SNOWDEN

FINAL

Rio Tinto: Mesa A Geotechnical Assessment

Project No. **5978**

May 2007

Prepared by R Fry
BSc (Eng), MSc, CEng, MIMMM
Principal Consultant

Reviewed by P Walker
PhD, MSc(Eng), DIC, BSc (Hons), MAusIMM, MSAIMM
Principal Consultant

Office Locations

Perth
87 Colin Street
West Perth WA 6005

PO Box 77
West Perth WA 6872
AUSTRALIA

Tel: +61 8 9213 9213
Fax: +61 8 9322 2576
ABN 99 085 319 562
perth@snowdengroup.com

Brisbane
Level 15, 300 Adelaide Street
Brisbane QLD 4000

PO Box 2207
Brisbane QLD 4001
AUSTRALIA

Tel: +61 7 3231 3800
Fax: +61 7 3211 9815
ABN 99 085 319 562
brisbane@snowdengroup.com

Vancouver
Suite 550
1090 West Pender Street
Vancouver BC V6E 2N7
CANADA

Tel: +1 604 683 7645
Fax: +1 604 683 7929
Reg No. 557150
vancouver@snowdengroup.com

Johannesburg
Technology House
Greenacres Office Park
Cnr. Victory and Rustenburg Roads
Victory Park
Johannesburg 2195
SOUTH AFRICA

PO Box 2613
Parklands 2121
SOUTH AFRICA

Tel: + 27 11 782 2379
Fax: + 27 11 782 2396
Reg No. 1998/023556/07
johannesburg@snowdengroup.com

London
Abbey House
Wellington Way
Weybridge
Surrey KT13 0TT, UK

Tel: + 44 (0) 1932 268 701
Fax: + 44 (0) 1932 268 702
london@snowdengroup.com

Website
www.snowdengroup.com

Subsidiary of Dower EDI Ltd

This report has been prepared by Snowden Mining Industry Consultants ('Snowden') on behalf of Rio Tinto.

Issued by: **Brisbane** Office
Doc Ref: 070521_Final_5978_RTINTO_Mesa A Geotech_G.doc

Print Date: 31 May 2007

Number of copies
Snowden: 2
Rio Tinto: 2

Executive summary

A geotechnical assessment has been undertaken of Robe Iron's Mesa A deposit by Snowden Mining Industry Consultants (Snowden), on behalf of Rio Tinto Iron Ore - Expansion Projects (RTIO).

This report presents the findings of the assessment, and provides recommendations for managing the geotechnical related issues arising from the proposed mining plan.

The study has assessed:

- the stability of the proposed Mesa A mine slopes
- the stability of natural mesa façades at Mesa A and other Robe River sites
- the potential effects of mining on natural mesa façades.

The study included:

- site visits to Mesa A and Robe River mine sites to assess the conditions of natural and mined mesa slopes
- a detailed geotechnical assessment of the proposed Mesa A mine slopes, including undertaking stability analyses using industry standard methods.

The study has concluded that:

- the proposed mine slopes will have a high degree of stability, substantially above the general industry standard
- mining activities have no discernable impact on the natural erosion rates of remnant mesa façades
- the probability of a catastrophic failure of the remnant mesa façades is extremely low and such an event is not a credible outcome.

Options for managing geotechnical risk and guidelines for safe operational geotechnical practices have been provided.

Tables

Figures

1 Introduction

A geotechnical assessment has been undertaken of Robe Iron's Mesa A deposit by Snowden Mining Consultants (Snowden), on behalf of Rio Tinto Iron Ore - Expansion Projects (RTIO).

This report presents the findings of the assessment, and provides recommendations for managing the geotechnical related issues arising from the proposed mining plan.

2 Scope of works

The initial scope of work for the assessment comprised the following:

- assess the stability of the proposed open-pit mine slopes
- assess the stability of the mesa façade perimeter
- provide guidelines on safe geotechnical practices in the mining operation
- consider issues pertaining to mine closure, including the long-term stability of the mesa façade
- preparation of the project report.

The scope of work was subsequently expanded to include visiting Robe Iron's Robe River operations at Mesa A and Mesa J, to review current stability conditions of mined and natural slopes, and visiting the RTIO Perth office to inspect and review aerial photographs of the sites.

The additional scope of work required to be addressed by the site visit and associated research studies comprised:

- location of any information on geomorphology and natural erosion rates of the Robe River mesa landforms, any publicly available aerial photographs that can provide information on erosion, and local rainfall records
- reviewing the conditions of the Mesa A scarps and locating the scarp sections showing the highest rates of erosion, describing their geomorphology and assessing the mechanisms contributing to erosion
- assessing the conditions of recent and older pit slopes at Robe River operations, the effects of blasting on face and crest conditions, and rates of erosion of mined slopes

3 Previous Studies

3.1 Geology

The development of the Mesa A geological model are described in the Robe River Mining Co report Mesa A Geological Model Report 2005, which summarises all work on the deposit up to 2004.

Mesa A is formed of Tertiary age sediments deposited within a palaeo-channel deeply incised in the underlying basement Proterozoic and Mesozoic age rocks.

The sediments comprise haematite and goethite pisolites and clayey brecciated pisolite, interspersed with layers of quartz clays and gravel. The pisolites are hardcapped and overlain with a thin veneer of Quaternary age silts, sands and gravels.

The basement rocks comprise weathered conglomerates of the Mesozoic Nanutarra Formation and shales and siltstones of the Proterozoic Ashburton Formation.

