WARWICK LIMESTONE MINE

GEOTECHNICAL RISK ASSESSMENT AND MANAGMENT

for

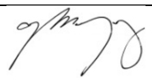
DOCUMENT CONTROL

Title	Warwick Limestone Mine: Geotechnical Risk Assessment and Management
Document Type	Report
Version	1.0
Date	June 2019
Author(s)	A G Meyers
Distribution	1. Sibelco Australia Ltd 2. Rocktest Consulting – Project File
Filename	ground stability assessment V0.pdf

DOCUMENT HISTORY

Version	Comments	Date Issued
1	Original report	5 June 2019

DOCUMENT APPROVAL

Signature	
Approval	A G Meyers
Position	Principal and Senior Rock Mechanics Engineer
Date	5 June 2019

Rocktest
Rock Engineering Consultants
ABN 51 760 370 906

46 Hastings Street
Glenelg South SA 5045
P: 0412 903 222
tony@rocktest.com.au

5 June 2019

Sibelco Australia Pty Ltd
Level 16, 111 Pacific Highway
North Sydney, NSW 2060, Australia

Attention: PAUL TIMMINS
via email to Paul.Timmins@sibelco.com.au

Dear Paul,

This report provides an opinion on the principal geotechnical hazards and associated risks currently applicable to the pits at Warwick. It recommends strategies for ensuring that the residual risks are as low as reasonably practicable post abandonment.

After the strategies have been implemented, there will still be non-mitigatable geotechnical risks associated with the site for the long-term due to the presence of the pits. The landholders must manage these risks to ensure they remain acceptable.

I trust that this report provides the information you require. Please contact this office if you wish to discuss any aspect of it or require further assistance.

For and on behalf of
ROCKTEST

Tony Meyers
Senior Principal Rock Mechanics Engineer
RPEQ 10442

CONTENTS

1 INTRODUCTION 6
1.1 Background 6
1.2 Scope of Works 6
1.3 Information Available 6
1.4 Terminology 7
2 GEOLOGY 8
2.1 General Stratigraphy 8
2.2 Macro Scale Geology 8
2.3 Micro Scale Geology 10
2.4 Earthquakes 14
3 SPECIFICATIONS OF THE PITS 15
4 PERFORMANCES OF THE PIT WALLS 17
4.1 Theoretical Stabilities of the Walls and Benches 17
4.2 Actual Performances of the Walls and Benches 19
5 PIT WALL RISK ASSESSMENTS 23
5.1 Qualitative Assessment 23
5.2 Quantitative Risk Assessment: Rockfalls Pit Floor 25
6 WASTE ROCK DUMPS 27
6.1 Characteristics of the WRDs 27
6.2 Stabilities of WRDs 29
7 RISK REDUCTION STRATEGIES FOR PITS 31
7.1 Partially Backfill Aspinal Pit 31
7.2 Accessibility to East-West and Phoenix Pits 32
7.3 Pit Crest Barriers 33
7.4 Access into Pits 36
7.5 Pit Floor 37
7.6 Water Management on Access Routes 37
7.7 Rockfall and Erosion Control Adjacent to Ramps 38
8 RISK REDUCTION STRATEGIES FOR WASTE ROCK DUMPS 41
8.1 Considerations 41
8.2 Construction Works 41
9 INSPECTIONS AND MAINTENANCE 43
9.1 Pits 43
9.2 Dumps 44

10 SUMMARY 45

10.1 Pits 45

10.2 Dumps 46

10.3 Additional Considerations 47

11 CLOSURE 48

ADDITIONAL INFORMATION 49

FIGURES 50

APPENDICES 94

APPENDIX 1 RISK ASSESSMENT CLASSIFICATIONS 95

APPENDIX 2 KINEMATIC STABILITIES OF THE PITS WALLS 97

APPENDIX 3 BARRIER OFFSETS FROM CRESTS 100

1 INTRODUCTION

1.1 Background

Sibelco Australia plans to relinquish the mining leases at the Warwick Limestone mine in 2019. Sibelco engaged Rocktest in April 2019 to prepare a geotechnical closure report.

Tony Meyers of Rocktest visited the site in May 2019 to obtain data necessary to prepare this report.

1.2 Scope of Works

The activities required of Rocktest by Sibelco were:

1. Visit Warwick mine to inspect the three pits, East-West, Phoenix and Aspinal (Figures 1 to 4), and the waste rock dumps adjacent to the East-West pit (Figures 5) and the Phoenix pit (Figures 6).
2. Collect geotechnical data from the walls of the pits.
3. Discuss the current performances of the walls and the dump slopes and the principal geotechnical hazards applicable to each.
4. Recommend strategies and controls to ensure the residual risks applicable to the features post relinquishment are acceptable for the long-term. The strategies and controls are to be practical and appropriate considering the intended use and proposed frequency of occupancy of the site.
5. Provide an opinion on the residual risks applicable to the hazards after strategies and controls have been implemented.

This report aims to address the scope of works within the following limitations:

- Access restrictions required data be obtained from relatively few locations[1] at which non-blast damaged rocks were exposed within safely accessible areas on the pit walls.
- Data was obtained from visual assessment of weathered rocks exposed on the walls. Some characteristics of the rocks will not be representative of the characteristics of less weathered rocks at depth.

These requirements imposed constraints on the study. These constraints are noted within the applicable section of text and, where necessary, recommendations are made for addressing them.

1.3 Information Available

Sibelco provided to Rocktest digital terrain model files:

- WAR20150721_75cm_South trim.dxf
- WAR20181211_Phoenix_Surface_50cm.dxf
- Gatewing 20150721 Aspinal Plant.dxf

[1] Relative to the areal extents of the walls.

1.4 Terminology

Time periods referred to in this report are:

- Short-term < 10 years
- Medium-term 10 – 100 years
- Long-term > 100 years

Strategies and recommendations in this study consider a 100-year period.

2 GEOLOGY

2.1 General Stratigraphy

Table 1 summarises the general stratigraphy in the area around the Warwick mine.

The stratigraphy comprises sandy clay topsoil overlying moderately[2] dipping altered siltstones which overly and underly limestones and marbles. Each rock unit dips [3] towards the south-west.

The relative proportions of the various carbonates in a particular area are a function of the degree to which alteration has occurred. Dissolution of the upper surfaces of the limestones have created karst features; predominantly an irregular upper surface (Figure 7) and dilated[4] joint apertures (Figure 8); the latter features being particularly evident at the east end of the East-West pit where caves are present.

Andesites have intruded throughout the site diluting the reserves (Figure 9).

2.2 Macro Scale Geology

The "bent" plan view of the East-West pit is due to the rocks in the region having been folded and faulted along strike. The hinge of a downward closing synclinal fold and associated faulting can be seen in the north-west corner of this pit (Figures 10). Evidence of folding is less obvious in the other pits.

The limestones at the northwest end of the East-West pit are offset from those at the southeast end of the pit by 100-m due to shearing along a very-highly persistent[5] northeast-southwest striking lateral fault located in the "bridge" midway between the east and west sections of the pit.

The limestones in the Phoenix pit are offset from those at the southeast end of the East-West pit by 330-m, due possibly to shearing along another very-highly persistent northeast-southwest striking lateral fault.

Many other less persistent faults extend across all pits (Figure 11). Many of these faults are parallel to, and likely associated with, the more persistent faults that have displaced the orebodies between pits. Displacements along the smaller faults have generally been small; the majority being less than 300-mm with a small proportion being up to ≈1000-mm.

The apertures of the faults are generally tight. They rarely contain gouge and adjacent surfaces are generally not crushed; characteristics favourable for rock mass strength. The lack of these features suggests that shearing along the faults may have occurred in a low stress environment. There is negligible evidence of the rockmass either side of most faults having been dragged (i.e. bent) during shearing; a characteristic also beneficial for rockmass strength. There are however shear zones, up to 300-mm thick, adjacent to some of the

---

[2] Dip terms: Very shallow 0-20^o; Shallow 20-40^o; Moderate 40-60^o; Steep 60-75^o; Very steep 75-90^o.

[3] Descriptions in these sections are based on ISRM (1985) International Society for Rock Mechanics. Suggested Methods for the Quantitative Description of Discontinuities in Rock Masses, Int. Jnl. Rock Mech., Min. Sci. & Geomech. Abstr. Vol. 15 pp.319-368.

[4] The term "dilation" is used to describe the aperture of a lineal feature, such as a joint, increasing in width. It can occur by chemical or physical weathering or by mechanical means for example by vibration or shear displacement.

[5] The term persistence refers to the areal extents of the faults. Persistence classification: 1-m ≤ Low ≤ 3-m ≤ Medium ≤ 10-m ≤ High ≤ 20 m, Very-high >20 m.

faults. These zones are not unexpected, especially adjacent to faults along which more extensive shear displacements occurred. Rocks within these zones have been unravelling.

The orientations of the faults tend to be similar to the orientations of either the bedding surfaces or the jointing. Benches that were designed for stabilities on the basis of the orientations of these latter discontinuities[6] have therefore been generally free from instabilities associated with one or more of the faults.

Bench scale instabilities involving intersections of two or more of the faults, or intersections of faults and jointing and/or bedding surfaces, have occurred to bench scale (Figure 12). Instabilities could extend over several benches although none of this scale has occurred to date.

Table 1. General stratigraphy

Approximate depths (m)	Material	Description
0-2	Topsoil	Tertiary age clayey sand, low to medium plasticity, dark-tan to light-brown, containing well-graded gravels to 5-mm diameter.
2-7		As above but including distinctly to extremely weathered floaters of altered siltstone up to 30 cm diameter.
7-15	Siltstone (overlying)	Altered siltstone ("rabbit rock"), fine grain, red-brown to dark-brown, medium to high strengths, slightly- to distinctly-weathered, highly jointed.
15-30	Limestone/ Marble	Limestone is fine grain cream to grey. Marble is crystalline white. High- to very-high strengths. Fresh to slightly-weathered, highly-jointed to massive. Discontinuities are sharp with some Fe staining.
>30	Siltstone (underlying)	Altered siltstone, fine grain, red-brown to dark-brown, medium- to high-strengths, slightly-weathered, highly-jointed.
Various	Andesite	Carbonates and overlying and underlying siltstones are intersected by Devonian age, mafic intrusions, possibly andesites. Finely crystalline, medium- to dark-grey, high-strengths, fresh to slightly-weathered, massive. The thicknesses of the intrusions range from 0.5-m to 2.0-m. They tend to follow vertical to sub-vertical jointing from depth until reduced vertical stresses at shallower depths have allowed them to extrude along horizontal jointing.

[6] The term discontinuity refers to any surfaces having tensile strengths less than those of the adjacent rocks. It includes faults, joints and bedding surfaces.

2.3 Micro Scale Geology

The macro scale faulting and folding have invariably contributed to high volumetric densities of less persistent discontinuities (i.e. bedding surfaces and joints) in all pits. The spatial and shear strength characteristics[7] of these discontinuities have been the primary contributors to the performance of the batters at bench scale.

A limited program of discontinuity mapping[8] was carried out in the East-West and Phoenix pits to obtain data necessary to quantify the characteristics of the discontinuities. Similarities in the orientation characteristics of the discontinuities mapped in each pit justified combining the data from the two pits. The relatively close proximities of the pits (< 850-m) with respect to the regional geology likely contributes to these similarities.

2.3.1 Discontinuity Orientations

Figures 13a show the poles[9] to the sampled discontinuities plotted as points on a stereonet[10]. Figure 13b shows the poles contoured based on densities. The sets are defined as the areas of highest densities.

Five distinct sets of discontinuities can be recognised. Set 1 contains bedding surfaces; Sets 2 to 5 contain joints. The number of sets is consistent with the rockmass having undergone moderate deformation[11].

Each of these sets is quantified by the average of the orientations of the discontinuities assigned to the set and a value for Fisher's constant; the latter value quantifying the maximum deviations of the orientations from the mean. The values of these parameters are listed in Table 1.
Set 1 dips moderately[12] towards the southwest.

- Set 2 dips steeply to very-steeply towards the northeast and the southwest.
- Set 3 dips steeply to very-steeply towards the northwest and southeast.
- Set 4 dips moderately to steeply towards the east.
- Set 5 dips steeply to very-steeply towards the west and the east.

---

[7] The spatial characteristics that have had the greatest influence on performance are (1) the number of sets of discontinuities, as it influences the number of discontinuities per unit volume of rockmass (2) the orientations of the discontinuities, as they influence the numbers of discontinuities that daylight from surfaces (3) the spacings between adjacent discontinuities, as they influence the sizes of individual rocks and (4) the persistences of the discontinuities, as they can influence the volumes involved in failure events.

[8] The orientation, location, size and roughness of 420 discontinuities that intersected 4 scanlines were recorded.

[9] A discontinuity is a 2D feature. It is represented on a stereonet as a "great circle". The "pole" to a discontinuity is a 1-dimensional downward directed line that is orientated perpendicular to the plane. It is represented on a stereonet as a point.

[10] The outer rim of the stereonet represents the dip direction (trend) of the discontinuity from 0^o (North) to 360^o. The dip (plunge) of the discontinuity from 0^o (horizontal) to 90^o (vertical) is represented as the distance from the rim of the stereonet towards its centre.

[11] Three sets are typical where negligible deformation has occurred. The number increases as the degree to which a rockmass has been deformed increases.

[12] Dip terms: Very shallow 0-20^o; Shallow 20-40^o; Moderate 40-60^o; Steep 60-75^o; Very steep 75-90^o.

Table 1. Characteristics of the discontinuity sets.

