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FLINDERS MINES LIMITED

Pilbara Iron Ore Project

Geotechnical Desk Study

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PILBARA IRON ORE PROJECT
GEOTECHNICAL DESK STUDY

SYNOPSIS

This report presents the results of a desktop study into the physiography and engineering geology at the site of proposed infrastructure for the Pilbara Iron Ore Project. The site geology comprises alluvium, colluvium, variably cemented pisolitic laterite and Channel Iron Deposits overlying Archaean units of the Hamersley Group. Site reconnaissance and subsurface investigation will be required to assess whether any of the potential geohazards listed are present at the site. Potential geohazards that could influence project development include asbestiform materials, seismicity, karst and scour.

To assist civil and structural designers, preliminary engineering parameters of key geological units are provided together with comments regarding construction material sources, excavatability and preliminary cut slope angles.

PROJECT 201000-00501 - PILBARA IRON ORE PROJECT

REV	DESCRIPTION	ORIG	REVIEW	WORLEY-PARSONS APPROVAL	DATE	CLIENT APPROVAL	DATE
A	Issued for internal review	J Petersen	P Baker	N/A	26-Aug-10	N/A	
0	Issued for Use	PP J Petersen	P Baker	P Hairsine	01-Sep-10	M. Watson	13/12/10

CONTENTS

1. INTRODUCTION

This document presents the results of a geotechnical desk study carried out as part of the prefeasibility study for the Pilbara Iron Ore Project. The project is still in the stages of defining locations for key ore handling and processing structures, and haul road and rail infrastructure.

1.1 Proposed Development

The development is understood to comprise:

- ROM pad;
- Ore Processing Facilities (OPF), including a primary and secondary crusher, and a screen house;
- Stockyard including ore stockpiles and stacker;
- Haul road, approximately 15 km in length;
- Train loader; and
- Rail spur, approximately 13 km in length, to link with the Rio Tinto Paraburdoo to Dampier railway.

1.2 Available Information

The following geological/geotechnical information is currently held by the project:

- 1:250,000 Geological maps and associated explanatory notes, published by the Geological Survey of Western Australia;
- 1:25,000 regolith map by Mr. R. Russell contracted to Flinders Mines;
- Satellite imagery and aerial photographs.

2. SITE CONDITIONS

2.1 Physiography

The project area is located within the Hamersley Range which is typified by resistant ridges dissected by ephemeral water courses. In the project area these ridges are defined by near vertical scarps, ranging in elevation from 660m Australian Height Datum (AHD) to 860m AHD, which give way to talus slopes, alluvial fans and eventually the valley floor that ranges in elevation from 550m AHD at the western end of the project area to approximately 450m AHD to the east.

Drainage comprises east and north draining upper catchment watercourses of Weelumurra Creek, a tributary of the Lower Fortescue River Basin.

2.2 Vegetation

Vegetation comprises assemblages typical of the Hamersley Range comprising mulga and spinifex within gently sloping valleys, and snappy gum and spinifex on elevated areas of shallow rock. Areas of sheetwash will likely to be vegetated with stands of mulga aligned perpendicular to the slope of the plain, and grasses. Active drainage channels will be lined with white eucalypts (e. camaldulensis).

2.3 Regional Geology

The geology of the project area comprises Archaean-aged sedimentary rocks of the Hamersley Basin, located on the southern margin of the Pilbara Craton. The Hamersley Basin is the result of rifting of the Pilbara Craton, and marine sediment deposition as the rift developed into a stable shelf and finally a passive continental margin. This resulted in the initial deposition of volcanic rocks (Fortescue Group) followed by the deposition of siltstones, sandstones, and carbonate rocks (Hamersley Group) and finally fine grained sedimentary units (Turee Creek Group).

These units were subsequently faulted and folded during the collision of the Pilbara and the Yilgarn Cratons known as the Capricorn Orogeny, which produced the broad, open Ophthalmia Fold Belt. As the Pilbara and Yilgarn Cratons eventually drifted apart subsequent basins were formed and sedimentary units deposited south of the Hamersley Basin.

During the Cainozoic the Hamersley Basin was less structurally active and was subjected to:

- Weathering under warm humid conditions producing laterites;

- Erosion of the weathered and laterised surface resulting in the deposition of consolidated and cemented colluvium as valley fill deposits (Czc); and
- Further erosion and deposition of the above materials by the present drainage system, resulting in the deposition of extensive alluvial fan and sheetwash deposits, and active drainage channel deposits (Qa).