The deposit has been divided into the following lithological units:

- Basal Tertiary pisolite (TPb)
- Detrital Tertiary pisolite (TPd)
- Tertiary clay and quartz (TE)
- Mixed Tertiary pisolite (TPm)
- Tertiary pisolite (TP)
- Hardcap Tertiary pisolite (HTP)
- Quaternary alluvium (Qa)

The ore grade material is contained mostly within the TP and HTP units, with some also contained within the TPd unit.

Wireframes of the geological units and the Vulcan pit design model were supplied by RTIO.

To date, no large scale structural features such as faults or intrusions have been identified within the Tertiary sediments. Dolerite has been intersected in drill holes within the underlying basement sequence.

3.2 Mine Plan

The mine design was provided to Snowden in the form of a Vulcan project file. Snowden understands this was last updated in March 2007. The design was imported to Datamine as a string file for viewing in conjunction with surface topography and geology wireframe models. A key aspect of the mine design is leaving intact a minimum 50 m wide perimeter zone at the margin of the mesa to provide a façade for environmental requirements. The mine plan shows that approximately one third of the remnant perimeter zone will be 50 m wide, while most of the rest will be at least 100 m width.

The mine plan envisages a shallow pit typically less than 20 m deep covering most of the mesa area, with a number of isolated pit sections within this up to 50 m deep below the original ground surface. The deeper sections of the mine have planned floor elevations varying from 45 mRL in the south-west to 51 mRL in the north-east.

Batters are planned with face angles of 75° and maximum heights of 9.0 m. Minimum berm widths will be 5.0 m with standard flitch heights of 3.0 m.

3.3 Geotechnical studies

Rio Tinto Technical Services undertook a review of the geotechnical knowledge and pit design criteria as part of the Warramboo and Mesa A Prefeasibility Study (PFS).

Subsequent to the PFS, geotechnical investigations were carried out as part of the Mesa A / Warramboo Feasibility Study by Pells Sullivan Meynink Pty Ltd (PSM) in two stages in 2005 and 2006. This work was reported in the following documents:

Mesa A Factual Geotechnical Report. June 2005.

Mesa A Factual Geotechnical Report II. December, 2006.

The geotechnical investigations have comprised:

- drilling and logging eleven fully cored boreholes (HQ diameter), and undertaking point load tests of core
- geotechnical mapping at seven locations around the mesa perimeter
- collecting core samples and undertaking laboratory strength testing programmes, including unconfined and triaxial compressive strength tests.

Snowden was provided with files containing the raw data obtained from these investigations.

Rio Tinto Expansion Projects are currently preparing the geotechnical section of the feasibility study report.

3.4 Hydro-geological studies

Hydro-geological investigations were undertaken as part of the feasibility study for the project, and groundwater levels measured in boreholes at the deposit have been provided to Snowden in the form of an untitled plan of the project.

3.5 Literature Search

A literature search was undertaken to locate information on erosion rates of mesa style landforms in arid/semiarid regions. This did not find any references to studies undertaken in the Pilbara or in similar geological conditions elsewhere.

Information on erosion rates of mesa style landforms in different geological conditions was obtained from the following papers:

Scarp retreat rates in semiarid environments from talus flatirons (Ebro Basin, NE Spain). Gutierrez, Sancho and Arauzo, 1998.

Argon chronology of the Leucite Hills, Wyoming: eruption rates, erosion rates, and an evolving temperature structure of the underlying mantle. Lange, Carmichael and Hall, 2000.

These studies show that natural retreat rates of mesa cliffs in approximately analogous geological and environmental conditions are very low.

4 Geotechnical Assessment

4.1 Geotechnical Description

This section provides a brief geotechnical description of the main geological units and summaries of the classification data obtained for them. The summary of geotechnical characteristics presented in Table 4.1 presents the combined data from the previous investigation reports (PSM 2005 & 2006). The RQD and Estimated Rock Strength values for each unit were calculated from the logged intervals as length weighted means.

Table 4.1 Geotechnical Characteristics

Unit		Description	Unit Weight (kN/m3)		RQD (%)	Estimated Strength (ISRM)	UCS (MPa)
			Mean	SD			
Basement		*Weathered shales, siltstones and conglomerates.*	25	-	80	R1	
Basal Pisolite	*TPb*	*Denatured and siliceous pisolite with high clay content.*	25.2	-	82	R2	6.3 (1)
Detrital Pisolite	*TPd*	*Enriched goethite/haematite pisolite (brecciated).*	29.5	-	49	R2	7.9 (2)
Clay	*TE*	*Quartzy clay lenses, jointed.*	25	-	0	R0	
Mixed Pisolite	*TPm*	*Partially denatured pisolite with clay bands.*	27.2	4	52	R1	11.3 (6)
Pisolite (Ore)	*TP*	*Goethite and haematite ooliths in goethite/haematite matrix.*	28.4	3	64	R2	10.3 (18)
Partial hardcap	*TPh*	*Semi-hardcapped or weathered pisolite.*	26.8	3	64	R3	11.1 (7)
Hardcap	*HTP*	*Hardcap goethite/haematite.*	26.8	4	56	R2	6.4 (10)

Note: Numbers in brackets () indicate number of UCS tests

PSM commented on the probable desiccation of some samples that were selected for strength tests. Snowden concurs that this may have had a significant effect on the strengths recorded for materials with substantial clay content (i.e., the TPm and TE units).