Set	Mean Orientation DipDirn/DipA (degrees)	Fisher's Constant, F	Number/ Weighted Number (%)	Mean Spacing (m)
1	228/48	15	80/242 (20/24)	0.38
2	039/82	19	94/280 (7/5)	0.40
3	305/88	24	81/164 (20/24)	0.79
4	070/37	16	48/149 (11/14)	0.53
5	271/89	17	65/125 (26/20)	0.69
Random	none	< 1	52/85 (12/9)	0.50
		Total	420/1055 (100/100)	

2.3.2 Discontinuity Deviations

The greater the degree to which a rock mass is deformed, the more the discontinuities within each set deviate from the mean orientation of the set. The amount of deviation influences how a section of a wall will perform relative to adjacent sections of the wall. Increasing deviation increases unpredictability. In this study, the deviations are defined in terms of Fisher's constants (F). The values applicable to the sets (i.e. $13 \leq F \leq 19$) equate to moderate deviations[13].

Random discontinuities develop during each stage of deformation; the proportion (P_r) increasing as cumulative damage occurred. The moderate[14] proportion within the data ($P_r = 9\%$) is consistent with the values of Fisher's constants.

The number of sets, the deviations about the mean values and the degree of randomness are consistent with the tectonic histories of the rockmasses around all pits involving moderate deformations; a result consistent with the observed folding and faulting at local and regional scales. These characteristics have contributed to the challengers in the past maintaining stable benches during mining, particularly during the period when the Aspinal pit and the upper benches in the East-West pit were excavated. During these periods, mining procedures were not as rigorous as they were when the other pits were subsequently excavated and blast damage and over-excavation occurred frequently.

[13] Values of Fisher's constants greater than 50 are rare as they imply the discontinuities within sets are more parallel than typically occurs. values of 25 to 35 are typical for many rock masses that have not been deformed significantly. Values above 15 typically occur when moderate deformation has occurred. Values less than 15 can be indicative of significant deformation having occurred.

[14] A proportion of random discontinuities less than 5% is rare. Values of 10% to 20% are typical for rock masses that have not been deformed significantly. Value exceeding 40% are high; often indicative of significant deformation.

2.3.3 Discontinuity Spacings and Rock Shapes

Spacings

The spacings between adjacent discontinuities from the same set have had a significant influence on the sizes of the individual rocks.

As indicated in Table 1, adjacent discontinuities from all sets are generally moderately to widely spaced[15], ranging from 0.4-m to 0.8 m. However, there are significant variabilities between the individual spacing values, which range from 50-mm to 7-m. This variation contributes to the wide distribution of rock sizes. This distribution can be seen within the walls and in heaps of blasted rocks where a few "very large" rocks occur with a much larger proportion of small to moderate sized rocks.

The significant fraction of moderate and greater sized rocks has contributed to the fair performances of most sections of most walls in all pits at multi-bench and overall scales[16]. There are however areas on every wall where spacings are significantly less than the mean values. The rock masses in these areas have lower strengths as evidenced by accelerated weathering and localised instabilities that extend over multiple benches (Figure 14).

Shapes

The combination of five sets of discontinuities, a moderate random component and moderate average spacings between adjacent discontinuities from all sets has resulted in individual rocks having shapes that range from tabular (i.e. slabby) to blocky[17].

The distribution of the sizes of the rocks and their shapes have influenced the trajectories of the rocks when they have detached from the batters.

- The blockier shaped rocks generally rolled and bounced down the batters. Some of the rocks gained sufficient momentum to traverse off lower berms. A moderate proportion of these rocks came to rest beyond the walls on the floors of the pits and on the ramps. Their run-out distances do not appear to have exceeded ≈20 m, even on the highest walls. The exceptions are those rocks that launched off protrusions in batters during their traverse.
- A high proportion of the more tabular shaped rocks that detached slid down the batters. Most of these rocks did not launch beyond the lower berms hence are the more common shapes accumulated on the berms and near the toes of the pit walls.

---

[15] Spacings: 0.06 ≤ Close ≤ 0.2-m ≤ Moderate ≤ 0.6-m ≤ Wide ≤ 2-m ≤ Very wide ≤ 6 m

[16] Large block sizes contribute to blocks interlocking which can contribute to rock mass strength, weathering rates and the long-term performances of the walls. However, loosening of the rocks by excessive blasting may have diminished much of the influence of block interlocking on rock mass strength.

[17] "Blocky": equi-dimensional; "Tabular": one dimension considerably smaller than the other two; "Columnar": one dimension considerably larger than the other two.

Most benches contain areas from which moderate volumes (< 10 m^3) of small rocks detached. These rocks would have flowed rather than bounced down the batters. The trajectories of a high proportion of these rocks would have been restricted by protrusions on the very-rough surfaces of most batters. Rocks that continued to flow collected in piles upon those lower berms that had sufficient retention volumes remaining after previous flows. Otherwise the rocks flowed off the berms and ended up collecting on the floors near the toes of the pit walls.

2.3.4 Persistences

The extents to which the discontinuities persist[18] beneath overlying rocks without terminating in solid rock or against other discontinuities has influenced the performances of the walls.

The persistences are functions of the lengths of the traces of the discontinuities exposed on the walls[19]. The average of these length for each set was estimated by observation; quantifying[20] them more accurately was unnecessary for this study.

The trace-lengths range from 0.9-m for Set 5 to 1.1-m for Set 2. The persistences of the discontinuities from these sets will be relatively similar to these lengths which classifies them as having low persistences.

The combination of low persistences and moderate spacings between adjacent discontinuities has been favourable for the stabilities of the walls at multi-bench and wall scales. For large instabilities to have developed, “down-stepping” between adjacent discontinuities has had to occur to enable very-highly persistent surfaces, required to underlie large masses of rocks, to form. The lack of bench scale and larger instabilities in all walls is evidence of this characteristic.

2.3.5. Discontinuity Shear Strengths

Instability have been dominated by gravity driven sliding of masses of rock and rotation of the individual rocks. Sliding occurred when the driving forces being applied to a mass of rocks exceeded the shear strengths of the discontinuities that underlay the rocks[21].

In this study, the shear strengths were quantified in terms of a degraded peak friction angle[22]. The discontinuities are assumed to have negligible cohesive strengths due to:

---

[18] The persistence is the two-dimensional areal extent of a discontinuity.

[19] When the 2D surface of a discontinuity intersects a 2D surface of a slope, the line formed along the slope by the intersection is referred to as the trace of the discontinuity. The length of the line is a function of the persistence of the discontinuity. The line cannot be longer than the maximum areal extent (e.g. diameter) of the discontinuity.

[20] Discontinuity persistence is challenging to quantify as it cannot be measured without pulling apart a rock mass and measuring the area of each discontinuity; an impossible task. The characteristics of the parameter must therefore be estimated using a statistical procedure. One such procedure assumes that the discontinuities are circular shaped discs, with diameters that are functions of the lengths of the traces exposed when the discontinuities intersect slopes. A numerical method is used to back analyse the diameters of the discs from the trace length data.

[21] Assuming the mass of rock is free to move out of the batter.

[22] Any movement along a discontinuity erodes some of the asperities that provide it with its initial peak strength. The movement destroys any cohesive bonds that were present leaving a surface that is purely frictional.

- blast damage having occurred to all benches in all pits, particularly in the East-West pit,
- most discontinuities having undergone shear displacement during tectonic deformation and
- relatively low stresses being applied to the discontinuities at the shallow depths of the pits.

In this study, the peak friction angle is defined according to the relationship of Barton and Bandis (1982[23]) in terms of the parameters listed in Table 2. Application of the relationship provides the range of peak frictions angles listed in the table. A lower bound friction angle of 21^{o} ($\bar{x}$ – 2S) is assumed in Section 4.1.

Table 2. Discontinuity shear strength parameters.

Characteristic	**# of tests**	**Min**	**Mean $\bar{x}$**	**Max**	**Stnd Dev. S**	**Source**
Intact rock densities ρ_i (kg/m^3)	14	2481	2650	2994	162	Immersion tests
Intact rock strengths σ_c (MPa)	20	5	65	105	25	Point load tests
Basic friction angles ϕ_b	28	14	18	28	3	Tilt tests
Joint Roughness Coefficients JRC	280	2	4	8	2	Field assessments using classification chart
Estimated peak friction angles ϕ_r		17	31	58	5	Barton-Bandis equation[24]

2.4 Earthquakes

Geoscience Australia (2013)[25] places Warwick in a zone of low earthquake hazard. It indicates that a ground accelerations of 0.06g have a 10% probability of being exceeded in a 250-year period. This relationship corresponds to a 2500-year average recurrence interval for this intensity of movement. There is therefore a 10% probability that an acceleration (A_e) of less than 0.03g (100/250^{ths} of 0.06g) will be exceeded during the 100-year period considered in this study.

Several studies have reported on PGA values exceeding 0.2g generating falls of individual rocks from pit walls[26] in low stress conditions. PGA values of 0.03g are unlikely to generate rockfalls. On this basis, a 100-year event at this site is unlikely to increase significantly the risk to persons within the pit when a large earthquake occurs.

Large (wall) scale instabilities being triggered by earthquakes within any pit are rare. They are not expected to do so at this site. Even so, implementing strategies to reduce to the greatest extent practical the likelihood for persons to be within the pits or close to the crests of the walls will be prudent to reduce the risk applicable is such an event occurs.

---

[23] Barton, N. and Bandis, S (1990) Review of predictive capabilities of JRC-JCS model in engineering practice. In *Proc. Rock Joints*. Balkema pp.803-810.

[24] A Monte-Carlo simulation method was applied to model the ranges in all parameters.

[25] Geoscience Australia (2013) Atlas of Seismic Hazard Maps Australia. (Edt. Leonard M. et.al.) GeoCat 77399.

[26] Rockfalls have been reported for PGA values of 0.16g in pits where discontinuities contain significant joint pressures.

3 SPECIFICATIONS OF THE PITS

Tables 3 and 4 list the average specifications of the pits.

- The East-West pit has the greatest surface areas and the greatest maximum depths of the three pits. In all pits, the maximum depths occur centrally; the depths reducing towards each end of each pit.
- The average strike of the major axis of each pit is parallel with the strike of the limestone orebody in that pit.
- The hanging-wall and footwall along the major axis of each pit comprise at least some siltstones. The walls parallel to the minor axes comprise limestones.
- The batter angles of the footwalls are either parallel to bedding surfaces within the limestones or the batters break back to these angles.

The depths of soil and extremely-weathered rocks and the overall slope angles and heights of the walls listed in Tables 5 and 6.

Table 3. Average specifications of the pit.

	East-West Pit		Phoenix Pit	Aspinal Pit
	West pit	East pit		
Strike of major axis	138^o	228^o	055^o	163^o
Max length at crest (m)	267	280	304	126
Min width at crest (m)	142	174	158	76
Maximum depth of pit (m)	40	51	32	19
Average batter angles	75^o	70^o	65^o	70^o
Max number of benches	6	6	5	2
Design berm widths (m)	7	7	7	6
Max bench heights (m)	21	14	12	15

Table 4. Dip directions of the pit walls.

		Wall			
		North (Sth dip)	South (Nth dip)	East (West dip)	West (East dip)
Pit		Dip direction (degrees)			
East-West	West	140→282	029→061	229→278	097→140
	East	223→230	057	273→358	085→148
Phoenix		141→179	315→333	045→102	228→290
Aspinal		162→212	none	263→284	068→071

Table 5. Maximum depths of soil and extremely weathered rocks.

		Wall			
		North (Sth dip)	South (Nth dip)	East (West dip)	West (East dip)
Pit		Depth (m)			
East-West	West	18	10*	10	13*
	East	9	5	2	9
Phoenix		5	11	10*	13*
Aspinal		15	none	19	15

* A high proportion of the soil is fill within karst in the weathered limestones.

Table 6. Maximum heights and average overall slope angles of walls.

		Wall			
		North (Sth dip)	South (Nth dip)	East (West dip)	West (East dip)
Pit		Depth (m)/Overall Slope Angle			
East-West	West	18/31^o	10/32^o	10/29^o	13/14^o
	East	9/28^o	5/38^o	2/34^o	9/25^o
Phoenix		5/34^o	11/32^o	10/12^o	13/29^o
Aspinal		15/16^o	none	19/31^o	15/25^o

4 PERFORMANCES OF THE PIT WALLS

4.1 Theoretical Stabilities of the Walls and Benches

Quantifying the propensities (P_f)[27] for instabilities to develop in each of the four pits provides a measure of their possible performances over the long-term. The technique applied in this study considers whether the orientations and the shear strengths of the discontinuities are favourable for rocks to slide or topple at bench and wall scales. The technique is discussed in Appendix 2.

The results of the analyses are listed in Table A2.1 and summarised in Figures 15 to 22. The figures also indicate the sections through each wall that were analysed. The results indicate:

- All walls in all pits have propensities to be unstable at bench and wall scales.
- Wedges of rocks underlain by pairs of intersecting discontinuities sliding towards the pits are overwhelming the most typical modes of instabilities in all pits. Toppling of masses of rocks towards the pits are the next mode likely modes albeit half as likely as wedges sliding. These results are consistent with observations.
    - ➢ Benches on north walls (south dipping) are most prone to wedge sliding and to a significantly lesser extent to block toppling.
    - ➢ Benches on south walls (north dipping) are similarly prone to toppling and wedge sliding.
    - ➢ Benches on east walls (west dipping) are most prone to wedge sliding and to a significantly lesser extent to flexural toppling.
    - ➢ Benches on west walls (east dipping) are most prone to wedge sliding and to a slightly lesser extent to flexural and block toppling..
- The propensities for overall scale instabilities are an average of 3.8 times greater than those for bench scale instabilities in all pits. This result is consistent by observation
- The walls and benches in East-West pit and Phoenix pit are similarly prone to instabilities at both scales. The walls and benches in Aspinal pit are slightly less prone to instabilities than those in the other pits. Batters in the latter pit have therefore been able to remain steeper for longer periods than have the batters in the other pits.

