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INTERIM REPORT ON THE PILBARA IRON ORE DEPOSITS

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SUMMARY

Two major types of iron ore exist within the Pilbara region. The reserves of both types are so vast as to overshadow all other known occurrences in Australia and amply justify the ranking of this field among the largest iron provinces of the world.

The hematite ores, with an average grade of 62 per cent total iron, are confined to the Brockman and Roy Hill Iron Formations of the Hamersley Series. These ores have developed in situ as a result of protracted weathering and selective leaching of silica and other impurities from the jaspilite of these formations. About fifty individual ore bodies have been recognized and the inferred reserves are of the order of 600 million tons. It appears certain that this figure will be greatly increased after further exploration.

The limonitic ores have an average grade within the limits of 53 to 59 per cent total iron and occur along the ancient drainage systems radiating from the jaspilite formations of the Hamersley Range. These ores represent the end-product of a protracted and complex cycle of upgrading of ferruginous fluviatile sediments. Inferred reserves of limonitic ore are approximately 5,000 million tons.

A great deal of work remains to be done before an accurate estimate of the total iron reserves of the Pilbara field can be gained. As the hematite ore is of direct shipping grade it is felt that the completion of the survey of the distribution of this type of ore is a task of prime importance. The known hematite ore bodies are much less favourably sited in relation to the coast than the lower grade limonitic ores. The discovery of additional hematite zones closer to the western boundary of the Hamersley Range could redress this lack of geographical balance in ore distribution.

Such an enormous quantity of limonitic ore is available that further exploration would be pointless at the present time. As the average grade is only a few per cent below

shipping grade, it would appear that the devising of methods of economical beneficiation should be investigated. These ores could be mined very cheaply, and their freedom from deleterious impurities would seem to make them ideal material for beneficiation.

INTRODUCTION

The Geological Survey of Western Australia commenced a regional investigation of the newly discovered iron ore deposits of the Pilbara region in May, 1962. The field team comprised the writer and Geologists L. de la Hunty and R. Halligan. The following report embodies the results of the initial stage of the survey.

The primary task has been the resolution of the principal stratigraphic units of the region, and the establishment of the relationship of the iron deposits to the stratigraphic column. All the major deposits have been visited, many have been sampled, and an overall appreciation of the grade and type of ore and of the resources of the region has been gained.

The second stage of the investigation which is now in progress includes detailed mapping on a scale of one mile to the inch of the main ore-bearing zones, combined with closer sampling and study of the individual deposits. During the present field season it is anticipated that mapping of the Mt. Bruce 4-mile sheet will be completed as well as relevant sections of the Wyloo and Yarraloola 4-mile sheets in the western portion of the iron province. Selected areas will be mapped on larger scale.

The Geological Survey is closely co-operating with the mining and exploration companies in the region. The regional survey is a logical and essential supplement to the company activities which henceforth will be largely directed to assessment of ore bodies and establishment of grade and reserves by drilling and large scale mapping.

STRATIGRAPHY AND STRUCTURE

The iron ore deposits under review constitute an integral mineral province within Precambrian rocks of the Nullagine System of the Hamersley and Ophthalmia Ranges. The province extends from Latitude 20° to 23° 30' S. and Longitude 116° to 120° E. covering an area of nearly 30,000 sq. miles. There has been no systematic geological mapping of the area prior to the present investigation.

Two distinct series, separated by an unconformity, have been recognised in this region. The older series consists of moderately folded quartzites, dolomites, shales, greywacke and chert breccia and is intruded by acid porphyry. This series is best exposed in the western area in the valley of Duck Creek and is provisionally termed the Duck Creek Series.

The younger series, with which the iron deposits are associated, extends in an east-west direction from Roy Hill to Deepdale on the Robe River, a distance of nearly 250 miles; and in a north-south direction from 21st Parallel to the Hardey River, a distance of 140 miles. The maximum observed thickness is approximately 7,000 feet.

Basal grits and conglomerates are overlain by a succession of widespread basalt flows whose total thickness exceeds 1,000 feet. There are thin sedimentary intercalations within the basaltic succession and these increase in thickness and proportion on passing higher in the sequence. The volcanic episode has been followed by a thick sequence of chemically deposited sediments represented by chert, jaspilite and dolomite These total over 3,000 feet in thickness. The succession terminates with acid volcanics which approach 1,500 feet in thickness, and a final group composed of interbedded shale and jaspilite.

