarse gravelly deposits of ferruginised BIF. Where the fans comprise hematite clasts lithified with goethite cement, the deposits are known as canga (Figures 3 and 4). These may be extensive, up to several tens of metres thick, and contain commercial volumes of iron ore. Passing down fan and away from the range fronts, the degree of cementation decreases, with canga becoming lenticular and pinching out as it interfingers with unlithified clasts. The clasts become finer grained, better sorted and more mixed with pisoliths.

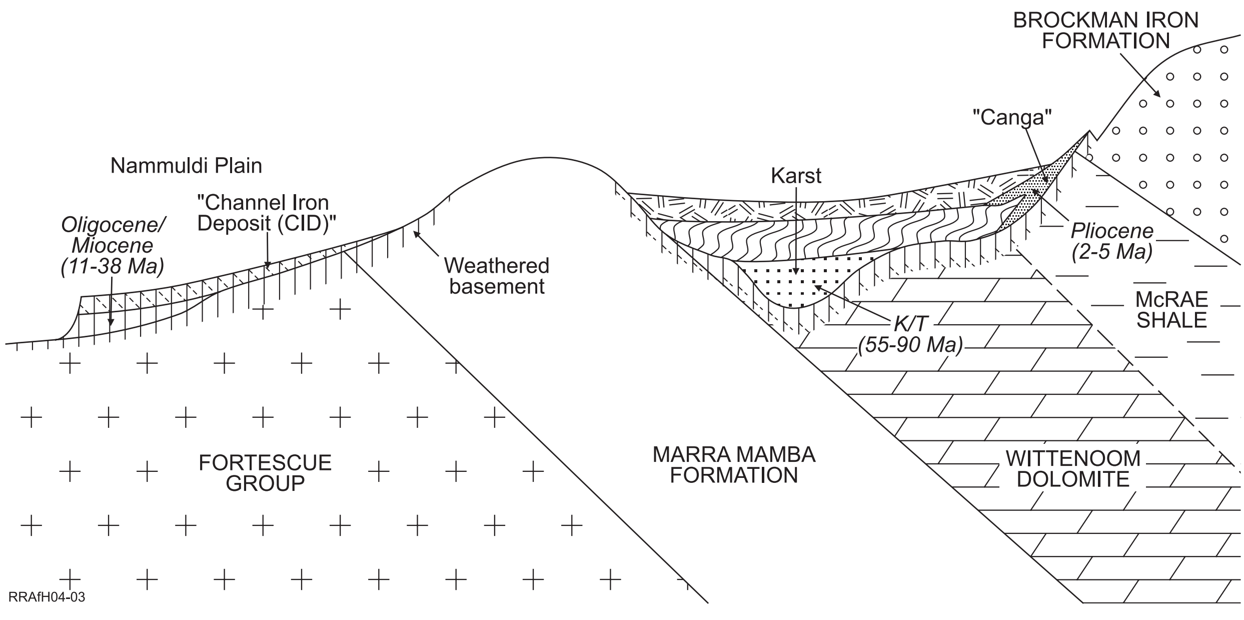

Figure 4. Age determinations for the different elements of the Hamersley Iron Province landscape. (data from Morris, 1994)

Pisolith deposits are most commonly preserved in the strike valleys, away from range fronts (Figures 3 and 4). They typically comprise uncemented granule- to pebble sized clasts, with a variable silty goethite matrix. Where exposed in the Brockman valley, they display sedimentary structures indicative deposition from sheetfloods passing from valley margins to centre, or fluvial systems running parallel with the main valley axis. Drilling results from the Fortescue Valley show that pisoliths fill a deeply incised palaeovalley (Figure 3).

The ferruginised wood fragments of the study area invariably overlie weathered basement. They are present mainly as cappings on mesas, and are mapped as Robe Pisolite (Thorne and Tyler, 1997). They are interpreted as the deposits of meandering channels. However, some of these hills and ridges with their ferruginous cappings slope more or less continuously up and onto valley sides, and merge into the rolling topography (Figure 4). This relationship suggests that the depositional environments were in part paludal, lacustrine or colluvial/alluvial.

Transported siliceous regolith

Siliceous transported regolith is the most abundant surficial and near-surface regolith type in the study area. It commonly overlies ferruginous regolith where present, and is therefore generally better exposed (Figure 3).