4.2 Geological Structure

Structural orientation data obtained by mapping mesa cliffs during the site investigations indicate that there are 4 sets of discontinuities present in the TP unit namely, one set of bedding planes and three sets of joints. The mean orientations and standard deviation of these sets are listed in Table 4.2.

Table 4.2 Geological Structure Sets

Structure Type	*Dip (°)*	*Dip Direction (°)*	*SD (°)*
Bedding Planes	00	000	7
Joint Set 1	90	178	10
Joint Set 2	86	037	8
Joint Set 3	85	320	9

Structural orientation data obtained from the core was limited to inclination (alpha) angles only. The distribution of these is summarised in Table 4.3. All geotechnical holes were drilled vertically hence this data is subject to bias against near-vertical structures.

Table 4.3 Inclination of structures in core

Dip	*Inclination (Alpha angle)*	*Proportion*
Steep	0 – 29	13.9%
Medium	30 – 59	21.1%
Flat	60 - 90	65%

The physical characteristics of the bedding planes and joints are summarised in Table 4.4.

Table 4.4 Characteristics of Structure Sets

Structure Type	*Persistence (m)*		*JRC (Micro - core)*		*JRC (Macro – 1m)*		*JCS (0.8*UCS) (MPa)*	
	Mean	*SD*	*Mean*	*SD*	*Mean*	*SD*	*Mean*	*SD*
Bedding Planes	3.9	3.17	15	6	15	6	8	3.7
Joint Set 1	3.0	2.20	17	5	10	3	8	3.7
Joint Set 2	3.0	2.20	17	5	10	3	8	3.7
Joint Set 3	3.0	2.20	17	5	10	3	8	3.7

The following comments on the geotechnical investigations have been prepared in order to assess the overall reliability of the geotechnical investigations and model development.

The geotechnical holes are well spaced around the deposit. However, those drilled in deeper SW sections of deposit do not reach depth of the proposed pit bottoms. Some data on the deeper pisolite strata was obtained from holes located on the NE margins of the deposit. However, only 9 UCS tests and 1 triaxial test have been conducted on the pisolitic and clay strata below the TP unit. Also, there has been no mapping of structure other than in the near-surface HTP and TP units. Hence the geotechnical and structural data for the TPm, TE and TPd strata are based largely on estimates and interpolation.

A small number of features with very low inclination angles (< 10°) to the core axes were logged as bedding – these would be near vertical. Similarly, a large number of features with high inclination angles (> 70°) were logged as joints – these would be near horizontal. Hence Snowden suspects that a substantial number of structures have been miss-categorised.

The core logs in the PSM reports indicate that structural features with medium dip (30° to 59°) are common throughout both the TPm unit and Basement rocks. Such features are largely absent from the mapping data for the HTP/TP units.

The core logging data-base contains characterisation data on the both planarity and roughness of structural features. However, the geotechnical mapping programme only contains data on the small-scale roughness of the structures. Hence there is a question regarding the reliability of the large-scale joint shear strength parameters that were of necessity derived only from core-scale assessments.

Although no detailed audit has been undertaken, a small number of factual errors were noted in the summary reports of the site investigations, such as the misallocation of the stratigraphical interval to test samples.

Snowden has attempted to address any limitations of the data-base, by adopting a conservative design approach utilising lower bound or the probable range of geotechnical design parameters, as appropriate.

4.3 Hydro-Geology

Ground-water levels measured in boreholes show the natural piezometric surface varies from about 54 mRL in the NE section of Mesa A, to about 49 mRL in the SW section. This data suggests the piezometric surface lies either within the basement rocks or the basal and detrital pisolite (TPb/TPm/TPd) horizons.

Most of the areas planned for mining are well above the natural ground-water levels. However, some of the sections of the mine accessing the deeper TPd ore have a planned floor elevation below the recorded ground-water levels.

5 Robe River Site Visit

R Fry (Principal Consultant, Snowden Mining industry Consultants) visited the RTIO Mesa A exploration site and the RTIO Robe River Mine operations at Pannawonica on 2-3 April, 2007. The observations and findings arising from the visit were reported separately[1]. A summary of the memorandum (with minor edits) is reproduced below.

> The following observations are based on a tour of the Mesa A plateau, viewing the crest and mesa slopes at a number of locations along the north-western and south-eastern sides, inspecting the gorge area in the south-eastern sector of the mesa, and circumnavigating the external limits of the mesa.
>
> - The mesa cliffs are typically between 8 m and 20 m high with slope angles between 60° and 80°. No recent failures of cliff faces have occurred (i.e. within the last 2 to 3 decades).
> - Lower slopes up to the base of the cliffs are formed by intact basement rocks, with a thin cover (< 0.5 m) of eroded pisolitic sandy gravel. Isolated areas of erosion of these slopes occur, possibly due to ground-water seepage from more weathered basement lithologies.
> - A small number of localities were noted with remnant blocks of hardcap lying on the lower slope, but none appeared to be recently formed when compared to the fresh, unweathered appearance of blocks formed by the trial blasts conducted about 30 years ago by BHP.
> - The principal erosion mechanism of the cliffs appears to be the localised collapse of the roofs of shallow caves ranging in size from 1 m to 3 m deep, formed either where lower strength pisolite is exposed between the hardcapped pisolite and the basement strata, or where the weathered palaeo-surface of the basement strata is weaker and more subject to erosion from ground-water seepage. The lack of evidence of any recent falls around the mesa, combined with indirect evidence such as the prevalence of mature trees growing on and directly below cliff faces suggests the cycle of cave formation leading to roof failure is a very slow process.
>
> The Robe River mining areas visited included the current mining operations at Mesa J, and the completed workings at Mesa K and Mesa M. The following observations were made.
>
> - Faces are typically 9 m to 15 m high, and blasted to a vertical perimeter. Higher faces have intermediate berms about 5 m wide or more.
> - No attempt is currently made to limit blast damage to final pit faces; no trim shots or angled perimeter holes are used. Crests typically sustain 1 to 2 m of backbreak.
> - Rill material is largely formed of blast damaged blocks; rill piles are rarely more than 3 m high off 9 to 12 m high batters.
> - Most faces show little if any natural erosion over 15 to 20 years. Small, localised sections of softer material erode at slightly higher rates.