Based on acceptance criteria suggested by Read and Stacey (2009[28]), the recommended maximum P_f values for bench and wall scale instabilities are less than 50% and 20% respectively on the bases that:

- The trajectories of a moderate proportion of individual rocks that fall are terminated on the berms. Most of the other rocks come to rest near the toes of the walls (Section 2.4.3)
- The combination of low discontinuity persistences and moderate spacings between adjacent discontinuities is favourable for the stabilities of the walls at multi-bench and wall scales.

---

[27] A value of P_r of 0% implies instability will not occur. A value of 100% implies it will occur sometime in the future. There is no measure of when it will occur.

[28] Reid, J and Stacey P (2009) Table 9.9 in *Guideline for Open Pit Slope Design*. CSIRO Publishing.

In addition, the likelihood of persons being within the trajectory of a falling rock at the time it falls is low due to:

- the pits being located on private land hence the frequency of occupation of a pit is low and
- most instabilities occur during or soon after long duration or intense rainfall when persons are unlikely to be within a pit.

A comparison of the acceptance criteria with the results summarised in Figures 15 to 22 indicates:

East-West pit: West Pit

The propensities for bench scale instabilities in benches dipping:

- towards the south (i.e. north wall) exceed by 10% the recommended level of acceptability;
- in other directions are near or at the level of acceptability.

The propensities for wall scale instabilities in walls dipping:

- towards the north (i.e. south wall) exceed slightly the recommended level of acceptability;
- in other directions are acceptable.

East-West pit: East Pit

The propensities for bench scale instabilities in benches dipping:

- towards the southwest (i.e. north wall) exceed by 11% the recommended level of acceptability;
- in other directions are near or at the level of acceptability.

The propensities for wall scale instabilities in all walls are acceptable.

Phoenix pit

The propensities for bench scale instabilities in benches dipping:

- towards the northeast (i.e. southwest wall) exceeds slightly the recommended level of acceptability;
- in other directions are acceptable.

The propensities for wall scale instabilities in all walls are acceptable.

Aspinal pit

The propensities for bench scale instabilities in any of the benches are acceptable.

The propensities for wall scale instabilities in walls dipping:

- towards the east (i.e. west wall) exceed by 15% the recommended level of acceptability
- in other directions are at or below the level of acceptability.

The following section compares these theoretically based conclusions with the actual performances of the benches and walls.

4.2 Actual Performances of the Walls and Benches

Historical mining practises were not always conducive to achieving stable benches and walls in the Aspinal pit and in the upper benches of the East-West pit because:

- Difficulties were encountered achieving design specifications using standard production blasting techniques in the structurally complex rocks.
- The strengths of the benches were reduced by excessive blast vibrations resulting in a requirement to . over-scale batters and crests in an attempt to remove damaged rocks.
- A lack of success in reducing blast induced overbreak along crests resulting in losses of berm widths.
- An inability to properly scale the batters of 15-m high benches with the available excavators left overhanging and loose rocks along crests.
- Inadequate scaling and limited cleaning of berms resulted in a moderate proportion of all berms containing excessive volumes of rockfall debris.
- Gradients on berms were inadequate to prevent water pooling and eventually draining into the underlying benches or over their crests. These actions have accelerated weathering of the rocks and destabilised some sections of batters.

These factors and the geotechnical characteristics of the rockmass have contributed to the historical performance of the walls and will continue to do so over the long-term. The performances of the components of each wall are considered in the following sections.

4.2.1 Walls and Crests

- No wall scale instabilities have occurred in any pit.
- Most (>98%) sections of the crests of all walls are at their planned limits and show negligible evidence of sections having broken back.
- The crests of all pits were walked and inspected for subsidence and/or the development of highly persistent cracking; indicators that wall scale instabilities may have been triggered. No evidence was observed around any pit.

These performances are consistent with the results of the stability analyses. Over the long-term, wall scale instabilities are not expected to occur.

4.2.2 Batters

- Most batter angles vary significantly ($\pm 15^{o}$) from the specified design angles. Some sections of some batters are overhanging.
- A high proportion of rocks that were loose at the time of mining fell prior to mining ceasing. Only a moderate proportion (<30%) of the total area of batters in East-West and Aspinal pits and a low proportion(<5%) of the area in Phoenix pit are estimated to still contain loose rocks. Many of these rocks will fall over the long-term.

- Most batters in the older benches in East-West pit and a few batters on the west and north walls of the Phoenix pit contain overhanging rocks (Figures 23 to 29). Some of the overhangs are expected to detach over the long-term.
- All benches in all pits contain evidence of bench or lesser scale instabilities having occurred (e.g. Figures 23 to 29).
  - Wedge and planar sliding modes are particularly evident on benches on the north and east walls of all pits. Wedge sliding has created the sawtooth roughness profile on most of the batters (Figure 30).
  - Some daylighting planes (i.e. "slippery-backs") are evidence of planar failures having occurred.
  - Toppling modes (Figure 31) are most evident on benches on south and west dipping walls in all pits.

  These observations are consistent with the results of the stability analyses.
- Falls of individual rocks and masses of rocks have resulted in the surfaces of all older batters ending up rough to very-rough. The roughness invariably causes falling rocks to launch out from the batters and end up out from their toes thereby increasing the rockfall hazards applicable to persons on the pit floors.
- Shallow instabilities triggered by erosion have occurred on batters cut in soil and in highly-weathered rocks. Obvious examples are in the batters adjacent to the central ramp in the East-West pit (Figure 32) and the main ramp in Phoenix pit (Figure 33). Both ramps are to be retained after mine closure therefore hazard control will be required to reduce the rates of erosion.
- Relatively few multi-bench instabilities have occurred in any pit. Those that have occurred have generally been shallow and involved two benches.

4.2.3 Berms

- Berm widths vary significantly, particularly in the East-West pit (Figure 34) and the Aspinal pit. Some sections of almost all berms have widths similar to or greater than the 3-m to 5-m widths generally recommended[29] for 10-m to 15-m high final benches. However, a high proportion (<60%) of the total lengths of berms in all pits are thinner than the widths recommended for the adjacent bench heights and some sections have lost their berms. These sections may be functioning as required when the volumes of debris collected upon them are less than the retention capacities of the sections. However, those sections that are at or near capacity will unlikely retain additional material or terminate the traverses of falling rocks.
- The only advantage of sections of some berms being thin and/or full of debris is that access by person along the berms is restricted or not possible.
- All berms were inspected[30] for subsidence and/or the development of cracking; indicators that bench or multi-bench scale instabilities having been triggered.

---

[29] As a rule of thumb, berms on a production bench should be 2/3^rds^ the height of the adjacent bench. Final berms should be 1/3^rd^ the height of the bench assuming the adjacent batter is well scaled and the bench is not blast damaged.

[30] Berms that cannot be accessed safely were inspected from safe locations using binoculars.

- ➢ A small number of cracks were observed in berms in the Phoenix and the Aspinal pits (<20 respectively).
- ➢ Many cracks were observed in berms in the East-West pit (<100).

All of the cracks observed have low persistences (< 3-m), are offset from crests by less than 1-m and generally appear to be shallow dipping. These characteristics indicate that most cracks are likely to be underlying relatively small volumes of rocks. They are unlikely to be associated with bench or greater scale instabilities.

4.2.4 Benches

- Most (>85%) benches on most walls are still present. Benches in Phoenix pit are generally more competent than older benches in the East-West pit.
- Although a high proportion of the older benches have been damaged by blasting, a general lack of dilated discontinuities within batters suggests that damaged sections of benches have failed and the remaining cores are generally competent.

4.2.5 Floors of Pits and Ramps

- The pit floors are relatively free of rockfall debris considering the large numbers of individual rocks that have fallen. Falls therefore occurred in the periods soon after the benches were excavated with the frequencies of falls progressively reducing in subsequent years.
- The floors of all pits are accessible by at least one ramp. A least one ramps into each pit is accessible by foot and by vehicle.

4.2.6 Overland Flows and Water within Pits

- The topographies surrounding all pits are moderately undulating. Overland flows of water sheeting off areas up contour of the walls have flowed to some sections of some wall pit crests unless bunds have been installed to redirect flows.
- Erosion by water flows has cut gullies along the sides of all ramps and along some haul-roads. Gullies are most apparent on ramps and haul-roads at the east and west ends of the East-West pit (Figures 36 to 38) and the Phoenix pit (Figures 39 and 40)..
- Erosion channels have been cut within those upper benches and ramps that comprise soils and extremely-weathered rocks containing filled karst (e.g. Figures 7 and 41). Channels are significantly less prevalent in the less weathered, more durable, limestones exposed in the lower batters.
- Flows of water down walls has contributed to water ponding on the floor of all pits.
- Groundwater has contributed to water ponding at both ends of the East-West pit and within Phoenix pit. The water restricts significantly access to the toes of adjacent sections of the walls which reduces somewhat the risks applicable to rockfall along these sections.

4.2.7 Summary of Observations

The performances of the walls and benches has been consistent with the results of the stability analyses.

The observed characteristics that highlight how the walls and benches have performed that are indicators of how they are likely to perform over the long-term are noted in Table 7. Based on these observations, in the long-term:

- wall and multi-bench scale instabilities will be rare;
- bench scale instabilities are unlikely;
- falls of individual rocks will likely occur from most benches due primarily to ongoing weathering.

Table 7. Summary of observed instabilities.

Scale of Instabilities	*Comments*
Wall scale	No wall scale instabilities have occurred in any pit at any time.
	No very-persistent cracks were observed beyond any of the pit crests
	Bedding surfaces dip into the hanging (south) walls hence are unlikely to act as surfaces upon which large-scale masses of rocks are likely to slide.
	The average low persistences of individual discontinuities and moderate spacings between adjacent discontinuities from the same sets have been favourable for the stabilities of the walls in relation to wall-scale and multi-bench scale instabilities.
Multi-bench scale	Most multi-bench scale instabilities have been associated with particular features including zones of closely spaced rocks, sheared zones around faults and occasional intersections of very highly-persistent (<20-m) faults and discontinuities which are infrequent. There are a few locations where multi-bench scale erosion channels have been cut by overland flows of water.
Bench scale	Bench-scale instabilities are more obvious than multi-bench and wall scale events, However, they are not prevalent even though the orientations of the discontinuities have been favourable to instabilities. The persistence of most discontinuities having been insufficiently large to underlie bench scale volumes of rocks.
Individual rocks	Large volumes of rocks on most berms are evidence that rockfalls have been frequent. However, a comparison of berms from the current time with those from 15-years ago (Figures 42 to 44) indicates that a significant proportion of the falls occurred in the years soon after each batter was cut with the frequency of falls decreasing progressively afterwards. This characteristic is conducive to the frequencies remaining relatively low during the long-term.

5 PIT WALL RISK ASSESSMENTS

5.1 Qualitative Assessment

A qualitative risk assessment for each credible potential geotechnical hazard identified in Section 4 is presented in Table 6. The risks are classified using a system based on Standards Australia AS/NZS ISO 31000:2009 *Risk Management – Principles and Guidelines*. The system rates likelihood and consequence according to the descriptors in Tables A1.1 and A1.2 in Appendix 1. The risk is classified for comparative purposes using the matrix in Table A1.3.

The following items were considered:

- Location/Domain. There are similar domains in all pits:
  - Pit floors.
  - Ramps.
  - Crests of the walls.
  - Berms.
- Likelihood of injury or loss-of-life for persons. Unauthorised access to the site by the public is assumed to be possible. Authorised access to the pits is assumed to be likely for a variety of reasons including:
  - installing and servicing water pumping equipment in pits containing pooled water;
  - rounding up stock or wildlife;
  - undertaking routine inspections to ascertain the performances of the pit walls and ground control infrastructure;
  - general interest.
- Hazard identification e.g. single rocks, masses of rocks and crest loss.
- Likelihood of event. Frequency of events is estimated based on observations of the numbers of instabilities in the pits.
- Likely initiating events for the hazards are not included in the table as they are consistent for all domains; progressive weathering of rocks, excess hydrostatic pressures and earthquakes.

Results of Risk Assessment

Table 6 is the risk assessment matrix.

The assessments indicate that the risks applicable to most scenarios are in the range of Moderate to High. These classifications are due primarily to the significant consequence of a person being impacted by a rock rather than the likelihood of an impact occurring, which is generally low due to the low frequency of occupation of a pit.

The implications of the risk classifications are listed in Table A1.4 in Appendix 1. In summary, the classifications indicate that the risks must be reduced by the application of controls.

The next stage of the assessment aims to quantify whether the residual risk applicable after applying controls will be acceptable.