For this succession it is proposed to introduce the term Hamersley Series. The provisional subdivision of the series is as follows:

			Thickness (Max. observed) Ft.
	Top	Boolgeeda Iron Formation	700
		Acid Volcanics	1,400
		Yerra Bluff Quartzite	300
		Brockman Iron Formation	1,500
		McRae Siltstone	340
		Sylvia Iron Formation	300
HAMERSLEY		Wittenoom Dolomite	450
SERIES		Roy Hill Iron Formation	300
		Shale and Quartzite with interbedded basalts	500
		Jeerinah Shale	300
		Basalt (with interbedded sediments)	1,000
		Basal Grits and Conglomerate	50
		Total (Max.)	7,140

The nomenclature and subdivision within this column are subject to modification pending more detailed mapping. However, it has been firmly established that the hematite ore bodies are confined to the Brockman and Roy Hill Iron Formations, mainly to the former. The mesaform limonite deposits, which represent an unusual, and perhaps unique, type of sedimentary iron ore, have accumulated in long established drainage systems which rise within and traverse these two formations.

The Brockman Iron Formation is composed almost entirely of chert and jaspilite. It is thinly bedded throughout with individual units rarely exceeding 2 inches in thickness. It is a typical banded iron formation very similar to those so abundantly represented in the Archaean areas of Western Australia. There are localized zones of violent contortion which may be due to slumping prior to complete consolidation. The overall iron content of the formation is estimated to be between 25 and 30 per cent. Within the Hamersley Range the Brockman Iron Formation outcrops over an area of nearly 6,000 sq. miles and dominates the topography due to a high resistance to erosion.

It is known to extend further to the south-east into the Ophthalmia Range. All the highest summits in the region such as Mounts Bruce (4,024 ft.), Brockman (3,654 ft.), Vigors (3,756 ft.), Turner (3,272 ft.) and many others exceeding 3,000 ft. in elevation are capped by the Brockman Iron Formation.

The Roy Hill Iron Formation is similarly composed of interbedded jaspilite and chert. The non-ferruginous chert bands are usually thicker than those of the Brockman Iron Formation and have a characteristic pinch and swell structure suggestive of differential compaction during consolidation. This unit has a lateral extent of at least 250 miles, and as it usually weathers to give a prominent scarp, it provides an excellent marker for both field and photogeological mapping.

The remarkable persistence of these two major lithological units over such a wide area is matched by a similar persistence of other units within the Hamersley succession. The consistency of thickness, the absence of facies change and the bold topographic definition of the highly resistant iron formations greatly facilitates geological mapping, and has permitted the ready delimitation of potential areas in which further iron ore bodies may be located.

In the northern and central sections of the Hamersley Basin the sediments are generally flat lying with a gentle regional dip to the south of less than 2 degrees. Local reversals of the regional dip are common and there are restricted zones of strong flexuring which have had an important influence in the development of the hematite bodies. In the southern section of the range, south of a line between Mt. Bruce and Hamersley Station, the rocks are more strongly folded into well-defined domes and synforms. The fold axes mainly trend E-W but there are numerous localized zones of cross-folding. The Brockman syncline is a major structural unit of the region and is of profound economic significance. The largest hematite bodies are located within the Brockman Iron Formation on the eroded upturned limbs of this fold. In addition the syncline has controlled the Duck Creek drainage pattern probably throughout the whole of Tertiary and Quaternary times. Within this drainage system the important Duck Creek and Boolgeeda limonitic iron ores have accumulated.

The southern and south-western sections of the Hamersley Range have been complexly faulted. Most of the faults dip steeply and trend between N. and NW. East-west trending strike faults have also been recorded in the limbs of the Brockman syncline.

The western boundary of the Hamersley Series is sharply defined by a major fault zone extending from a point north of the Robe River for a distance of 150 miles southwestwards to the Hardey River. This major tectonic feature is designated as the Hamersley Boundary Fault. The Hamersley Series has been downthrown along the fault against the older Duck Creek Series.

THE IRON ORE DEPOSITS

There are two major types of iron ore occurrence within the region. The high grade hematite ores have developed in situ within the jaspilites of the Brockman and Roy Hill Iron Formations and range in size from small bodies of only a few hundreds of thousands of tons to impressively large deposits exceeding 100 million tons. The inferred tonnage of this type of ore totals about 600 million tons. The lower grade limonitic ores, which represent an unusual, and perhaps unique, type of sedimentary ore, occur along the long established drainage channels which arise within and traverse the iron formations. The inferred tonnage of this type of ore is approximately 5,000 million tons.

The Hematite Ores

Origin.