[1] Mesa A Geotechnical Studies - Robe River Site Visit Memorandum. Snowden, April 2007.
File: 070417_Mesa A Site Visit Summary

- No significant batter scale failures were observed at any of the mines. Minor slope failures (of batter-scale or less) are controlled by intersecting geological structures (i.e. joints and bedding planes).

A preliminary review of aerial photographs of the Robe River mining and exploration leases identified a number of features of interest in the natural and mined landforms. The following observations are based on this review.

- Sections of remnant mesa perimeters in the Middle Robe pits mined 20 to 25 years ago showed some blast damage to the natural slope cliffs only where the width of the remnant was reduced to 15 m.
- A remnant natural bluff with a maximum width of 63 m and minimum width of 3 m directly adjacent to a section of a mesa mined over 20 years ago showed no damage from blasting, and no recent erosion effects.
- A number of small isolated natural mesas with widths less than 50 m show no evidence of instability or accelerated erosion.

The following preliminary findings were made on the basis of the site visit observations and review of aerial photographs.

- Overall the natural mesa cliffs appear to be stable landforms, undergoing a very slow process of erosion triggered by formation of shallow caves in softer pisolitic or basement material undercutting the surface hardcap layer, which is generally very resistant to erosion.
- The rate of erosion of mine slopes is very low. The overwhelming bulk of rill material formed at the toes of pit batters consists of blast damaged rock.
- There are plentiful examples of natural remnant mesas of 50 m width or less that are stable and not exhibiting evidence of erosion rates any higher than larger natural mesas.
- In general, the 50 m wide protection zone is adequate to prevent any blast related damage to the mesa façade and any increase in natural erosion rates provided that mining activities such as final face blasting are undertaken with appropriate techniques.

6 Pit Slope Stability Assessments

6.1 Assessment of potential Pit Slope failure mechanisms

Based on the observations made during the Mesa A site visit and the data summarised above, typical geotechnical conditions of the geological units exposed in the proposed pit wall will be as follows:

- The majority of the pit slopes will be formed in the hardcap and upper pisolite units (HTP/TPh/TP). These pits will have relatively low heights (less than 25 m) and will be well above ground-water levels. The hardcap and pisolite materials are reasonably competent, although containing up to 4 sets of rock-mass discontinuities. Hence, these slopes are assessed to be at risk only from kinematic-style failure mechanisms, such as slab, wedge and block formation as a result of combinations of the structural sets intersecting and daylighting in pit faces.
- Small pits will be mined within the main pit in order to extract the isolated, deeper sections of ore-grade pisolite lenses within the TPd unit. These pit walls will be formed in a layered sequence comprising competent pisolite, clay and clayey pisolite. Groundwater levels are also anticipated to be above the final pit floor in some of these pits, exacerbating geotechnical risks. Hence, these areas are assessed as being at risk from developing rotational style shear failures as well as the kinematic-style failures described above.

6.2 Kinematic Analyses

Available data indicates three sub-vertical joint sets in addition to sub-horizontal bedding comprise the dominant structural features at Mesa A. Mean orientations for these four structural sets have been estimated from face mapping undertaken predominantly within the TP rock unit as summarised in Table 4.2. Joint and bedding continuities have also been estimated from face mapping data as summarised in Table 4.4. Joint and bedding surface characteristics and infill have been logged in core and face mapping. Core logging data has been used to quantify defect surface roughness as summarised in Table 4.4. Joint and bedding are indicated to be clay, limonite or iron oxide infilled or clean. Infill thicknesses range from surface staining to 1 – 5 mm. Within the TP horizon 15% of joints are indicated as clay infilled. However, within other rock units clay infilling is more common.

Given the sub-vertical orientation of the three dominant joint sets identified, wedge instability will be the likely form of kinematic instability. The Rocscience programme Swedge[2] has been used to assess the stability of the proposed 75° batters at Mesa A for the likely wedge failure mechanisms formed by the interaction of the three joint sets. Given the sub-horizontal orientation of the bedding set, these defects are unlikely to contribute to kinematic instability and have not been assessed. Stability analyses have been undertaken using downgraded JRC values to reflect the defect roughness scale effect at a scale of 1 m. Analyses have also been undertaken assuming all joints are clay infilled with a friction angle of 20° representing a lower bound for joint shear strength. This conservative approach was adopted in order to address limitations in the database (see Section 4.2).

[2] Swedge v4. Rocscience 2007. (www.rocscience.com)

Analyses have considered the effects of the limited joint persistence, as indicated by the available face mapping data, and have been undertaken for 3, 6 and 9 m high batters. Analyses have been conducted for batter faces oriented normal to the line of intersection of the wedge. Output in the form of probability of failure, volume of failed wedge and width of failed wedge at the batter crest has been assessed.