Table 6. Qualitative "Current" Risk Assessment

		i	ii	iii	iv		
Domain	**Hazard/Event**	**Likelihood of hazard being triggered**	**Likelihood of impact**	**Likelihood of event (i & ii)**	**Consequence of impact**	**Current risk Level (iii & iv)**	
Floors	Individual rock impacts person	B	D	C	1 - 3	M - H	moderate to high
	Mass of rocks engulfs person	D	D	D	1	H	high
Ramps	Individual rock impacts vehicle	B	C - D	C	1 - 4	M - H	moderate to high
	Mass of rocks impacts vehicle	D	C - D	C	1 - 3	M - H	moderate to high
	Collapse of the shoulder of the ramp subsumes vehicle	D	D - E	D	1 - 2	M - H	moderate to high
Crests	Collapse of a crest subsumes person	C	D	C	1 - 3	M - H	moderate to high
Berms	Individual rock impacts person on a berm on a high wall	A	D - E	C	1 - 3	M - H	moderate to high
	Mass of rocks engulfs person on a berm	C	D - E	D	1	H	high
	Collapse of a berm subsumes person	D	D - E	D	1 - 3	M - H	moderate to high

5.2 Quantitative Risk Assessment: Rockfalls Pit Floor

A quantitative risk assessment was completed to quantify the risk applicable to one or more persons after strategies have been implemented to manage the risks. The assessment assumes that the strategies aim to limit the number of persons who access the pits and to restrict entry to the areas around them. The assessment is based on the general principals outlined in AGS (2007) [31].

The scenario considered involves one or more persons associated with the private land being in a pit within the trajectory of a falling rock. A series of simplifying assumptions are made to estimate the risk to the person/s:

- An average of 17.3 trips to a pit per annum; one trip every 3 weeks.
- Each trip involves occupying a potential impact zone within a pit for an average of 30 minutes (0.5 hours). This time exceeds that required for most tasks.

The probability of persons occupying a zone is:

$(0.5/24) \times (17.3/365) = 9.9 \times 10^{-4}$

The lack of a high number of recently fallen rocks on the ramps and on the floors suggests that the average annual frequency of rocks traversing beyond the toes of the walls and impacting a zone is low (< 2 impacts p.a.[32]). However, the stability assessments indicate a high propensity for rocks to fall from benches and an expected increase in falls as weathering progresses. On this basis, an indicative conservative annual frequency for the long-term is assumed to be 5[33] impacts p.a.

The average number of rockfalls that occur in a zone each day is therefore:

$5 / 365 = 1.4 \times 10^{-2}$

The probability of one or more persons being impacted by a rock is equal to 1 minus the probability of no person being impacted:

$1 - (1 - 9.9 \times 10^{-4})^{1.4 \times 10^{-2}} = 1.4 \times 10^{-5}$

Impact by a rock is assumed to result in loss-of-life; a conservative assumption as less than half the number of persons impacted by rocks are usually killed.

AGS (2007) suggest that the limit of tolerability for loss-of-life associated with a rockfall from an existing slope is 1×10^{-4} for the person most at risk. Acceptable risks[34] are usually considered to be at least one order of magnitude smaller than the limit of tolerability i.e. 1×10^{-5}. The estimated risk to persons of 1.4×10^{-5} is at the

[31] Australian Geomechanics Society Sub-Committee on Landslide Risk Management. In *Australian Geomechanics* Vol. 35 pp.49-92, 2007

[32] per annum.

[33] This number is not an estimate of the average number of rocks that impact the floors of all pits each year. It is the number of rocks that impact a specific location in a pit each year.

[34] Acceptable risks are within a range that society desires to achieve. Tolerable risks are risks within a range that society are prepared to live with to secure certain benefits, even though society would prefer the risks to be lower (i.e. within the range of acceptability). It is a range of risks that is non-negligible and that should be kept under review and reduced as low as reasonably practical (ALARP principle).

limit of acceptability. On this basis, the risk over the long-term may be acceptable but would benefit from being reduced.

The decision to accept or not the risk should not be based solely on this result. There are issues that must be considered in relation to the risk assessment procedures:

- The 10^{-5} acceptance criterion is not absolute. Society shows a wide range of tolerance to risk, and the criteria are only mathematical expressions of general societal opinions. A value higher than the 1×10^{-5} acceptance criterion may be considered to be acceptable if the risk is "As Low As Reasonable Achievable" (ALARA).
- Defining whether the 1×10^{-5} acceptance criterion is applicable for this site requires input from all stakeholders including Sibelco, the landholder and the Regulating Authority.
- There are many approaches that can be used to calculate risk. Each approach potentially gives significantly different outcomes for the same scenario and when applied by different practitioners. In addition, the data upon which any assessment is based relies on judgement and estimates due to the lack of long-term reliable records of rockfall frequencies at this site. How the pits will be used by various landholders over the long-term and the frequencies the pits will be accessed cannot be known. These limitations result in there being considerable uncertainty in any estimated risk value no matter how it is calculated.
- Invariably, a more thorough understanding of the risks would result from additional time and effort collecting and interpreting field data and setting up a more representative risk model. However, the cost required to do so would outweigh the benefits of having a better model. The issue therefore becomes one of matching the data collection and analysis methods to the scale of the problem, the resources available and the aversion of the stakeholders to risk.

Notwithstanding these issues, based on the result of the qualitative and quantitative analyses:

- The risks must be reduced.
- Hazardous areas should not be accessed by persons until risk controls are developed, approved by Sibelco and the Regulating Authority and implemented.
- Controls can involve elimination, substitution or isolation. The latter control is most likely to be the one most applicable to this site. Applying it pragmatically requires a combination of strategies; restricting as much as possible persons from accessing areas within the pits and behind their crests, reducing hazards and controlling the trajectories of falling rocks.

6 WASTE ROCK DUMPS

The site contains two waste rock dumps (WRDs). WRD 1 is located adjacent to the East-West pit. WRD 2 is located adjacent to Phoenix pit.

The dumps comprise a mixture of moderately-to extremely-weathered siltstones and slightly- to moderately-weathered limestones. The rocks are well-graded; containing a mix of sizings from fines to boulders.

6.1 Characteristics of the WRDs

6.1.1 East-West Pit: WRD 1

- WRD 1 (Figures 1, 2 and 5) is located west of the East-West pit. It is centred at 412586-mE, 6858469-mN. The toe of its north slope is close (-m) to the crest of the south pit wall.
- The major axis along the length of the dump trends northwest and is 290-m long. Its minor axis trends northwest and is 183-m wide.
- The dump has a surface area of ≈56,200-m^2.
- Its maximum height of 32-m occurs centrally along the major axis.
- It has been constructed in up to 5 benches. The maximum bench height is 14-m occurring on the south side of the dump.
- The footing below the dump is natural ground which dips slightly at 6^o to the southwest. No information is available as to whether the topsoil was stripped from the ground prior to constructing the dump.
- Most of the batters have been cut back to shallow 17^o to 25^o other than a 90-m length on the south side that is at the 36^o angle-of-repose[35] of the loose rocks.
- Rocks were last placed on the dump in 2013. Since then, the upper surface has been contoured and a thin layer of topsoil placed. A sparse to moderate density of grasses has established naturally (Figure 45); evidence that vegetation will grow on the dumps.

6.1.2 Phoenix Pit: WRD 2

- WRD 2 is located southeast of Phoenix pit (Figure 6).
- It comprises two sections, North (Figure 6a) and South (Figure 6b). The sections are separated by 5,600-m^2 of natural scrub.
- Topsoil was stripped from the natural surfaces to form the footings for each section of the dump.

---

[35] The angle-of-repose is a function primarily of the ranges of rock sizes and the dynamics of the dumping and rilling processes and less a function of the mineralogy of the rocks. The angles were measured at many locations on the surveyed DXF surface of the dumps.

- Rocks were last placed on the dump in 2019 (Figure 46). The slopes and upper surfaces have not subsequently been contoured and no topsoil has been spread. Doing so will be required.

North Section

- The north section is centred at 413772-mE, 6858422-mN. Its west slope is 70-m from the crest of the east wall of the pit.
- The major axis along the length of the section trends north and is 80-m long. The minor axis trends east and is 96-m wide.
- The section has a surface area of ≈20,088-m^2.
- Its maximum height of 20-m occurs at the north end of the major axis.
- It has been constructed in up to 3 benches. The maximum bench height is 13-m.
- The footing at the base of the section dips at 2^o to the east.

South Section

- The south section is centred at 413655-mE, 6858229-mN. Its north slope is 150-m from the crest of the south wall of the pit.
- The major axis along the length of the section trends northeast and is 230-m long. The minor axis trends northeast and is 106-m wide.
- The section has a surface area of ≈20,088-m^2.
- Its maximum height of 7.5-m occurs at the southwest end of the major axis.
- It has been constructed in up to 2 benches. The maximum bench height is 10.5-m.
- The footing at the base of the section dips at 2^o to the southwest.

6.1.3 Construction Methods

WRD 1 and WRD 2 were constructed by edge tipping from tip heads at the crests of the dumps.

Trucks laden with waste rocks backed up to a tip head and tipped the rocks over the crest. Alternatively, the trucks dumped rocks on the flat upper surfaces from where the rocks were pushed by dozer over the crests. In both scenarios, the rocks rilled down the underlying slope upon previously dumped rocks thereby creating "rill slopes" at the 34^o to 36^o angles-of-repose of the loose rocks.

Densification of the rocks within the bodies of the dumps was minimal; comprising normal consolidation and compaction of relatively thin upper layers by vehicle wheel loading.

6.1.4 Weathering and Drainage

The stabilities of the dumps have been, and will continue to be, influenced by the rates at which the rocks within them weather. These rates are influenced primarily by flows of stormwater across and through the dumps. The flows occur generally during long-duration rainfall and/or intense rainfall events[36].

All dumps have experienced all rainfall conditions typical in this temperate region. The lack of significant deposition of fines down contour of any of the dumps is evidence that these events have not eroded significantly the rocks and/or causes significant volumes of fines to migrate through the dumps. Additional factors that may have contributed to the lack of fines are:

- The upper surfaces of WRD 1 is graded to shed water towards the edges of the dump rather than allow it to pool on the surface and migrate through the body of the dump.
- The well-graded sizings of the materials within the dumps and minor compaction and consolidation of these materials has been conducive to achieving moderate to low permeabilities.
- The medium to high strengths of the siltstones and the high to very-high strengths of the limestones contributes to high durabilities which are not conducive to rapid weathering.
- The formation of a shallow crust of low permeability cemented carbonates on the surfaces of the dumps reduces the ingress of water into their bodies.

6.2 Stabilities of WRDs

6.2.1 Current Stabilities

Edge tipping resulted in the slopes of both dumps dipping at the 36^o to 38^o angles-of-repose of the rocks after slight consolidation over time.

- Most of the slopes on WRD 1 were subsequently been cut back to ≈17^o to 25^o (average = 25^o). At these angles, the slopes are very-stable.
- The slopes remain at the angles-of-repose on both sections of WRD 2. These slopes are currently sufficiently strong to support their own weights.

No evidence was observed of significant instabilities on any of the slopes on any of the dumps.

[36] Intense rainfall events cause water to pool and run off surfaces. Long duration rainfall events involve greater than 25 mm of rain falling within a 48-hour period.

6.2.2 Long-Term Stabilities

The angles of the slopes of WRD 2 are to be reduced prior to site abandonment. Subsequently the stabilities of the slopes will be similar to those of the slopes of WRD 1. At these angles, the slopes are likely to remain stable unless conditions change significantly. The most likely changes that can reduce the stabilities are:

- Excess static loads applied close to the crests of the slopes by the wheels of very-heavy vehicles. Bunds placed around the toes of the dumps will ensure that once the site is vacated, no vehicles are likely to traverse these areas.
- Dynamic forces being applied within the dump. These forces would likely be caused by dynamic loading by an earthquake. As discussed in Section 2.5, an earthquake having an intensity at the dumps sufficiently strong[37] to fail slopes is unlikely to occur in this region over the period considered in this study.
- A decrease in the shear strengths of potential sliding surfaces within the dump due likely to:
  - A significant increase in water pressures along the sliding surfaces during periods of long-durations and/or high intensity rainfall. A sufficiently high increase in pressure is unlikely due to vegetation, surface contours and compaction limiting the rates of infiltrations into the bodies of the dumps and hence internal flows through the dumps.
  - A reduction in the strengths of the intact materials along the sliding surfaces due to weathering. Any significant reductions are unlikely due to the high durabilities of the materials.
- Excessive erosion due to overland flows causes deep gullying in a slope. Gullies on any of the slopes are currently neither wide nor deep due likely to the high durabilities of most of the rocks. Progressive increases in rainfall frequency and intensity during the long-term are not expected to be sufficiently great to increase significantly the flow rates.

Based on these considerations, the slopes are expected to perform acceptably over the long-term. If any instabilities do occur, the likelihood of a person being impacted by displacing materials or engulfed in crest subsidence is low because:

- An instability will reduce the angle of the respective slope by only a few degrees. Flows will likely involve relatively small volumes of rocks as most sections of most benches are not high (<8-m). Some of the displaced rock will be retained on berms. Those that are not retained and traverse to the toes of the slopes will have short run out distances due to the slope angles and heights of the benches being insufficient for the rocks to gain significant momentums. The rocks are unlikely to traverse to low (1-m) bunds that are to be placed 10-m out from the toes of all slopes.
- Flows of rocks will generally occur during, or within a few hours after, periods of long duration and/or intense rainfall events. Persons are very-unlikely to be on a section of a crest that subsides, or be below the subsidence zone, at the time a flow occurs.

Implementation of the strategies described in Section 8 will reduce further the risks applicable to instabilities.

---

[37] A strong earthquake is defined as one where the intensity at a dump equals or exceeds MM-V1 on the Modified Mercalli intensity scale.

7 RISK REDUCTION STRATEGIES FOR PITS

The principal hazards applicable to persons in the pits during the short- to long-terms are falls of individual rocks and masses of rocks. This conclusion is supported by the results of stability analyses (Section 4.1) and observation (Section 4.2).