2.4 Site Geology

Site geology has been based the 1:250,000 scale GSWA Mount Bruce geological map. Geological Units that occur in the project area comprise the following (in order from youngest to oldest):

Cainozoic Units

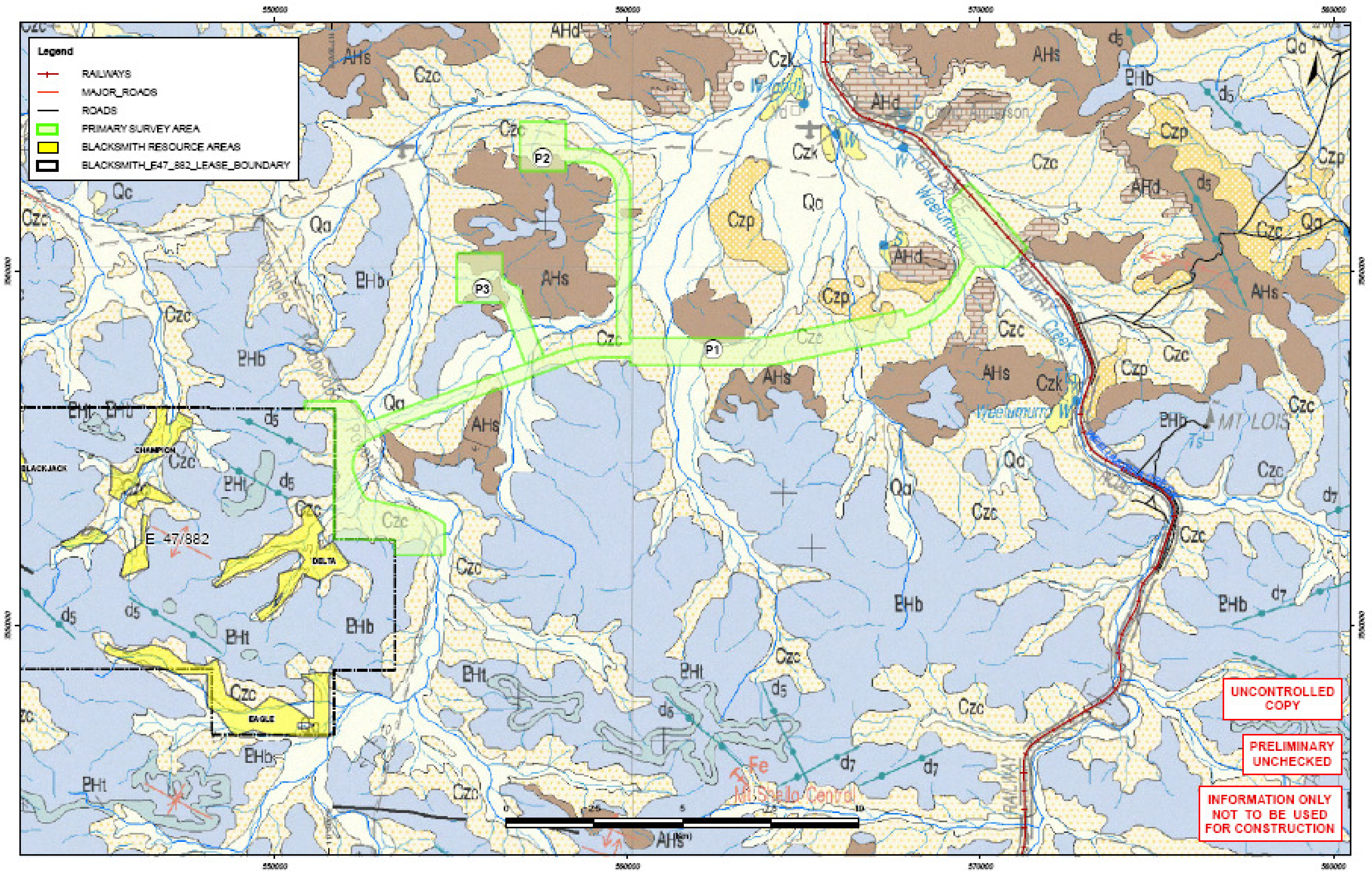
- ***Alluvium (Qa)*** – Interlayered, normally consolidated, medium dense to dense sandy gravels and gravelly sands, and very stiff to hard, silty and sandy clays;
- ***Colluvium (Czc)*** – Clayey and sandy gravels and gravelly sand / clays, normally consolidated forms scree and talus slopes, includes older variably cemented units that occur as raised terraces within valley floors or on the edges of valleys (mapped by Russell as Oakover Formation Equivalent);
- ***Robe River Pisolite (Czp)*** – Variably iron cemented pisolitic laterite, low to medium strength, may contain uncemented lenses or layers, forms elevated mesas approximately 15m to 45m in height.
- ***Channel Iron Deposits (CID) including Detrital Iron Deposits (DID)*** – Iron cemented pisolitic gravels, not mapped at 1:250,000 scale but outcrops on the margins of valleys and at the head of valleys, medium to very high strength, may encounter pockets of medium dense gravel.