Results of the stability analyses are summarised in Table 6.1 and indicate low probabilities of failure (P(f)), less than 10%, for all potential wedges assuming lower bound joint shear strength parameters and for the maximum batter height of 9 m. Wedge sizes are also small in terms of weight and width at the batter crest. Where Barton-Bandis defect shear strengths are assumed based on core logging, P(f) are very low (< 2%).

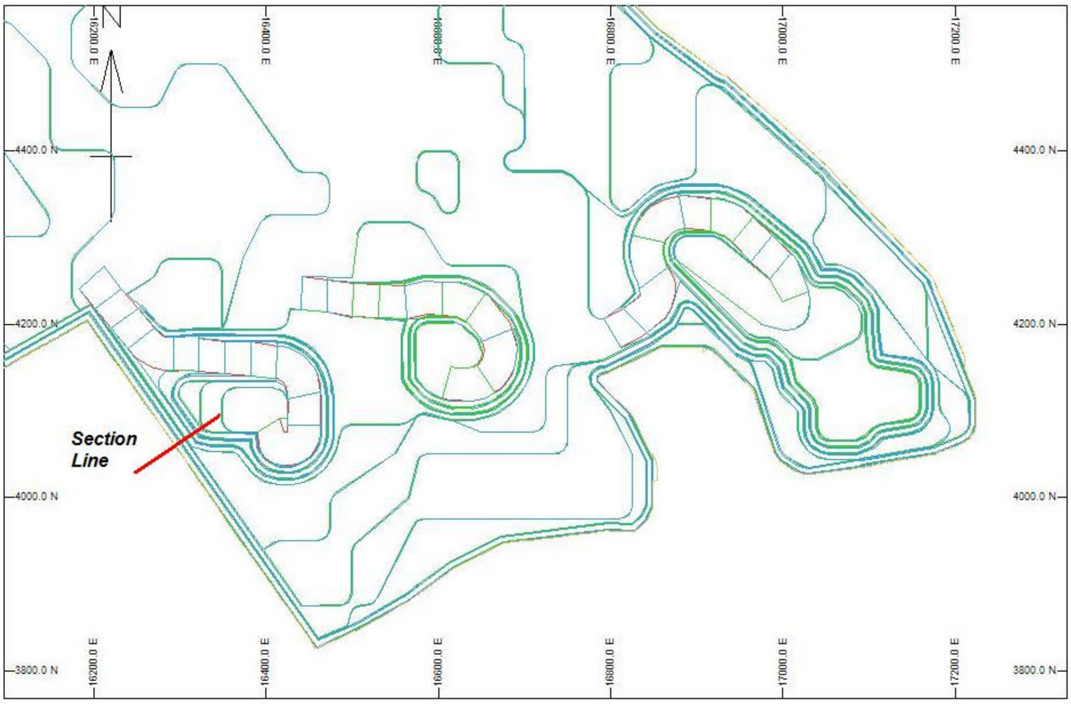
Table 6.1 Wedge stability assessment

Mesa A Wedge Analysis				
	Set 1 and 2	Set 1 and 3	Set 2 and 3	
	Lower Bound Joint Shear Strength Model			
PoF	6.50%	8.50%	1.50%	Batter Height = 9 m
Max Wedge Weight (tonnes) (95 percentile)	2.6	3.7	1.1	
Wedge Width at Crest (m) (95 percentile)	1	1.2	0.3	
	Barton-Bandis Defect Shear Strength Model			
PoF	0.01%	0.01%	0.70%	Batter Height = 9 m
Max Wedge Weight (tonnes) (95 percentile)	5	4.2	1.4	
Wedge Width at Crest (m) (95 percentile)	0.9	1.2	0.25	
PoF	0.01%	0.01%	1.10%	Batter Height = 6 m
Max Wedge Weight (tonnes) (95 percentile)	3.3	4.5	1	
Wedge Width at Crest (m) (95 percentile)	0.9	1.2	0.25	
PoF	0.02%	0.01%	1.98%	Batter Height = 3 m
Max Wedge Weight (tonnes) (95 percentile)	1	1.1	0.4	
Wedge Width at Crest (m) (95 percentile)	0.7	0.8	0.22	