Partially backfilling Aspinal pit will reduce significantly the long-term residual risks applicable to rockfalls. However, achieving a similar reduction in risks by reducing the number and frequency of rockfall hazards in the East-West and Phoenix pits is neither possible nor would be cost effective as:

- Fully or partially backfilling the pits will require:
  - Modifying a stable topography and destroying revegetation on WRD 1 to obtain backfill.
  - Permanently modifying the local topography, destroying landholder value and temporarily destroying vegetation to excavate additional backfill from beyond the pits.
  - Preventing the pits from being used as permanent sources of water for the landholder.
- Alternatively, battering back the walls of the pits will increase by greater than 150% the footprint of each pit which will modify the local topography, destroy landholder value and permanently destroy vegetation.
- Draping the walls in rockfall control mesh would be prohibitively expensive.

For these reasons, East-West and Phoenix pits will, for the long-term, likely remain as permanent voids within which rocks will fall at times and from locations that are spaced randomly. The strategies recommended in the next sections aim to still achieve acceptable long-term residual risks by limiting as much as practical the likelihood of persons being at location where and when the rocks impact within the pit floor i.e. no persons results in no risk.

Even if all strategies are implemented, there will be non-mitigatable geotechnical risks for the long-term due to the presence of the voids. The landholder must manage these risks over the long-term to ensure that they remain acceptable. Requirements for on-going management are noted in Section 7.6.

7.1 Partially Backfill Aspinal Pit

Partially backfill Aspinal pit to eliminate the hazards associated with wall instabilities and to remove the requirement to install abandonment barriers around the pit.

<u>Materials</u>

- The backfill is to comprise superfluous ore, fines and waste rocks stockpiled near to the pit.
- Where possible, aim to select materials that have as uniform grading as possible. Uniformity will assist in providing consistent compaction. If practical, screen out -25 mm rock. The oversize rock will form the armour. The undersize will comprises the backfill.

<u>Construction</u>

1. Trucks are to end dump backfill in front of a section of crest of a wall. Trucks are not to end dump directly over the crest.
2. Using a dozer, push the backfill off the crest.
3. Repeat Steps 1 and 2 until backfill is at, or lower than, the angle-of-repose of the loose rocks when uncompacted of approximately 35^{o}. The highest point of the fill should be slightly above the crest.
4. Using the dozer, continue to push backfill off the crest, while tracking down the backfill previously placed. Continue the process until the backfill extends to the pit floor.
5. Repeat Steps 1 to 4 until backfill extends from every section of the pit crest to the floor.
6. Compact each section of backfill by successively tracking from the pit crest to the floor until no further compaction occurs. A lack of wheel ruts with successive passes is an indicator of compaction being sufficient.
7. If necessary, repeat Steps 1 to 6 until the pit walls comprise all well compacted backfill dipping from the crests to the floor.

7.2 Accessibility to East-West and Phoenix Pits

- The presence of the pits should not to be promoted. Remove all signage from areas visible to the public indicating their presence. Where possible and practical establish tree lines to block visual lines of site from publicly accessible areas.
- Access to the general area around the pits should be via sturdy locked gates with signs indicating “Authorised Entry Only”.
- The only persons allowed near the pits should be those associated with the landholding or accompanied by such persons.
- Children should not be allowed within the general area of the pits. They should be actively discouraged from encroaching beyond the pit crest barriers.
- Deep rip (35 – 50 cm) all tracks that provide access to the pits other than the minimum number required by the landholder to access the ramp/s into each pit. Deep ripping will:
  - reduce the visibilities of tracks and their accessibility for vehicles;
  - reduce overland flows of water by creating paths for water to permeate into the ground rather than flow over pit crests and
  - uncompact the soil and provide it with a rough surface that is likely to collect windblown seed which may with time germinate and stabilise the soils beyond the pits.
- Haul-roads that are located between pit crests and pit crest abandonment barriers (Section 7.3) are to be removed. For example, the haul-roads at both ends of Phoenix pit (Figures 39 and 47) and East-West pit are to be removed. If access is required at these ends of the pit, new roads shall be constructed behind the barriers.

7.3 Pit Crest Barriers

A minimum of one physical barrier is required beyond potential failure zones behind the crest of each wall. Barriers are to be obvious and must have the longevity necessary to restrict access by vehicles, persons and stock to exclusion zones behind the crests for the long-term.

Barriers are to encircle each pit. There are to be no gaps. Locked gates can be incorporated into barriers to enable access to ramps.

7.3.1 Offsets and Locations of Barriers from Pit Crests

In lieu of Queensland specific guidelines on barriers, the offsets of barriers from wall crests should comply with the requirements in the Western Australian Guidelines (1997)[38].

The WA Guidelines require barriers to be offset 10-m behind the point at which a construction line from the toe of a wall intersects the natural ground surface. The line is to be orientated at 45^{o} in fresh rocks and 25^{o} in weathered rocks. The minimum offsets calculated on these bases for each of the sections highlighted in Figures 15 to 22 are listed in Table A3.1. The assessments indicate that all barriers are to be offset from walls a minimum of 10-m[39]. The exceptions are in the East-West pit where 14-m offsets are required at Sections 4 on the south wall of the west pit and on the southwest wall of the east pit.

The barriers are to fully encircle the pits. There is to be no access anywhere between a barrier and the pit crest. The only break in a barrier will be at the section of road leading to the top of the ramp that enables access to the pit floor. The barrier is to extend either side of the road to the pit crest thereby ensuring no access can be gained to the area behind the crest.

7.3.2 Abandonment Bunds

Bunds are to be used rather than fences wherever safe and practical to do so. Bunds remain in place for the long-term with negligible maintenance whereas fences fall down if not maintained.

<u>Bund Specifications</u>

- Bunds are to be constructed from unweathered, durable limestones. The limestones are to be excavated from WRD 2 adjacent to Phoenix pit using a top-down method.
- Desirably, rocks should be screened of the fine fraction (<5-mm) to ensure bunds are free-draining. However, if impractical to do so, water flows through bunds will eventually dissipate the fines leaving the coarse fraction within the bund.

---

[38] Government of Western Australia Department of Industry and Resources (1997) *Safety Bund Walls Around Abandoned Open Pit Mines: Guideline*. MOSHAB Approved. Document No: ZMA048HA. 14 pages.

[39] The overall slope angle is a primary parameter in the offset calculation. The lower the angles, the lesser the offsets required. The angles are moderately shallow at most sections of all pits. Hence only minimum 10-m offsets are required.

- Bunds are to have a nominal minimum height of ≈2-m which requires a base width of ≈5 to 6-m.
- Leave gaps, 0.5-m wide at the toes of the bunds at contour lows where water has obviously been flowing. These gaps are required to reduce the likelihoods of the bunds changing significantly the flow characteristics of the natural surfaces and being eroded by the flows.

East-West Pit

- An abandonment bund is to fully encircle the East-West pit. A gate shall be provided within the bund to enable access to the road leading to the central ramp.
- A bund is required along the south wall of the East-West pit even though WRD 1 is located along this wall. The bund is to be placed on the crest of the north wall of the dump. It shall replace a small (0.5-m) bund currently installed at this location (Figure 1b). A bund shall proceed up the east and west slopes of the dump

Phoenix Pit

- An abandonment bund is to fully encircle Phoenix pit. A gate shall be provided within the bund to enable access to the road leading to the main ramp.
- A 316-m long bund has been installed behind the crest of the east wall of the pit. The bund is 3.5-m high which is acceptable for an abandonment bund. However, the bund is offset only 7.5-m from the crest, 2.5-m less than the offset required based on the Guidelines. On this basis, the offset should be increased. However, doing so is unnecessary as the wall is unlikely to experience wall-scale instabilities.
- A haulroad currently located between the east wall bund and the crest is to be removed.

7.3.3 Fences

Fences can be used where bunds are inappropriate, for example:

- The topography prevents safe access by earthmoving equipment hence is inaccessible by vehicles.
- Trees prevent accessibility or vegetation is too sensitive to be cleared to enable bunds to be installed.
- Property boundaries and access tracks required by the landholder are inconsistent with bund locations.
- Locations within contour lows that act as wide water courses during flood conditions. Bunds across these locations could impede natural flows.

Fence Specifications

- Fences should be of the Type B style. This style has 7 plain-strand, high-tensile, 2.5-mm diameter wires. Barbed wires are not to be used[40]. Figure 48 shows a general specifications of the fence.
- The upper wire of a fence should be a minimum of 1.15-m above ground level to discourage persons from stepping over the fence.
- Posts should be spaced no greater than 5.4-m apart.
- Intermediate star droppers should be spaced no greater than 1.8-m apart.
- Vehicular access through fences requires gates. Gates require:
  - A secure lock that cannot be accessed to be cut.
  - Rigid wire mesh that cannot be cut readily.
  - A sturdy frame attached to rigid posts with sturdy hinges that cannot be removed.
  - Heavy galvanising of all components.
- Attach signs along each run of each fence and to gates at maximum 20-m spacings.
- Fences can be expected to remain functional for 10 to 15 years. Longevity will require routine inspection and maintenance to ensure fences remain sturdy and damage and corrosion are addressed.

7.3.4 Signs

- Bunds, fences and gates require signs warning "Danger Deep Void" or similar.
  - Signs should incorporate a drawing of the hazard in addition to words so that children and non-English speaking persons can understand its meaning.
  - Signs should comprise aluminium sheets; a minimum of 30 cm x 30 cm in
  - Letters should be at least 3.5 cm high. Graphics should be enamelled.
  - Signs should be placed at maximum 20-m spacings.
  - Posts upon which signs are attached should be sturdy. Secure galvanised fasteners should be used.
  - Place signs where they can be seen by persons approaching from any direction. They should be placed wherever an access route or track meets a fence.
  - Secure galvanised fasteners should be used to attach signs to posts, gates and fences.

[40] Barbs cause serious injuries to kangaroos and emus that jump or clamber through fences.

7.4 Access into Pits

- Children are not to be allowed to enter a pit unsupervised by a responsible adult.
- A pit should be entered only if doing so is absolutely necessary. Tasks that do not need to be completed within a pit (e.g. servicing pumps and generators) should be completed elsewhere.
- Pits must not be accessed or remained within while rain is falling. They are not to be accessed within 2-days of an intense rainfall event or if rain has been falling sporadically for a long duration (e.g. 5 days).
- All ramps into any pit that the leaseholder does not wish to access are to be deep ripped.
- If access is required into a pit, and multiple ramps are available into that pit, retain only one of the ramps. Other ramps and access routes are to be deep ripped prior to installing barriers (i.e. abandonment bunds or fences) behind the crests. The ramps retained are to be the least hazardous of the available ramps based on:
  - ➢ the widths of the ramps - wider is preferable;
  - ➢ the competency of the rocks in the underlying benches – cracks in the surface must not be present and the bench not have been blast-damaged;
  - ➢ the conditions and performances of the adjacent slopes as evidenced by low numbers and small sizes of rocks on the ramps.
- The recommended ramps are:
  - ➢ East-West Pit: The central ramp on the north wall (Figure 49) and possibly the western ramp on the west wall (Figure 50).
  - ➢ Phoenix Pit: The main ramp along the east pit wall (Figure 33).

  Do not use other ramps.
- Install sturdy locked gates across the entire width of the top of the ramps being retained to restrict entry to the pit by vehicles and stock. The gate is to contain signs "Danger Rockfall Hazard" and "Danger Deep Void" or similar. The general requirements for signs are listed in Section 7.3.4.
- A fence or a bund a minimum of 1.6-m high should be installed anywhere along the length of the access ramp or anywhere else within a pit where access can be gained to a berm or elsewhere on to a wall.
- Drivers should not stop vehicles on a ramp.

7.5 Pit Floor

- Areas around the pit floors that are accessible yet are not required are to be deep ripped.
- Place toe bunds (rock traps) on the floor out from each wall to:
  - limit the traverses of rocks that roll off walls and reduce the likelihood of rocks entering accessible areas;
  - prevent vehicles and restrict persons from accessing potentially more hazardous areas.
- Toe bunds are to be a minimum of 1.8-m high. They are to be constructed from rocks having the same characteristics as those used for abandonment bunds and constructed using the same procedure (Section 7.3.2).
- Vehicles are to park along the major axis long the pit as far away from the pit walls as practical. Areas for parking are to be defined by toe bunds.
- Persons should remain in the pit for the minimum time necessary to complete a task.
- Limit to the greatest extent practical, the amount of equipment (pumps, generators etc.) on the floors of the pits.

7.6 Water Management on Access Routes

Ongoing erosion of the ramps, haul-roads and upper batters cut in topsoils, filled karst and extremely weathered rocks will be primary triggers for instabilities.

- Remove unrequired ramps and haul-roads, other than those required to access ramps, to reduce water flows and scouring along these routes:
  - Rip to loosen and furrow to depths of between 0.25-m and 0.5-m the upper surface of roads and ramps using a winged-tyne. Furrows should be cut perpendicular to the natural contours. The final surfaces should comprise a 'hummock' or wave profile within which natural seeds and rain can collect.
  - If flows of water along an inclined surface may cause erosion to the surface, construct a series of low bunds at regular intervals along contour down the surface.
    - Bund spacings should not exceed 20-m for gradients less the 8^{o} (12%). Spacings should be 15-m for greater gradients.
    - Bunds should be a minimum of 1-m high.
    - Bunds should comprise a low to moderate permeability core of compacted durable limestones. The limestones should be well-graded with a range of rock sizes.
- Ramps and haul-roads that are to be retained require quality drains to be installed:
  - Grade surfaces to achieve cross-slopes of 3^{o} (19H:1V) with the grade falling away from pit crests towards the adjacent batters.
  - Side drains should be cut along the toe of the batter:
    - Drains should be a minimum of 1.8-m wide (where possible) and 0.3-m deep.