The hematite ore bodies have originated within the iron formations as a result of selective leaching of silica and other impurities from the jaspilite. The original magnetite of the jaspilite has recrystallized to hematite (martite) and additional iron has been introduced into the leached zones in the form of goethite.

The leaching is presumed to have been accomplished by meteoric waters over a protracted period of time, and the ore bodies have been developed only in zones where structural controls have favoured a freer access and migration of water. Favoured zones are within the gently dipping limbs and along the troughs of synclinal flexures, and also in strongly faulted zones where the rocks have been fractured and large blocks disorientated and uptilted. The ore bodies are always vertically close to the widespread remnants of the Tertiary surface and have not been seen to extend to depths greater than 120 feet beneath this surface.

The ores have a similar origin and mode of occurrence to those of the Lake Superior region, but have undergone less metamorphism and are of better average grade.

Composition.

The hematite ores range in grade between 58 and 66 per cent total iron. Considerable textural variations are to be observed within any one ore body. Bands of massive hematite up to several feet in width with little indication of bedding are intercalated with strongly banded and platy, porous material with which there is a considerable admixture of goethitic cement. The porous ore, locally termed 'biscuit ore', forms the greater part of most ore bodies and averages about 61 per cent total iron. The more massive ore ranges between 64 and 67 per cent total iron. There are abrupt variations both vertically and along the strike in the grade and type of ore but the overall iron content has been shown to be above 60 per cent in all ore bodies which have been sampled and drilled, even inclusive of low-grade, intercalated chert bands.

The parent jaspilite contains about 50 per cent silica. In the ore bodies leaching has proceeded to such a degree to reduce the silica content to less than 4 per cent. The alumina content of the ore averages about 1.5 per cent, sulphur ranges between 0.03 and 0.06 per cent, titanium is less than 0.1 per cent and combined water less than 1 per cent. The phosphorus content averages about 0.12 per cent with an extreme range of 0.07 to 0.17. This is a rather higher figure than the hematite of the Middleback Ranges and Yampi but still within reasonable limits. In all, the hematite of the Hamersley Range compares very favourably with other major deposits of hematite in the world.

Distribution and Reserves.

The initial reconnaissance survey of the Rio Tinto geologists located several groups of ore bodies in widely scattered areas of the Hamersley Range. About forty hematite localities were recognized. A further six ore bodies have since been discovered by the Geological Survey. Other hematite occurrences are known in the Ophthalmia Range near the extreme southeastern corner of the iron province.

The distribution of the ore bodies is outlined in the following table:

Group	No. of Ore Bodies	Total Inferred Tonnage (Million tons)
Hamersley Station	12	60
Mt. Brockman	10	250
Fortesque R. (S. Branch)	3	40
Mt. Pyrton	7	30
Mt. Lockyer	5	30
Palm Spring - Mt. Brockman Hstd	5	30
Duck Creek	3	50
Mt. Newman (Ophthalmia Ra.)	3	120
Total	48	610

At the present stage of the investigation the above figures for inferred tonnage must be regarded as very approximate. Conzinc Rio Tinto Australia Pty. Ltd. have made a fairly close assessment of the reserves available in some of the ore bodies near Hamersley Station (vide Report by Campana and Hughes and the company is at present engaged in drilling two large bodies near Mt. Brockman. Due to the excellent exposures of the ore both on gentle hill slopes and in steep natural cliff sections estimates of inferred tonnage are fairly reliable. The company is now embarking on an intensive programme of assessment of the individual ore bodies and more accurate figures for reserves should be available later in the year.

The hematite zones have no expression on existing air photographs, but the consistent structural controls of flexuring and faulting are more apparent, and potential zones of ore occurrence can be delimited by careful photo examination. Many hundreds of square miles of rugged country remain to be examined, and much painstaking ground traversing is necessary before the full picture of the extent and distribution of the high-grade hematite ores is complete.

Several likely areas of exposure of the Brockman Iron Formation in which further hematite bodies may be found have been recognized in the present investigation. These are as follows:

(a) The western extensions of both limbs of the Brockman syncline, particularly where the limbs are cut by N- and NW-trending faults.

(b) The strongly folded zone of E-W trend near Mt. Farquhar.

(c) The limbs of the shallow synclinal troughs south of Mt. Silvergrass.

(d) Along the strong N-S flexure zone about 10 miles east of Mt. Bruce.

(e) The faulted and folded zone between Duck Creek Homestead and Mt. Wall.

(f) The limbs of the Mt. Turner syncline.

These areas will be examined by the Geological Survey during the remainder of the present field season.