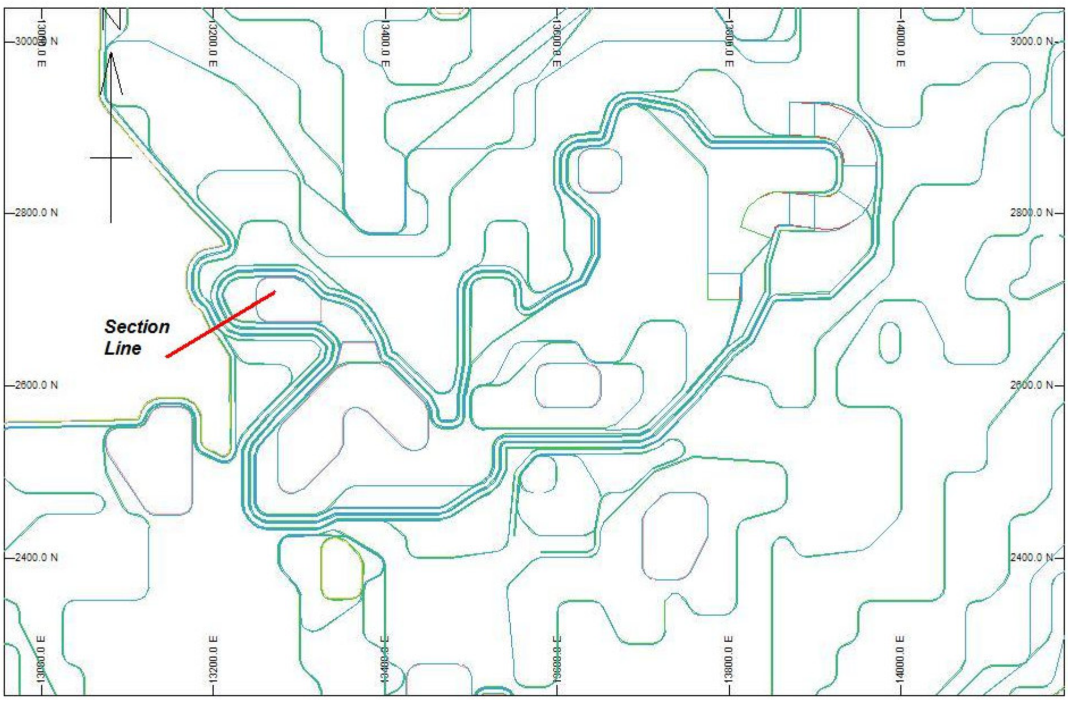
6.3 Limit Equilibrium Analyses

A series of rotational limit-equilibrium analyses have been undertaken on slope sections identified from the pit design and geological model as potentially hazardous. The criteria used for this assessment included proximity to the perimeter zone, overall slope angle and height, presence of clayey strata in the pit walls, and a pit floor elevation at or below the local groundwater level. The locations of the sections chosen for analysis are shown in Figure 6.1.

Figure 6.1 Location of Slope Stability Analysis Sections



North-East Section



South-West Section

6.3.1 Material Strength Parameters

Isotropic Mohr-Coulomb shear strength parameters were developed for each rock unit with the Hoek-Brown approach implemented in the Rocscience software RocLab[3]. For this, RMR/GSI values were calculated from the available geotechnical classification and data.

Values of material parameter m_i were allocated on the basis of particle size in accordance with RocLab recommendations, as follows:

Fine-grained materials (silt/clay sized particles) – "siltstone" : 7

Coarse grained materials (sand/gravel/cobble sized particles) - "sandstone" : 17

Mixed fine and coarse grained materials – low end of range for "sandstone" : 13

A rock mass disturbance value "D" of 0.7 was used for the units within the mining section as being appropriate for the typical blasting practices at Robe River, and for the anticipated shallow depth of critical failure paths; the Basement rocks are considered to lie outside the zone of blast effects hence "D" was set to 0 for this unit.

A normal stress range appropriate to the depth of cover for each material was also applied.

Some stratigraphic units such as the TPb, TPd, TPm and TE horizons, were considered to be "data-limited", hence the rock-mass characterisation parameters are subject to some uncertainty. To account for this, standard deviations have been estimated for the unit weight and shear strength parameters on the basis of Snowden's experience of similar materials elsewhere in the Pilbara.

The parameters derived by this process are summarised in Table 6.2.

Table 6.2 Material Shear Strength Parameters

Stratigraphic Unit	UCS (MPa)	GSI	m_i	Max σ_3 (kPa)	Cohesion (kPa)		Friction Angle (°)	
					Mean	SD	Mean	SD
Basement	3	48	7	500	101	13	30.2	3
Basal Pisolite	6	55	13	500	125	16	36.1	3.6
Detrital Pisolite	8	48	17	500	130	16	37.5	3.8
Clay*	0.5				175	23	20	2
Mixed Pisolite	10	47	13	500	125	16	36.5	3.7
Pisolite (Ore)	10	52	17	250	100	13	46.9	4.7
Hardcapped material	15	52	17	250	116	15	50.1	5

* The strength parameters for the clay were estimated from its material description and field strength, as it is considered to be outside the range of applicability of the Hoek-Brown methodology.

[3] RocLab v1.031. Rocscience 2007. (www.rocscience.com)

6.3.2 Analysis method/software

The limit equilibrium analyses were carried out with the Rocscience software Slide[4] using the Morgernstern-Price method of slices. Two failure path selection methods were applied to each section: randomly generated, optimised non-circular paths and circular arc paths centred on a grid.

In order to assess the risk to slope stability from the potential variability of the rock-mass strength parameters, probabilistic analysis methods were utilised by applying Monte Carlo sampling techniques to the estimated distributions of weight and strength parameters. This procedure provides an estimate of the Probability of Failure (P(f)) for the failure surface returning the global minimum Factor of Safety (FoS).

6.3.3 Results

The results of the slope stability analyses are summarised in Table 6.3, and shown on Figure 6.2 and Figure 6.3.