  - Drains should be lined. Concrete canvas (Figure 51) provides a good lining for the long-term. The canvas should be 5-mm thick and installed according to the manufacturer's instructions. Alternatively, drains should be lined with high permeability, coarse (no fines), durable limestones.
- ➢ Cross drains should be cut at regular intervals down the inclines of ramps and haul-roads:
  - Cross drain spacings should not exceed 20-m for gradients less the 8^o (12%). Spacings should be 15-m for greater gradients.
  - Drains should be a minimum of 1.0-m wide and 0.3-m deep.
  - They should be filled with high permeability, coarse (no fines), durable limestones.

- Water shedding off the 550-mRL berm (Figure 52) above the batter adjacent to the central ramp is destabilising the batter below and eroding the ramp.
  - ➢ If water is flowing on to the berm from the 560-mRL berm above, install bunds to modify drainage paths to force water to flow to the west and not towards the 550-mRL berm.
  - ➢ If water cannot be prevented from flowing on to the 550-mRL berm, a horizontal lined berm drain will be required to direct water to a vertical lined batter drain. The drains are to be lined with concrete canvas (Figure 51). The canvas is to be fixed securely to the surface with deep anchors.

7.7 Rockfall and Erosion Control Adjacent to Ramps

Rockfall management is required on batters adjacent to accessible ramps. These ramps will be:

- East-West pit: The central ramp on the north wall (Figure 49) and possibly the western ramp on the west wall (Figure 50);
- Phoenix pit: Main ramp on the eastern wall (Figure 33).

The procedures recommended for managing the hazards are outlined in the following sections.

7.7.1 East West Pit Rockfall Control

<u>Central Ramp</u>

Rockfalls are being generated primarily from the crest of the 550-mRL berm. Several shallow slips have occurred along the 80-m long section of the batter. The primary triggers of these instabilities are surface erosion by water shedding off the 550-mRL berm above the ramp and the 60^o batter angle being too steep for the weathered rocks.

The 60^o batter angle cannot practically or cost effectively be reduced to 50^o or lower as required to achieve acceptable stabilities. Insufficient widths (< 7-m) are available on the 550-mRL berm to enable a standard mining drill rig to access to the berm.

The hazard can be addressed effectively, and at a lower cost than drilling and blasting, by draping the batter in rockfall mesh woven from high-tensile strength wires (Figures 53 and 54). Doing so is commonplace in pits. The drapery will:

- apply minor support to the surface rocks,
- hold the concrete canvas batter drain securely,
- control the horizontal displacements of individual rocks that detach to ensure they do not launch beyond the shoulder of the ramp,
- retain masses of fallen rocks within the width of the shoulder thereby preventing them from flowing on to the ramp.

Construction

- The mesh is supported by an upper boundary rope on the 550-mRL berm and attached to a lower boundary rope adjacent to the ramp. Attachment of the mesh to the ropes is with press claws, hog rings or lacing wire. Contractors specialising in the installation of drapery have small drill rigs than can access the berm safely.
- The upper boundary rope will be secured taught to the berm with a series of spiral rope anchors spaced at 3.5-m centres maximum or at the widths of the mesh panels. This style of anchor provides better dynamic loading characteristics than do solid dowels.
- The ends of the lower boundary rope will be terminated at spiral rope anchors. Along its length, the rope will be clipped with shackles to fully-grouted threadbar type dowels or wire-rope anchors at 3.5-m centres maximum or roll widths.

Drapery of the area required can typically be installed in less than 10-days.

The unit cost to supply and install drapery is approximately $80 per square metre plus mobilisation costs. With a surface area of approximately 1280-m^2 to be covered, the total cost is likely to be approximately $103,000 plus mobilisation. A more accurate quote will be provided by a ground control contractor[41].

Western Ramp

Remove the ramp from service if practical to do so using the ripping procedure noted in Section 7.6.

If the ramp is required to be retained:

- Increase, to a minimum of 1.8-m, the height of the toe bund (rock traps) currently installed out from the toe of the adjacent batter (Figure 50b).
- The bund is to be continuous, unlike the current bund.
- The location of the inner toe of the bund is to coincide with the inner toe of the current bunds.
- The bund is to be constructed from rocks having the same characteristics as those used for abandonment bunds and constructed using the same procedure (Section 7.3.2).

[41] This office can provide details of suitable contractors.

7.7.2 *Phoenix Pit Ramp Erosion Control*

Main Ramp Erosion and Rockfall Control

Gullying in topsoil, karst fill and in weathered limestones on the east batter adjacent to the main ramp is associated with waterflows resulting from direct impact of the batter by rain. Gullying may also have been associated with surface water flowing over the crest of the wall. However, a bund along the crest is likely to be sufficiently high (1-m) to prevent these flows.

Erosion will be ongoing and, if not addressed, in the medium- to long-terms the associated gullying will trigger instabilities. Eventually instabilities could render the ramp unusable.

The rate of erosion can be reduced significantly by installing quality erosion control matting. However, quality matting (not jute) is costly and requires significant time to install properly. Installing matting without seeding will provides only medium-term erosion control.

Hydroseeding

Reducing the rate of erosion for the long-term requires establishing grasses within the soils to bind and reinforce the grains which will reduce their displacements downslope. Grasses also reduce the rate of runoff and allow surface water to infiltrate the soil rather than flow over it.

The most efficient and cost-effective method to seed the large area (3020-m^2) of the steep slope (35^o to 50^o), its crest and the ripped haul-road behind the crest by hydroseeding[42] (Figure 55). The combination of hydroseeding and hydromulching is an accepted method for rehabilitating mine slopes comprising soils and weathered materials similar to those in this batter.

Hydromulching[43] the batter, using a product suitable for use on steep slopes, is recommended after hydroseeding to provide a protective layer over the seeds from rain and wind and reduce the loss of soil moisture, much like an erosion control blanket. It will remain effective for 6 to 12 months during which time the seed should have germinated; likely required as rainfall in this area can be difficult to predict.

The unit cost for hydroseeding is approximately $23,000 per hectare. At this rate, the batter, crest and the haul-road would cost approximately $9,000 to spray. Hydromulching would double the cost but provide a superior result. A more accurate quote will be provided by a hydroseeding contractor[44].

Aim to achieve as dense a seed distribution on the slopes as practical. Spraying should occur at a time when regular rainfall is most likely to occur and temperatures are mild to encourage germination.

---

[42] Hydroseeding is the hydraulic application of water, seed, fertiliser and the option of growth supporting additives.

[43] Hydromulching is the hydraulic application of mulch to increase erosion control effectiveness, growth establishment and functional longevity

[44] This office can provide details of suitable contractors.

8 RISK REDUCTION STRATEGIES FOR WASTE ROCK DUMPS

8.1 Considerations

The primary factors that will influence their performances are associated with water flows; gullying caused by overland flows and water permeating through the bodies of the dumps. As discussed in Section 6.2, the slopes on the two dumps are likely to perform generally acceptably over the long-term after abandonment works have been completed. These works involve grading and shaping the surfaces to ensure they shed water effectively and slowly. These works are required predominantly on WRD 2, less so on WRD 1.

8.2 Construction Works

8.2.1 Grading and Shaping WRD 2

- Works on the dump are to begin after limestones have been extracted from the dump to create abandonment bunds around East-West and Phoenix pits and various other bunds required around the site (incl. pit floors). Rocks required for the bunds etc. are to be extracted from the upper surface of the dump using a top-down method. Doing so will reduce the overall height of the dump. Rocks are not to be excavated by undercutting the toes of the slopes. The greater the total volume of rocks removed, the less will be the height of the dump and the lower will be the residual risk after the site is vacated.
- Reduce to 25^{o} or less the angles of the slopes.
- Create uniform upper surfaces. Crown the surfaces and establish grades of between 3^{o} (30H:1V) and 5^{o} (11H:1V) from the crown to the crests of the slopes to encourages water to sheet off the surfaces rather than pool.
- Compact the surfaces to achieve as high a material density as practical by successively tracking across it with a dozer or preferably a roller. Tracking should occur parallel to the slope crests to reduce the likelihood of creating contour lows that could result in gullying perpendicular to the crests.
- Repeat compaction until no further displacement of the surfaces occurs with additional tracking. A lack of wheel ruts with successive passes is an indicator that compaction is sufficient.

8.2.2 Remove access to WRD 1

Figure 56 highlights the ramp that provides access to the upper surface of WRD 1. A shallow (0.5-m) gully has developed adjacent to the ramp (Figure 37). The ramp should be removed and the gully reinstated.

1. Install the abandonment bund along the north crest of the dump accessing the crest using the ramp using the procedure in Section 7.3.2.
2. Remove the ramp by ripping using the procedure in Section 7.6.
3. To prevent scouring of the ripped materials, install check dams down the inclined surface at 10-m intervals. Dams should comprise low (0.5-m) bunds constructed from coarse durable rocks.

8.2.3 Establish Grass on the Surfaces

Vegetation will increase the strengths of the material underlying the surfaces and slopes of WRD2, reduce their erodibilities and enhance the visual amenity of the area.

- Spread a layer of topsoil a minimum of 10-mm thick over the upper surfaces and slopes.
- Hydroseed the topsoil with seeds from native grasses. The area to be covered can be determined after rocks for bunds have been removed and the dump has been graded and shaped.
- Aim to achieve as dense a seed distribution as practical. Spraying should occur at a time when regular rainfall is most likely to occur and temperatures are mild to encourage germination.

5.2.4 Manage Rockfalls on WRD 1 and WRD 2

Place a rock catch bund a minimum distance of 10-m out from the toes of the slopes to:

- intercept the trajectories of rocks that roll off the slopes
- prevent overland flows from up contour of a dump from inundating the toes;
- delineate an exclusion zone to prevent vehicles from accessing the slopes.

The bunds should be a minimum of 1-m high. they should be constructed from compacted, durable limestones comprising a wide range of rock sizes.

9 INSPECTIONS AND MAINTENANCE

9.1 Pits

- The landholder should undertake inspections on foot. The inspection can be carried out by any adult person having good physical health[45] and a diligent nature.
- Fences generally remain functional for 10 to 15 years. Maintaining longevity require routine inspections at maximum 1 yearly intervals or whenever the landholder is nearby. Check for damage and corrosion. These conditions will require maintenance. Sections of fences deemed to be no longer functional are to be replaced. Vegetation which may obstruct signs should be trimmed routinely.
- Rockfall mesh generally remain functional for a minimum of 50 years if not overloaded with fallen rocks. Maintaining longevity require routine inspections at maximum 1 yearly intervals or whenever the landholder is nearby. Check for damage and corrosion. These conditions will require maintenance. Sections of mesh deemed to be no longer functional are to be replaced. Large masses of rocks within mesh should be removed by unshackling the lower boundary rope. Specialist contractors should be engaged to undertake these works.
- Maintenance on bunds is likely to be minimal. Routine inspections at maximum 2 yearly intervals or whenever the landholder is nearby are required. Check for damage and erosion; conditions that will require maintenance.
- If a section of a barrier (fence or a bund) has been damaged by wall instability or instability encroaches 5-m or greater towards a barrier, install a new section of barrier 10-m behind the existing section.
- Pit walls should be inspected whenever the landholder is within a pit.
- Inspection of pit walls and the areas between their crests and the bunds should aim to identify development of new or widening cracks. Cracks having a nominal length of approximately 20-m and 5-m or more behind the crest may be evidence that a wall scale instability is developing. If so, the area on the adjacent section of floor must not be accessed until the failure event has occurred or there have been no changes in the crack widths, lengths or the number of cracks for a minimum of two-years.
- If any event occurs that may have implications for the risks to persons in a pit, do not access the areas and obtain advice from a mining rock mechanics specialist.
- Remain vigilant for unauthorised access to a pit. Increase security if access is suspected.
- Remain aware of the residual risks associated with the pits. Pass on this awareness to all parties involved with the site over the long-term.

---

[45] The inspection route is relatively long.

9.2 Dumps

- Annual inspections of dumps are required prior to the wet season and after intense rainfall or periods of long duration rainfall to check for instabilities and excessive erosion that may require remediation.
- Crowning and shallow surface grades on the surfaces of the dumps will reduce the likelihood for preferential flow paths to develop. However invariably they will, eventually resulting in gullies developing down slopes.
  - Gullies should be lined with geotextile fabric, erosion control mesh or rocks.
  - Flow velocities should be reduced with check dams placed within gullies. Dams can comprise straw bales fixed with wooden stakes or low (0.5-m) bunds constructed from coarse durable rocks.
- Water pools in wheel ruts. Failures of sections of dumps elsewhere have been associated with ruts, within a distance of 20-m to the crests, being routinely filled. To prevent rutting, and for safety, vehicles are not to be driven on dumps.
- Promptly seal off cracks that develop in the surfaces, particularly cracks within 20-m of a crest, to prevent water ingress. Do so by compacting the areas around cracks and replace any settled fill with compacted clay.
- If practical to do so, encourage grasses to develop in barren areas by covering the area with a thin layer of clays, hand seeding and fertilising then applying another layer of clay. Temporary fencing may be required to keep animals away from germinating grasses.

10 SUMMARY

10.1 Pits

Over the long term, the most significant geotechnical hazards are falls of individual rocks from all walls in all pits. As the rocks weather, localised bench scale instabilities may occur. Multi-bench and wall scale instabilities are unlikely. A series of quantitative and qualitative risk assessments indicated that the risks applicable to the instabilities are sufficiently high that strategies must be implemented to reduce the risks to acceptable levels.