Mining Conditions.

The ore bodies are exposed on the surfaces of ridges and spurs well above the water table and often surrounded partially or wholly by steep cliff faces. They present almost ideal conditions for open cast or quarrying operations. The occasional unleached chert bands which are found within all the ore bodies may necessitate selective mining in some localities but as these are usually well-defined and persistent, no serious problems should arise.

The Limonitic Iron Ores

Origin

The limonitic iron ores are most extensively developed in the drainage systems of the Robe River and Duck Creek and appear to be the end-product of a protracted and complicated cycle of mechanical and chemical deposition. The most significant developments of this type of ore are confined to drainages which directly impinge on the Brockman or Roy Hill Iron Formations. This fact would seem to imply that these jaspilites have been the ultimate source of the parent detrital material from which the limonite ore has developed. The great uniformity in composition of the source rocks serves in some measure to account for the uniformity of the ore over such a wide area.

It would appear that the ore has been produced by upgrading of these ferruginous fluviatile sediments by processes akin to those of lateritization. It is not yet known to what extent, if any, the basement rocks have influenced the ore formation although it is perhaps of some significance that the highest grades of pisolitic limonite so far located are those in the Robe River where the iron deposits directly overlie basalt, and poorer grades of ore have been noted in Duck Creek and further west in the Robe River where the iron overlies fluviatile sediments and dolomite.

The limonitic ores usually are distinctly stratified with the highest grades of ore in the upper red pisolite layer and poorer material in the lower more massive layer. On passing upwards in any one deposit the lowermost portions are seen to be porous and earthy with considerable admixture of yellow ocherous clay. This low-grade zone is transitional upward to a thick zone of more massive pisolitic limonite of higher grade which on weathering develops columnar jointing. The grade of this lower ore zone generally ranges between 40 and 54 per cent total iron. The massive ore is usually sharply demarcated from the upper red pisolitic layer in which the highest ore grades are found with a range of 54 to 59 per cent iron. There are great differences in the relative thicknesses of the layers in different parts of the field and even within mesas within the one drainage system. In assessment of reserves this stratified feature of the ore is of vital importance.

It is considered that the upper high-grade layer is of later origin than the lower massive ore and is due to mechanical re-sorting and concentration of pisolitic detritus produced by weathering of the lower massive layer. A hiatus in the process of ore development is indicated by the sharp boundary surface between the layers and the correspondingly rapid change in grade of ore. Furthermore in the Robe River mesas this sharp boundary surface between the ore layers is seen to have a consistent inward slope towards the centre line of the old drainage channel suggesting that the upper pisolite layer is a later infilling of a shallow trough incised in the lower iron layer.

In summation the origin of the limonite ores is suggested and believed to have been controlled by the following processes:

1. Erosion of Hamersley iron formations and deposition of thick accumulations of ferruginous detritus in the drainage systems.

2. Lateritization of ferruginous sediments to produce the lower earthy porous layers and the thick capping of massive limonitic ore.

3. Weathering of massive limonite to produce pisolitic scree and resorting and concentration of this material on the surface of massive limonite to provide the high-grade upper layer.

4. Uplift above water table and erosion of stratified ferruginous layers to produce mesaform iron deposits.

Composition of the Limonitic Ores

A great volume of chemical data on the limonitic ores is now available. Practically all the significant deposits held under Temporary Reserves have been sampled by the companies concerned and some have been drilled. A feature which has emerged is the remarkable consistency in composition of the upper high-grade pisolitic ore over the entire province. This contains between 55 and 59 per cent iron, the silica content is between 4 and 8 per cent, alumina between 2 and 4 per cent and ignition loss due to combined water between 9 and 12 per cent. Sulphur, phosphorus and manganese are usually below 0.10 per cent. Titanium, nickel, chromium and vanadium are present only in trace amounts.

A comprehensive sampling programme of fourteen of the mesas in the middle section of the Robe River has been recently completed by Basic Materials Co. Pty. Ltd. The results clearly illustrate the general tenor of the ore and are summarized in the following table:

Average thickness of pisolitic ore	44 feet.
Total estimated reserves	230 million tons.
Average total Fe in high grade ore	57.0 per cent.
Range of Fe content	53.8 to 59.5 per cent.

Average	SiO_2	- 5.0	(Range 4.2-6.0)
"	Al_2O_3	- 3.0	(" 2.2-4.1)
"	S	-0.07	(" 0.05-0.11)
"	P	-0.06	(" 0.05-0.08)
"	Ign.Loss	-10.0	(" 9.5 -11.0)

Number of face samples - 85.