Table 6.3 Limit Equilibrium Analysis Results

Area	Slope Height	Path	Factor of Safety		P(f)
			Mean	Minimum	
NE	43 m	Random, optimised	1.57	1.23	0.00%
	43 m	Circular	1.59	1.25	0.00%
SW	39 m	Random, optimised	1.64	1.35	0.00%
	39 m	Circular	1.67	1.38	0.00%

[4] Slide v5.028. Rocscience 2007. (www.rocscience.com)

Figure 6.2 Analysis Section for North-East Area

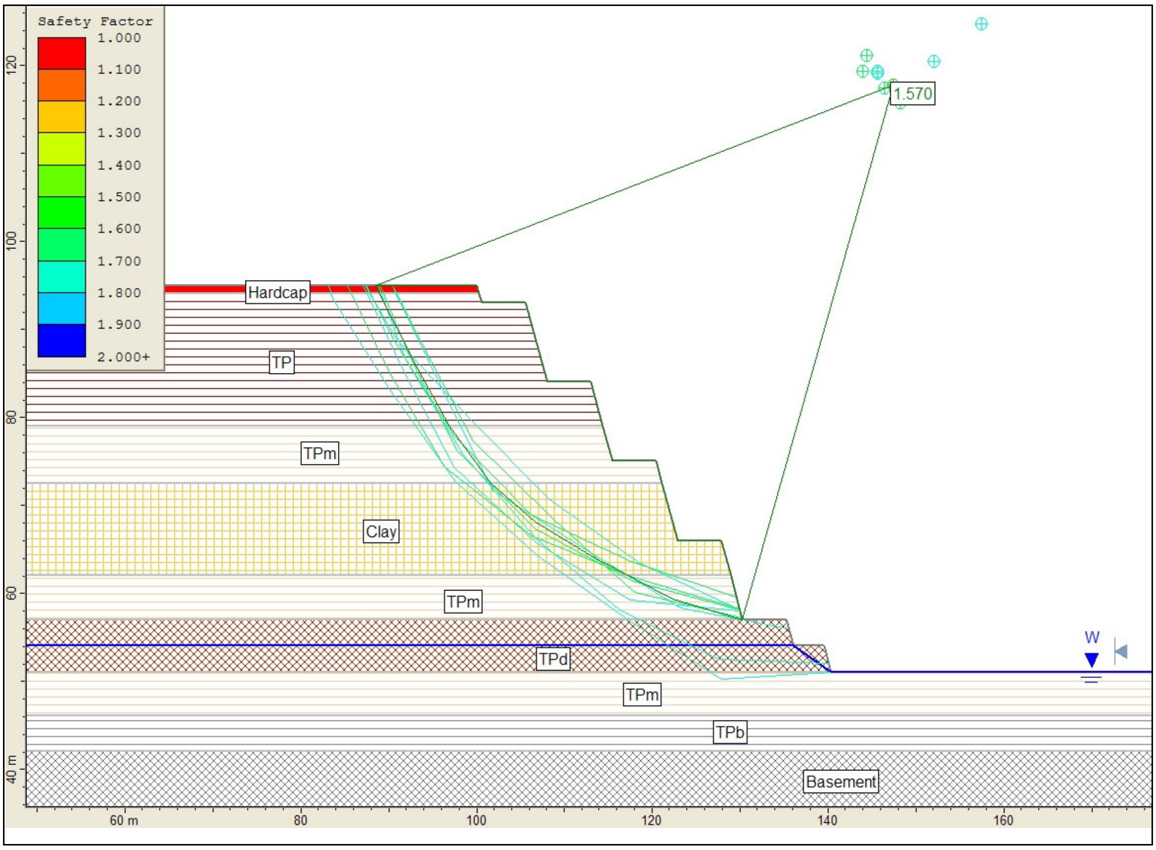
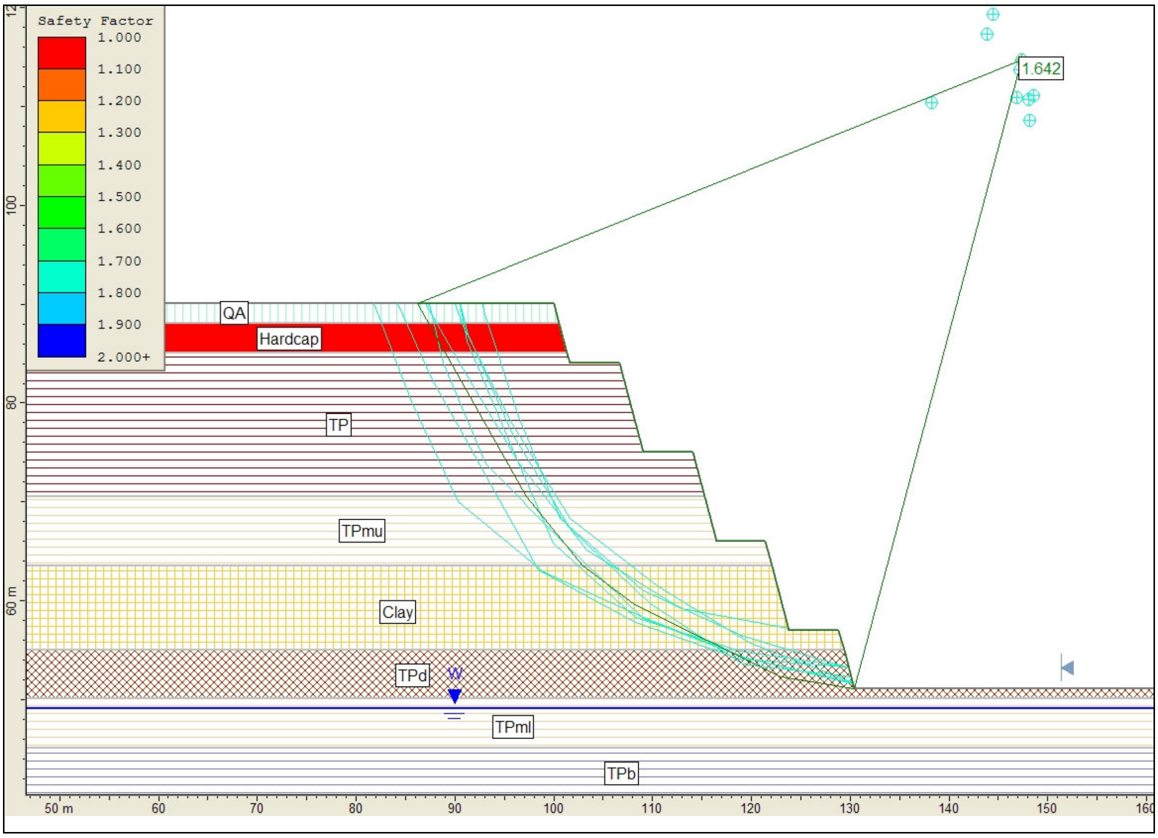