The most effective way to eliminate the risks is to prevent all access to all pits or to undertake major excavation works on the walls which will increase the heights of the floors to above the standing groundwater level. Neither strategy is practical nor desired by the landholder as they wish to access permanent water in the pits.

The following strategies enable landholder access to the pits and reduce the risks to acceptable levels. The strategies are detailed in the sections noted. These sections provide important details on each strategy.

- Partially backfill Aspinall pit with superfluous stockpiled limestones and waste rocks to reduce the angles of the walls to less than 35^{o} (Section 7.1).
- Apply rigorous access restrictions to the general areas around the pits and within the pits (Sections 7.2 and 7.4). The pit floors must not be accessed for 2-days after intense or long duration rainfall. They are to be accessed only be adults and by children when supervised by an adult. Berms must not be accessed.
- Delineate safely accessible areas on the pit floor with high bunds. The specifications of the bunds are to be the same as those of the abandonment bunds (Section 7.5).
- All haulroads within and around the pits are to be removed by ripping (Section 7.2).
- Access to the floor of the East-West pit shall be restricted to the central ramp.
    - Water flowing down the ramp is to be controlled by installing a side drain and cross drains (Section 7.6).
    - Water flowing over the crest of the 550-mRL berm above the ramp is to be controlled with berm and batter drains (Section 7.6).
    - Rockfall mesh is to be draped down the batters adjacent to the ramp (Section 7.7.1).
- Access to the floor of Phoenix pit shall be restricted to the main ramp. All other ramps are to be ripped (Section 7.4).
    - Water flowing down the ramp is to be controlled by installing a side drain and cross drains (Section 7.6).
    - The batter adjacent to the ramp is to be hydroseeded (Section 7.7.2).
- Abandonment barriers are to be installed a minimum of 10-m beyond the crests of both pits (Section 7.3).
    - There are to be no gaps in the barriers that could allow access to the areas between them and the pit crests. The only gaps are to allow access to the roads to the ramps. Access through the gap will be via locked gates with signs. The barrier is to extend either side of the road to the pit crest thereby preventing access to the area behind the crest.

- The barriers are to comprise bunds with signs except in areas where bunds are unsuitable. Type B fences with signs can be used in these areas.
- On the south wall of the East-West pit, an abandonment bund is to be located along the crest of the north slope of the waste rock dump WRD 1 (Sections 7.3.1 and 7.3.2). It is to join the bund encircling the pit crests without gaps.
- An existing bund, that is offset 8-m from the crest of the east wall of Phoenix pit, is suitable as an abandonment bund. The haul-road between it and the pit crest is to be removed (Section 7.6).

10.2 Dumps

The primary factors that will influence the performances of the dumps during the long-terms are associated with water flows; gullying caused by overland flows and water permeating through the bodies of the dumps. The slopes on the dumps are likely to perform generally acceptably over the long-term after abandonment works have been completed.

East-West Pit Waste Rock Dump (WRD 1)

- The dump is to remain in-situ with only minor works.
- No rocks are to be extracted from the dump for constructing abandonment bunds etc.
- The access ramp at the west end of the dump is to be removed. Check-dams are to be installed down the incline to reduce the velocities of water flows (Section 8.2.2).
- An abandonment bund is to be located along the crest of the north slope of the dump (Sections 7.3.1 and 7.3.2).

Phoenix Pit Waste Rock Dump (WRD 2)

- Rocks for abandonment bunds and other bunds are to be obtained from this dump using a top-down extraction method. Rocks are not to be sourced from the toes of the dump slopes (Section 8.2.1).
- Uniform well compacted upper surfaces are to be created. The surfaces are to be crowned with grades of between 3^o (30H:1V) and 5^o (11H:1V). The angles of the slopes are to be reduced to 25^o or less (Section 8.2.1).
- Topsoil is to be spread and hydroseeded (Section 8.2.3).

Both WRDs

- A rock catch bund is to be placed a minimum distance of 10-m out from the toes of the slopes (Section 5.2.4).

10.3 Additional Considerations

- Regular inspections are required of the abandonment bunds and fences, rockfall mesh, crests and walls (Section 9.1).
- Undertake repairs on fences, bunds and erosion gullies as required.
- Seek advice from a ground control contractor if rockfall mesh is damaged or requires cleaning.
- If any instability may increase the risk to person on the pit floor do not access the area and seek advice from a mining rock mechanics specialist.
- If persistent cracks develop behind the crest of a wall, the area on the adjacent section of floor must not be accessed until the failure event has occurred or there have been no changes in the crack widths, lengths or the number of cracks for a minimum of two-years.
- There will be non-mitigatable residual risks for the long-term due to the presence of the pits and the dumps. The landholders must manage these risks over the long-term to ensure that they remain acceptable.

11 CLOSURE

As required by Sibelco, this report has:

- Discussed the performances of the walls in the pits and the dump slopes and the principal geotechnical hazards applicable to them currently and over the long-term.
- Provided comments on the principal geotechnical risks.
- Recommend controls for reducing the risks associated with each hazard identified. The controls are practical and appropriate considering the intended use and proposed frequency of occupation of the site post abandonment.
- Provided an opinion on the residual risks applicable to the hazards after controls have been implemented.

We trust that it provides the information you require. Please contact this office if you have any queries on any matter discussed within it or wish to discuss any aspect of the report in more detail.

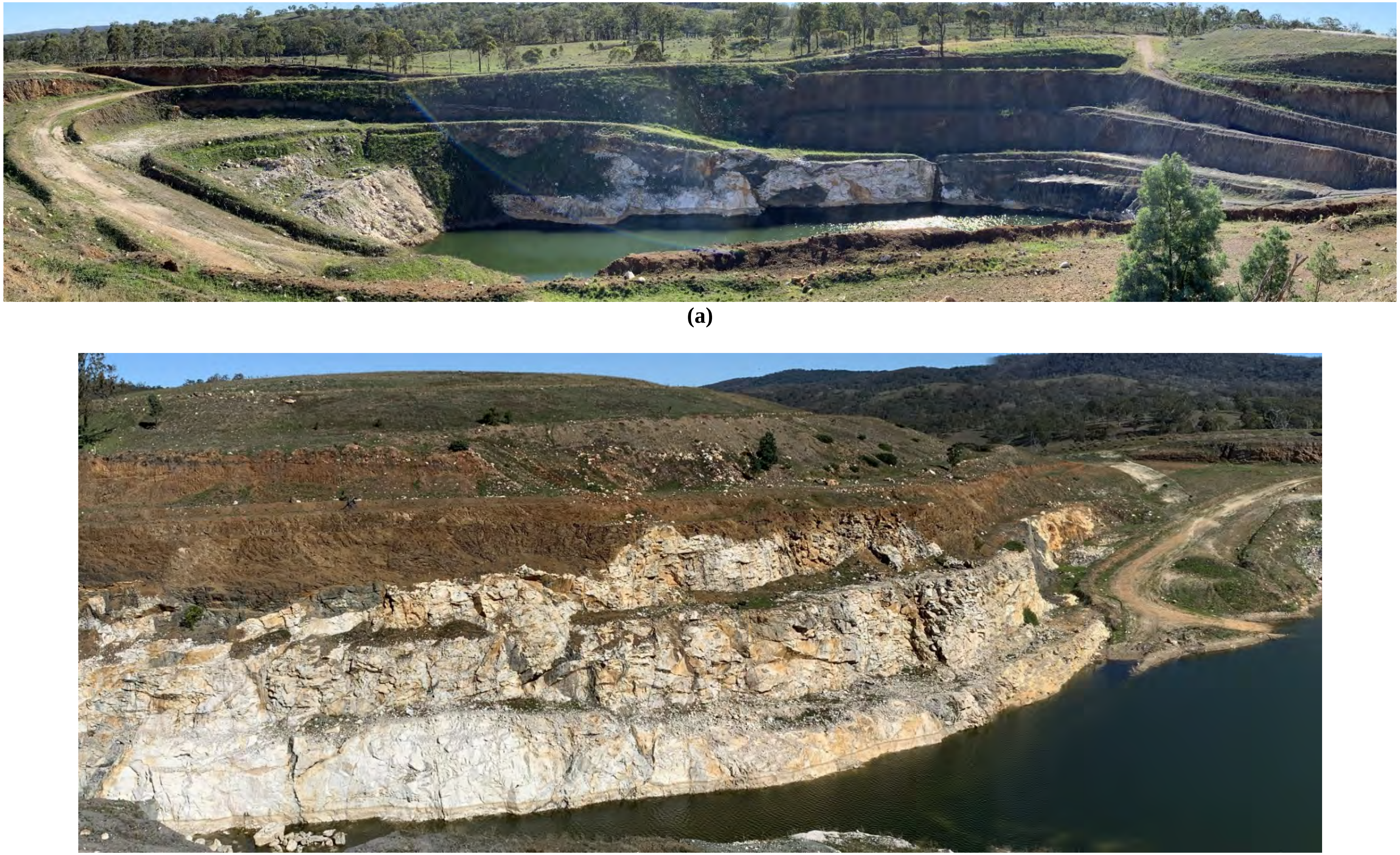
Anthony (Tony) Meyers
B.Eng (Mining), PhD (Rock Mechanics) MIEAust, CPEng, NPER(Civil), MAusIMM, RPEQ, IntPE(Aus)
Senior Principal Rock Mechanics Engineer

ADDITIONAL INFORMATION

- The recommendations in this report have been based on certain assumptions and very few observations. It would be very rare if the conditions at the site did not vary from those observed even if exhaustive investigations had been undertaken. Hence, it is unlikely that the conditions observed will represent the extremes of conditions that exist. As such, even though the aim of this report is to address issues influencing geotechnical related risks applicable at the Warwick limestone mine, it is possible for events to occur or conditions to exist that were not planned for and as such should not be unexpected.
- The report was prepared on completion of the field work and is based on conditions encountered and reviewed at the time of preparation. Natural developments in, and changes to, or surrounding a volume of geomaterials over time, which are out the control of the Rocktest Engineer ("Engineer"), will change the stresses that act through the geomaterials and their engineering characteristics. Changes in these conditions may significantly alter the way in which the ground conditions behave. As such, the conclusions reached in this report will be less applicable over time and may not be applicable or relevant at a later point in time. Rocktest disclaims responsibility for any changes that might have occurred or the implication of these changes on the assessments or recommendations in this report.
- This report was prepared specifically for Sibelco Australia Pty Ltd ("Client") and for a specific purpose. It was not prepared for the use by any party other than the client and its respective consulting advisers.
- It is not possible to make a proper assessment of the report without a clear understanding of the terms of engagement upon which it was prepared, including the scope of instructions, directions and information provided by the client to those who prepared the report and the assumptions made in the report. The report may not address issues that would need to be addressed if the intention, environment, circumstances, time requirements and brief were different from those for which the report was prepared. Only the Engineer has a true understanding of the affects that these limitations and the assumptions made in the report may have on the conclusion reached within the report. As such, no party other than the Client should use the data, contents of the report or the techniques used in it for application to conditions different from those for which the report was intended without an independent and detailed review being carried out as to its suitability, relevance and accuracy.
- This report must be read in full. No responsibility is accepted for use of any part of the report in any other context or for any other purpose other than that for which it was prepared.
- Where engineering advice, recommendations and/or designs are provided, all elements/components of the advice, recommendations and/or designs are intended to function in combination. The Engineer accept no liability arising out of their partial application.
- The Engineer will not accept any responsibility for negligence, nor any loss or damage suffered by the Client due to the occurrence of events or the existence of any factors which are out of the Engineer's control. The Engineer will indemnify the Client for claims or loss arising from a breach of professional duty in the provision of the professional services. The liability of the Engineer is reduced to the extent that the Client or other person(s) caused or contributed to the loss or occurrence which gave rise to the claim.
- This report does not purport to give legal advice. Legal advice can only be given by qualified legal practitioners.

The above clauses do not in any way attempt to absolve the Engineer from any professional responsibilities in relation to the diligent and careful performance of duties in providing this report. Rather, they are intended to be a guide as to where the Engineer's responsibilities end, and where forces of nature assume responsibility for the composition of a volume of geomaterials and its performance.

FIGURES



(a)

(b)

Figure 1. (a) North and (b) South walls at the west end of East-West pit. Waste rock dump WRD 1 is behind the crest. The west ramp (right) may be retained.

(a)

(b)

Figure 2. (a) Northeast and (b) Southwest walls at the south end of East-West pit. Waste rock dump WRD 1 is behind the crest.

(a)

(b)

Figure 3. (a) North and (b) South walls of Phoenix pit. The main ramp is to be retained.

(a)

(b)

Figure 4. (a) East and (b) West walls of Aspinal pit. The pit to be partially filled thereby reducing the slope angles .

(a)

(b)

Figure 5. WRD 1 to the west of the East-West pit. The dump to remain in-situ. (b) The bund along the crest is inadequate as an abandonment barrier. It is to be replaced with an abandonment bund (Section 7.3.2). The bund is to tie into the bund encircling the pit at the east and west ends of the dump.

(a)

(b)

Figure 6. WRD 2 a) North section 35-m east of the Phoenix pit and b) South section 140-m south of the pit. The dump will provide rocks for the abandonment bunds. The dumps will then be graded, shaped, topsoil placed and hydroseeded.