In contrast, the lower layers in the same group of mesas were found to range in iron content between 31 and 53 per cent.

The consistency in composition of the upper pisolite layer would be a highly favourable factor if it were ever planned to beneficiate these ores.

Distribution and Reserves of Limonitic Ores

The limonitic ores are widely distributed in the province and appear on all drainage systems radiating from the jaspilites of the Hamersley Ranges. Similar ores also occur north of the Hamersley Range at Pincunah and Abydos on drainage systems from Archaean jaspilites.

The most important localities within the Hamersley Range are as follows:

1. The Robe River.

The limonite deposits here reach their maximum development within the province and extend along the river for a distance of 80 miles. The largest mesaform deposits are in the western section between Deepdale Homestead and Warramboo on the North-West Coastal Highway. These are covered by Broken Hill Pty. Co. Ltd.

The limonites in the middle and upper sections of the Robe River are held by Basic Materials Co. Pty. Ltd. The river mesas here are smaller but, from results so far available, the grade of ore appears to be slightly higher than that further downstream.

Within the Hamersley Range there are thick and extensive gorge deposits of limonitic ore in the upper reaches of the river. These have not yet been investigated in detail but preliminary examination indicates thicknesses of up to 120 feet of ore of comparable quality to that in the river mesas. One of the gorge deposits is known to extend almost continuously for about 12 miles and in places is over 100 feet thick.

2. Duck Creek.

The limonite deposits in the Duck Creek valley have been investigated by both B.H.P. and Rio Tinto. Here the upper pisolite layer is generally thinner than in the Robe River area and the ore of slightly lower grade. Although the mesas are numerous many of them have undergone deep dissection and in consequence the reserves of high-grade ore are less.

3. Boolgeeda Creek.

These deposits are situated within the Brockman syncline on either flank of the broad valley. Although continuously developed for many miles the upper, high-grade ore layers are thin or often absent.

4. Turner River.

These deposits extend almost continuously for 15 miles in the valley of the Turner River and are held under Temporary Reserve by Conzinc Rio Tinto. The upper pisolite layer is generally thinner than that of the deposits of the Robe River but the grade of ore is comparable. Assays by the company indicate a range in iron content of between 54 and 57 per cent and average silica and alumina contents of 8.15 and 2.18 per cent respectively. Manganese, sulphur, phosphorous and titanium are all less than 0.05 per cent.

5. South Branch of Fortesque River.

These deposits are situated near the northern edge of the Hamersley Range west of Wittenoom. They have not yet been examined in detail but it is known that the thickness of high-grade ore approaches 70 feet with an iron content of between 52 and 59 per cent.

6. Dales Gorge.

Limonite deposits up to 50 feet thick are exposed in the steep walls of Dales Gorge, about 30 miles SE of Wittenoom township. These appear to have accumulated within a local internal drainage basin at the confluence of the streams. In this area the Miocene profile is preserved over a wide area and it seems likely further extensive deposits may occur nearby in other broad and level valleys. The ore is of similar iron content to other localities but has a rather high sulphur content of 0.19 per cent.

As most of the limonite deposits occur as mesas cappings with three dimensions of the ore in sight, computations of indicated tonnage can be made once adequate numbers of face samples have been taken. Drilling results appear to agree closely with face sample assays.

Reserves quoted in the following table are partly derived from company surveys and partly from our own observation They must be regarded as approximate pending more detailed measurements of the individual ore bodies.

Inferred Limonite Reserves

Area	Company holding T.R's.	Inferred Reserves (Million tons)
Lower Robe River	B.H.P.	2,800
Middle Robe River	Basic Materials	230
Upper Robe River	Basic Materials	500
Duck Creek	Conzinc Rio Tinto	520
	B.H.P.	75
Boolgeeda Creek	Conzinc Rio Tinto	110
Turner River	Conzinc Rio Tinto	240
Fortesque River	Conzinc Rio Tinto	270
Dales Gorge	Conzinc Rio Tinto	100
All other localities		100
	Total	4,945

The above table indicates the great preponderance of ore in the Robe River drainage system. The above estimate is conservatively based on an average ore thickness of 40 feet. Drilling by B.H.P. has indicated thicknesses in excess of 100 feet in some of the mesas. One of the large ore bodies near Deepdale Homestead has an indicated tonnage of 400 million tons with ore between 70 and 110 feet thick and averaging 56 per cent total iron. The estimate of ore in the Upper Robe River is similarly conservative and could be double the figure quoted.