Figure 6.3 Analysis Section for South-West Area



6.3.4 Stability of Batters

An assessment of the stability of the proposed 9 m high by 75° batter designs was also made using simple limit equilibrium analyses with optimised non-circular paths. The material parameters for the Clay (TE) horizon were used for this as these constitute a "worst case". The resulting FoS for the batters was 4.2, demonstrating a very high degree of stability.

7 Findings

Findings made on the basis of the site visit observations and geotechnical assessment for Mesa A are presented below.

7.1 Geotechnical Information

The upper horizons of the ore deposit (HTP/TP) have plentiful coverage of drillholes and test data. However, the investigation of the deeper horizons (TPm/TE(Clay)/TPd) was limited, with no geotechnical holes drilled within the sections planned to be mined, and limited geotechnical testing on samples from these three units.

Reliable structural data is available from mapping only for the upper horizons of the deposit. The data for deeper sections is limited to that provided from the geotechnical drillholes. The geotechnical logs indicate that there are rock-mass structures with mid-range dips in the TPm unit. If common, such features could lead to adverse stability conditions in the walls of the deeper pit sections.

Overall, Snowden considers there is adequate geotechnical information for the design and development of mining at Mesa A, and the information obtained for the lithological units that will form the remnant perimeter zone is of appropriately high quality.

The units below the TP unit have been investigated to a lesser degree. However these units will not be exposed in any section of pit walls forming the 50 m wide perimeter zone. More detailed and specific information on rock strength and structural conditions in these units should be obtained during mining to confirm current designs are appropriate for operational safety reasons.

7.2 Stability of pit slopes

7.2.1 Kinematic Analyses

The currently proposed 75° batters have low probabilities of failure for the likely wedge instability mechanism. It is considered likely that the majority of wedge failures will take place at the time of mining as a result of primarily blast-induced disturbance.

Lower-bound geotechnical design parameters were adopted for these analyses in order to address limitations in the database.

7.2.2 Limit Equilibrium Analyses

Current pit shells designed to extract the deeper TPd ore horizons have high factors of safety for rotational style failures and a very low probability of failure, less than 0.001 (0.1%). The generally accepted limit for probability of failure of a mine slope is 0.1 (10%)[5].

The issue of limited geotechnical data for some stratigraphic units has been addressed by using probabilistic stability analysis techniques. The results demonstrate that for lower bound geotechnical parameters, the pit walls will have more than adequate stability.

Given the high levels of pit wall stability predicted for Mesa A and the absence of identified major fault structures, Snowden concludes that the remnant perimeter zones will not be subject to long-term mining-related stability issues.

[5] Geotechnical Considerations in Open Pit Mines. WA Department of Minerals and Energy. 1999.

7.2.3 Batter and Berm Design

The slope stability analyses confirm that the proposed configuration of batters and berms is suitable for the geotechnical conditions. Batters formed in the clay horizons will also have a adequate stability.

7.3 Mesa erosion/retreat rates

No firm evidence of natural erosion rates has been found. A subjective estimation of the cycle time for cave formation at the base of the cliffs leading to failure of the cliff face above, suggests the natural retreat rate of the Robe River mesa scarps is very low. This is in line with studies from other arid regions in analogous geological conditions.

Within mined mesas, the erosion rates of pit slopes do not appear to be any greater than the rate for natural slopes. Given the lack of evidence of recent natural failures of the mesa cliffs through-out the area, Snowden believes that the proposed remnant perimeter zones will continue to erode at the natural, very slow rate.

7.4 Perimeter zone stability

Mining operations adjacent to natural mesa façades have not caused large (face) scale instability of the natural slopes. Blast damage to the natural façade of remnant mesas has been observed only where the width of the perimeter zone has been reduced to about 15 m.

Based on these observations, Snowden believes that mining operations using appropriate blasting techniques at the external pit limits can create a stable 50 m wide perimeter zone at Mesa A without damaging the natural façade.

8 Recommendations

Snowden makes the following recommendations in regard to the geotechnical aspects of mining the Mesa A iron ore deposits

- A risk mitigation plan to identify and protect any vulnerable sections of the perimeter zone façades should be developed. This work can be done before mining operations approach close to (within about 100 m) any sections of the perimeter zone.
- Additional investigations should be undertaken on the geotechnical conditions in the proposed deeper sections of mine, targeted at the pisolitic and clay materials below the main TP horizon. These may be done in parallel with mining operations within the upper horizons of the deposit and should aim to enhance current geotechnical models of the lower units.

9 References

Mesa A Factual Geotechnical Report. Pells Sullivan Meynink Report 31.R44.. June 2005.

Mesa A Factual Geotechnical Report II – Pells Sullivan Meynink Report 31.R52.. December, 2006.