Hamersley Group (based on GSWA Mount Bruce geological map)

- ***Brockman Iron Formation (PHb) –*** BIF, chert and pelite. Generally highly weathered, high to very high strength. Forms the distinct ridges of the Hamersley Ranges.
- ***Mount McRae Shale (AHs) –*** Pelite, chert and BIF. Highly weathered medium to very high strength.
- ***Wittenoom Formation (AHd) –*** Dolomite, pelite, chert and volcaniclastic sandstone, expected to be encountered near the Rio Tinto Tom Price Railway.

Figure 2.1 illustrates the occurrence of these geological units in relation to the pre-feasibility structure plan.

Figure 2.1: Project Footprint (Primary Survey Area) with Regional Geology



3. ENGINEERING GEOLOGY

3.1 Geohazards

Significant geohazards and construction issues expected to influence the development are discussed in the following section. Attention is drawn to the fact that these issues may influence the economics and performance of certain infrastructure. It should be noted that conclusions drawn here are based on published geological information and desktop assessment. Site reconnaissance and subsurface investigation will be required to confirm or reject the presence and extent of geohazards.

3.1.1 Asbestiform or Fibrous Materials

Based on the Department of Industry and Resources Asbestiform risk map (Brice, 1992) the Brockman Formation (Phb) is associated with a high probability of encountering asbestos minerals. As the Cainizoic Units (Qa, Czc) are derived from the Brockman Formation there is also a risk of encountering asbestos material within these units.

Construction in areas known to contain asbestiform minerals will require the application of an Asbestos Management Plan. This management plan should have procedures in place to aid in assessing, managing and controlling the risks associated with asbestiform material. By using the appropriate management and control mechanisms, the risk of contamination can be managed effectively.

3.1.2 Seismicity

Based on Australian Standard AS 1170.4 – 2007 the design seismic hazard factor for a 1 in 500 year earthquake event in the project area is 0.12. The Subsoil class of Ce may be assumed at this stage of the project. However, this should be reviewed once site data comes available.

3.1.3 Karst

Karst landforms are generally not well developed within the Pilbara. However, there has been incidence of karst associated with large calcrete (Czk) deposits overlying the Wittenoom Formation (AHd) on other projects within the Hamersley Range. This assemblage is noted to occur near the eastern end of the proposed rail alignment. Furthermore, the rail will be required to cross the Weelumurra Creek at this location. Hence, it is considered that encountering dissolution features may have a significant impact on rail embankment stability. Identifying the presence of karst by using both geophysical techniques confirmed with either test pitting or boreholes is recommended in this area.

3.1.4 Scour

The semi arid environment and cyclonic rainfall events of the region provides the potential for large scale flash flooding in drainage channels and adjacent low lying areas. Hence, infrastructure or facilities located within, crossing or close to active drainage and flood prone areas will be required to be founded below scour levels or comprise adequate scour protection. This is particularily important for the Weelumurra Creek crossing

3.2 Engineering Geological Model

Table 3.1 provides details of the geological units expected at the site together with an assessment of possible strength characteristics and design/construction considerations.

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Table 3.1: Summary of Engineering Geological Units