The proximal to distal relationships show a fining trend, from boulder conglomerates with goethitic silt and soil matrix, to mainly sandy/silty goethite with gravel and cobble lenses. Clasts are dominantly siliceous BIF, but include a minor component of re-mobilised siliceous and ferruginous conglomerate, mineralised BIF and pisoliths.

Bedding structures are generally poorly preserved. Away from range fronts the finer grained facies show a tendency to coarsen upwards. Typically, surfaces have been deflated and are armoured with patchy siliceous and ferruginous gravel lags. Cementation is variably developed with moderate induration of matrix-rich sediments; calcretes being preserved as topographic highs, and some goethitic cementation exposed in creek beds.

DATING

Palynological evidence (Morris, 1994, Figure 4) indicates that ferruginised sediments in the Brockman strike valley overlie Late Cretaceous to early Tertiary deposits. Channel Iron Deposits at Yandi, Hope Downs and Robe (outside the study area) overlie Late Oligocene to Middle Miocene sediments. The alluvial fans of the Brockman Valley contain fossilised wood fragments of probable Pliocene age.

REGOLITH EVOLUTION

The gross morphology of the modern Hamersley Iron Province landscape in the study area is essentially pre-Tertiary (Killick *et al.*, 1996, Figure 5). By early Tertiary times, a weathered mantle blanketed the Pilbara land surface at all levels. This probably developed in response to the warm and humid Cretaceous–early Tertiary climatic conditions. Since then, the climate has become more arid, and erosion has outpaced weathering. The weathered materials at high levels in the landscape were preferentially eroded, and were deposited on the flanks and floors of the valleys. These deposits preserve the low-level *in situ* weathered material, and record an inverted stratigraphy (siliceous over ferruginous material) of the high level weathered zones (ferruginous over siliceous). The ferruginised sediments were sourced from a "laterite" zone which previously blanketed the landscape.

Ferruginised sediments are generally widely dispersed throughout the region. Concentrations have been preserved due to combinations of local and regional circumstances. In the northern part of the study area, significant concentrations of canga occur where fans have been funnelled into the heads of dendritic valleys incised into the Brockman Iron Formation. To the south, structural topographic ridges running axially along the strike valleys have created barriers to flow from valley margins towards their axes. This has effectively trapped the earliest sediments,

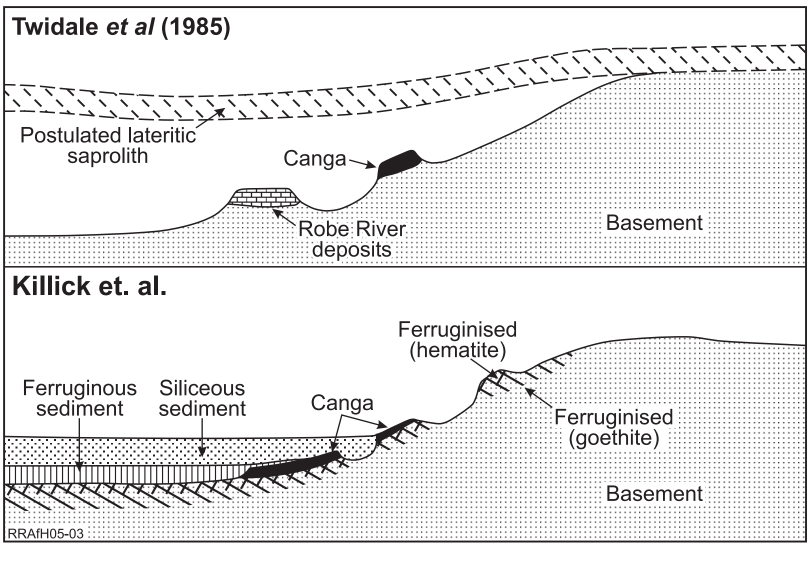

Figure 5. Model of regolith–landform development proposed by Twildale *et al*. (1985), compared to that developed during this study.

causing mineralised BIF clasts and pisoliths to be concentrated.

This model is based on the demonstrable presence of the majority of the oldest (weathered) parts of the landscape in the valley floors, and fresh rock on the high hills. The nature and disposition of weathered and detrital materials suggests the existing landscape is essentially early Tertiary or older.

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