Age	Unit	Typical Thickness	Lithology	Distribution and Morphology	Consistency / Density / Strength	Geohazards / Design and Construction Considerations
Holocene	**Alluvium (Qa)**	0.5 to 5m	Interlayered, normally consolidated, sandy gravels and gravelly sands, silty and sandy clays, often covered with a veneer of loose sand.	Alluvial fan, channel and sheet flow deposits located on margins of and on the floor of valleys	Loose surficial soils underlain by medium dense to dense / very stiff to hard soils.	Scour within active drainage channels, good source of general and select construction material.
	Calcrete (Czk)	<5m	Nodules, layers and lenses of carbonate, in a clay matrix.	Occurs in the east of the project area outcropping in two isolated areas underlain by the carbonate rock of the Wittenoom Formation.	Medium dense to dense nodular gavels and very stiff to hard clays.	Potential karst comprising voids or lower density zones
Late Tertiary to Pleistocene	**Robe River Pisolite (Czp)**	15m to 40m (1)	Variably cemented iron pisolitic gravel.	Forms isolated, elevated mesas located at the eastern end of the proposed rail / haul road corridor near the Rio Tinto rail alignment.	Laterally and vertically variably cemented, ranging from uncemented dense gravels to moderately cemented exhibiting medium strength rock properties.	Potential for inverted density profile (decrease in density with depth).
	Colluvium (Czc)	0 to 10m	Clays, sands and gravels variably cemented.	Commonly occurs on the perimeter of valleys and gullies, and isolated outcrops on the valley floor. Underlies the Holocene sediments.	Medium dense to dense / very stiff to hard, laterally and vertically variable cementing ranging from uncemented to moderately cemented.	Younger colluvium materials potential source of general and select fill material.
	Channel Iron Deposits (CID/ DID)	0 to +40m	Iron cemented / enriched pisolite gravels.	Sporadically outcrops around the perimeter of valleys, and underlies the alluvium / colluvium (Qa) and Older Colluvium (Czc) within the valley floors.	Medium to very high strength, may encounter pockets of medium dense gravel.	Variability of cementation will require confirmation, Suitable founding strata for footing systems, drilling of pile foundations is likely to be difficult and slow.
Archaean	**Brockman Formation (PHb)**	<300m (1)	Sedimentary - interlayered chert, iron beds, siltstone and shale, likely to have a 0.5 - 1m thick zones of goethite, haematite enriched weathered rock.	Outcrops on ridges and encountered at depth beneath the OPF.	High to very high strength.	Suitable founding strata for footing systems, drilling of pile foundations is likely to be difficult and slow.
	Mount Rae Shale (AHs)	<70m (1)	Sedimentary - interlayered shale, dolomitic shale and minor BIF.	Outcrops on lower slopes within the rail and haul road corridors, encountered at depth below the Brockman Formation (PHb).	Low to medium strength.	Suitable founding strata for footing systems.
	Wittenoom Formation (AHd)	<700m (1)	Sedimentary - argilite and dolomitic argilite with minor chert, carbonate, volcaniclastic sandstone and BIF.	Outcrops on low lying hills near Weelumurra Creek and encountered at depth across the whole site, considered basement for the project area.	Very low to medium strength.	Potential karst comprising voids or low density zones

Notes: (1) Unit thickness from Thorne and Tyler (1993)

4. GEOTECHNICAL CONSIDERATIONS

Preliminary geotechnical assessment is provided herein with the current understanding of the subsurface conditions based on published geological information for the project region. It is emphasised that the advice provided is at a pre-Bankable Feasibility Study level and will require confirmation through site reconnaissance and geotechnical investigation.

4.1 Geotechnical Parameters for Design and Analysis

In the absence of geotechnical data and subsurface profile information within the project area, preliminary geotechnical parameters are provided in Table 4.1. These parameters are based on the expected ground conditions and experience with similar conditions elsewhere in the Pilbara. It should be noted that the following parameters should be considered preliminary only.

Table 4.1: Design Soil Profile and Preliminary Geotechnical Parameters

Unit	**Thickness**	**Geotechnical Parameters**						
	Range	**ν**	**Φ' (°)**	**c' (kPa)**	**γ' (kN/m^3)**	**E (MPa)**	**UCS (MPa)**	**RQD**
Alluvium (Qa)	<5m	0.35	32 to 36	0 - 2	20	50 - 100	na	na
Colluvium (Czc)	<10m	0.3	34 to 38		20	50 - 200	na	na
Channel Iron Deposits (CID / DID)	<40m	0.3	38	5	22	100 - 500	5 - 10	30 - 50
Brockman Formation (PHb)	<300m	Na	Na	Na	24	20,000 – 50,000	5 – 50	30 - 50

4.2 Foundations

Foundation considerations relating to processing facility infrastructure include the potential for large bearing pressures, dynamic loading and often strict tolerances on both total and differential settlements. Ideally, these factors can be accommodated by founding structures directly on bedrock, however, this is not always viable and cost effective. Based on preliminary information the depth of soil across the plant site is expected to vary from shallow bedrock, located on the upper slopes, to over 10m, within the valley floor. Additionally rock, when it is encountered is likely to comprise either Channel Iron Deposits (CID) or BIF of the Brockman Formation (PHb). These units are likely to provide suitable end bearing for larger loads, however, extending pile sockets into these units is likely to be difficult. Hence, footings required to overcome large uplift or tension forces are likely to require anchors socketed into rock to provide capacity in tension.

Holocene soils such as Alluvium (Qa), and normally consolidated soils of the Colluvium (Czc) unit are likely to be suitable founding units for lightly loaded structures.

4.3 Construction Materials

Construction of the ore processing facility, haul road and rail embankment will require several construction materials including:

- General and select fill for bulk and detailed earthworks;
- Sub-basecourse and basecourse pavement materials;
- General fill and sub-ballast capping for the rail embankment;
- Concrete aggregates and sands;
- Rock fill and armour rock; and
- Low permeability material for water retention structures.

Based on the desk study information and experience on projects within the region, it is considered that the materials suitable for the above purposes may be won from within the project area. Table 4.2 presents likely sources of construction materials.

Table 4.2: Construction Material Suitability

Geological Unit	General	Select	Aggregate	Rock
Alluvium (Qa)	√	√	√(1)	X
Calcrete (Czk)	X	X	X	X
Robe River Pisolite (Czp)	√	√	X	√
Colluvium (Czc)	√	√	X	√
Channel Iron Deposits (CID/ DID)	-	-	-	√
Brockman Formation (PHb)	√	-	-	√
Mount Rae Shale (AHs)	√	X	X	√(2)
Wittenoom Formation (AHd)	√	X	X	√(2)

Notes (1) In particular bedload deposits within active drainage channels

(2) Defect spacing is likely to be to close to form large enough blocks for use as armour rock

It is noted that development of the site is likely to required only limited cut. Therefore the majority of the construction material is likely to be sourced from mine prestrip and designated borrow areas. Once required volumes for earthworks and available volumes from mine prestrip is known, potential sources of borrow may be identified.

4.4 Preliminary Cut Slope Angles

The following preliminary slope angles are considered to be appropriate for excavation up to 8 m vertical height within the geological units anticipated in the proposed development area:

- 26.6° (2H:1V) for Alluvium (Qa), Colluvium (Czc) and Calcrete (Czk) or extremely weathered rock / residual soils (5 m maximum vertical height without benching) ;
- 45° for cemented Colluvium (Czc), Robe Pisolite and weathered Mount Rae Shale (AHs) and Wittenoom (AHd) Formations (8 m maximum vertical height without benching); and
- 70° for Brockman Formation (8 m maximum vertical height without benching).

It should be noted that these angles are preliminary only and subject to update. Further geotechnical assessment will be required to confirm these values during subsequent phases of the project.

4.5 Excavatability

A summary of the excavation techniques that may be required for the geological units in the project area are presented in Table 4.3.

Table 4.3: Excavatability by Geological Unit.

Geological Unit	Excavator / Common	Rip	Rock Breaker	Drill and Blast
Alluvium (Qa) Calcrete (Czk)	X			
Colluvium (Czc)	X	X		
Channel Iron Deposits (CID / DID) Mount Rae Shale (AHs) Wittenoom Formation (AHd) Brockman Formation (AHb)			X	X`

Based on the proposed general arrangement (201000-00501-5000-CI-DSK-0001 Rev B) and the published geology (Figure 2.1), the ROM pad and processing facility are likely to be located on shallow BIF rock of the Brockman Formation. Hence, excavation within these areas is likely to be require hard ripping, for shallower excavations, or drill and blast for excavation extending deeper.

The stockyards, accommodation village and proposed haul road are all located on areas underlain by alluvium (Qa) and Colluvium (Czc) and excavation is expected to comprise common excavation with some ripping possibly required of cemented layers / lenses.

5. CONCLUSIONS

- Engineering geological units have been identified and preliminary geotechnical parameters provided. However, the distribution of engineering geological units and confirmation of parameters will be required by detailed geotechnical investigation and laboratory testing.

- Geohazards have been identified for the project area. These are not considered to pose a large risk to the project schedule or cost. However, this will need to be confirmed through geotechnical and geophysical fieldwork.

- Most construction materials for earthworks are expected to be able to be sourced locally. Due to the envisaged quantity of cut, soils will likely have to be won form borrow areas, and rock from either the mine or a specific quarry.

- Lightly loaded structures may be founded in the superficial alluvial and colluvial units, below any loose materials. Heavily or dynamically loaded structures or structures sensitive to settlement are likely to have to be founded on rock. With in the valley floors piling may be required to extend footings through the superficial soils. Extending pile sockets into rock is expected to be costly and difficult, hence anchors are likely to be required to provide capacity in tension.

6. REFERENCES

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