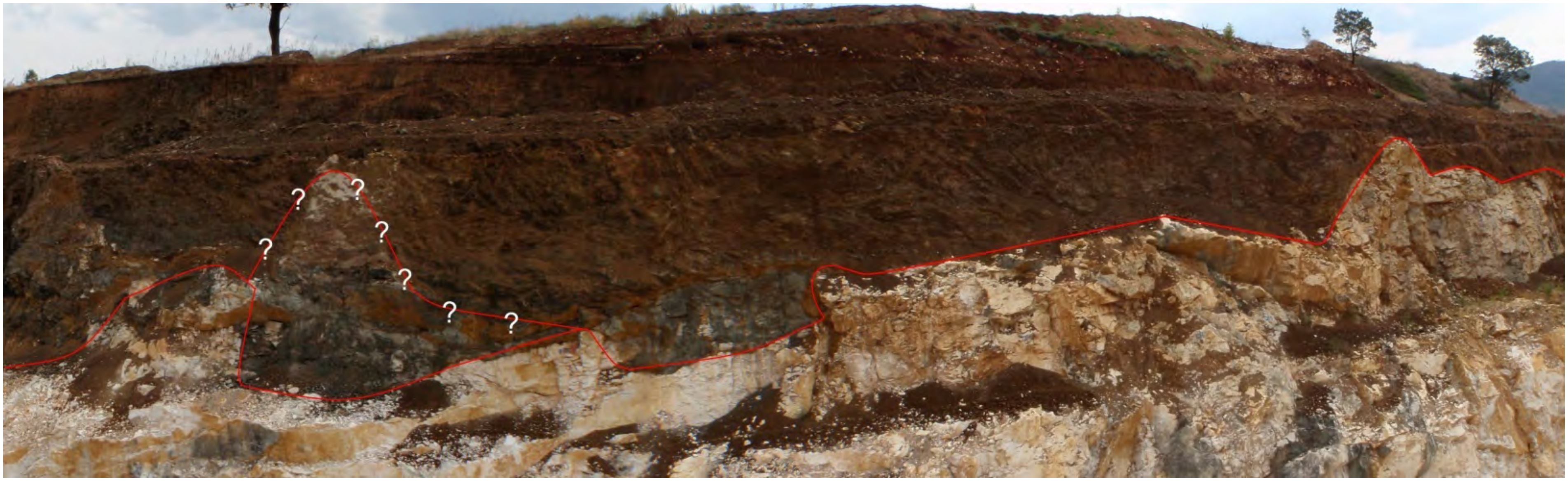


Figure 7. Dissolution has resulted in the upper surface of the limestone being karstified hence irregular. Example is from the south wall at the north end of the East-West pit.

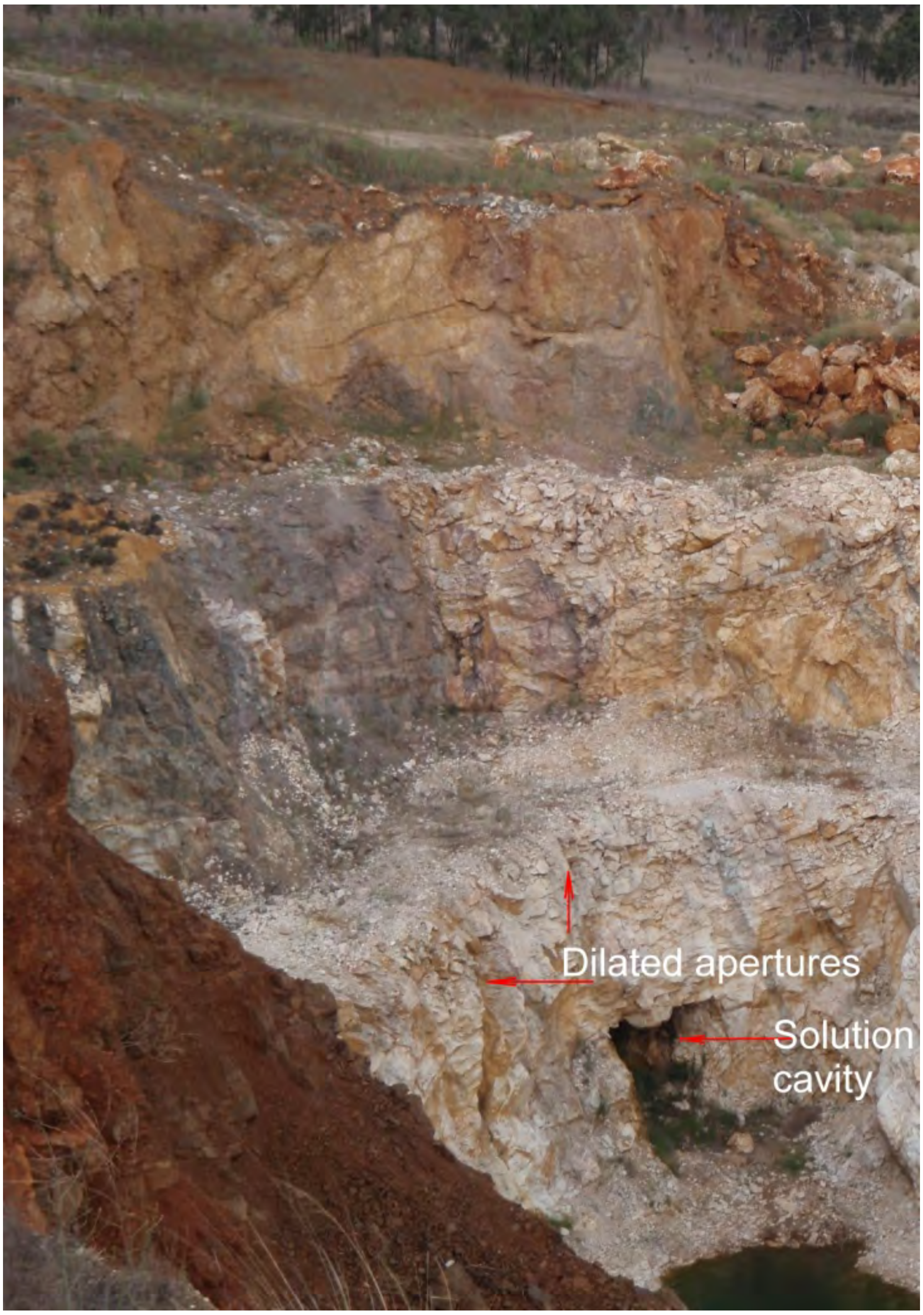


Figure 8. Karst features exposed in the northwest wall at the south end of the East-West pit.

Figure 9. Limestone intruded by grey andesite exposed in the west wall at the north end of the East-West pit.

Figure 10. Example of synclinal fold in the upper benches at the west end of the East-West pit.

Figure 11. Examples of faulting exposed in the upper benches at the west end of the East-West pit.

Figure 12. Examples of traces of large wedges formed by the intersections of faults and bedding.

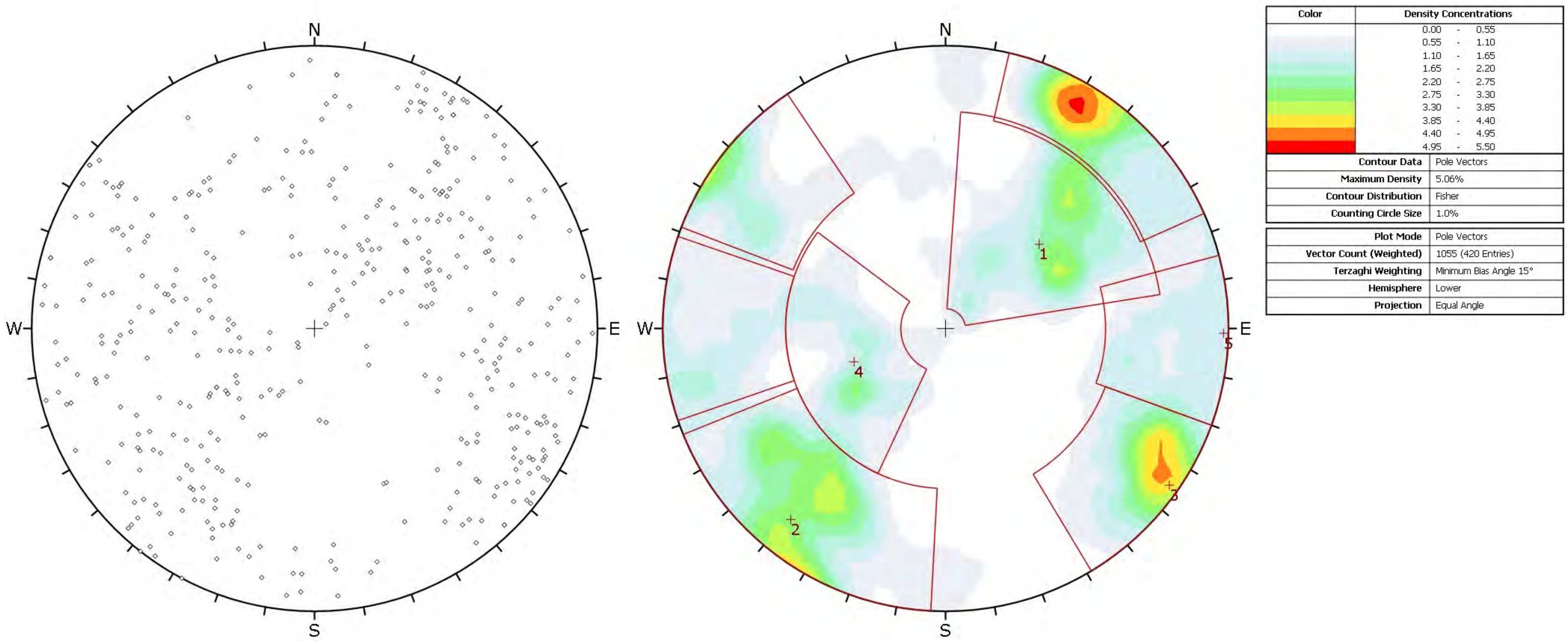


Figure 13 a) Poles to the logged discontinuities plotted on a stereonet.
b) Poles contoured to highlight five sets of discontinuities.

Figure 14. Examples on the south wall at the west end of the East-West pit of discontinuity spacings being significantly less than the mean values. The rock masses in these areas have accelerated weathering and localised instabilities that extend over multiple benches.

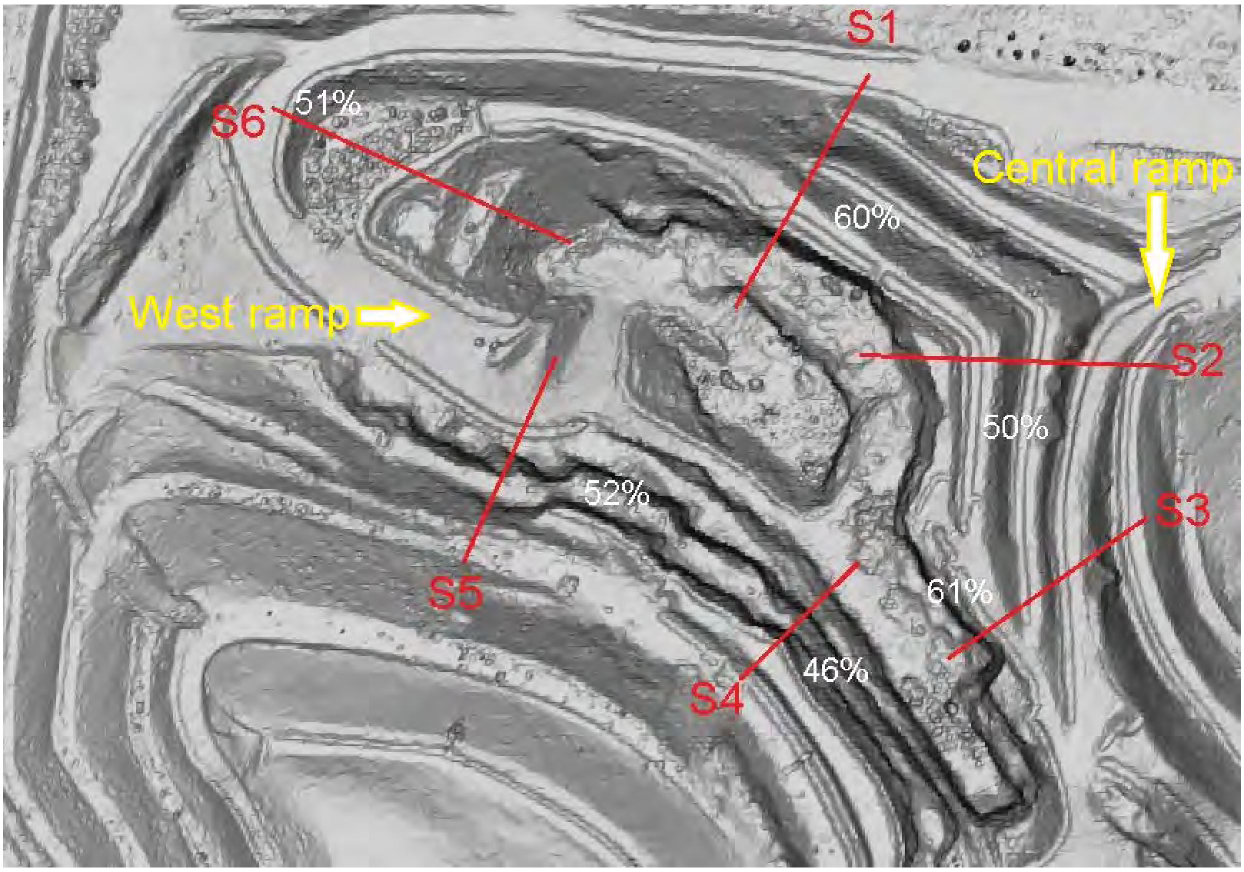


Figure 15. Upper bound bench scale stabilities (PoFs) at the west end of the East-West pit.

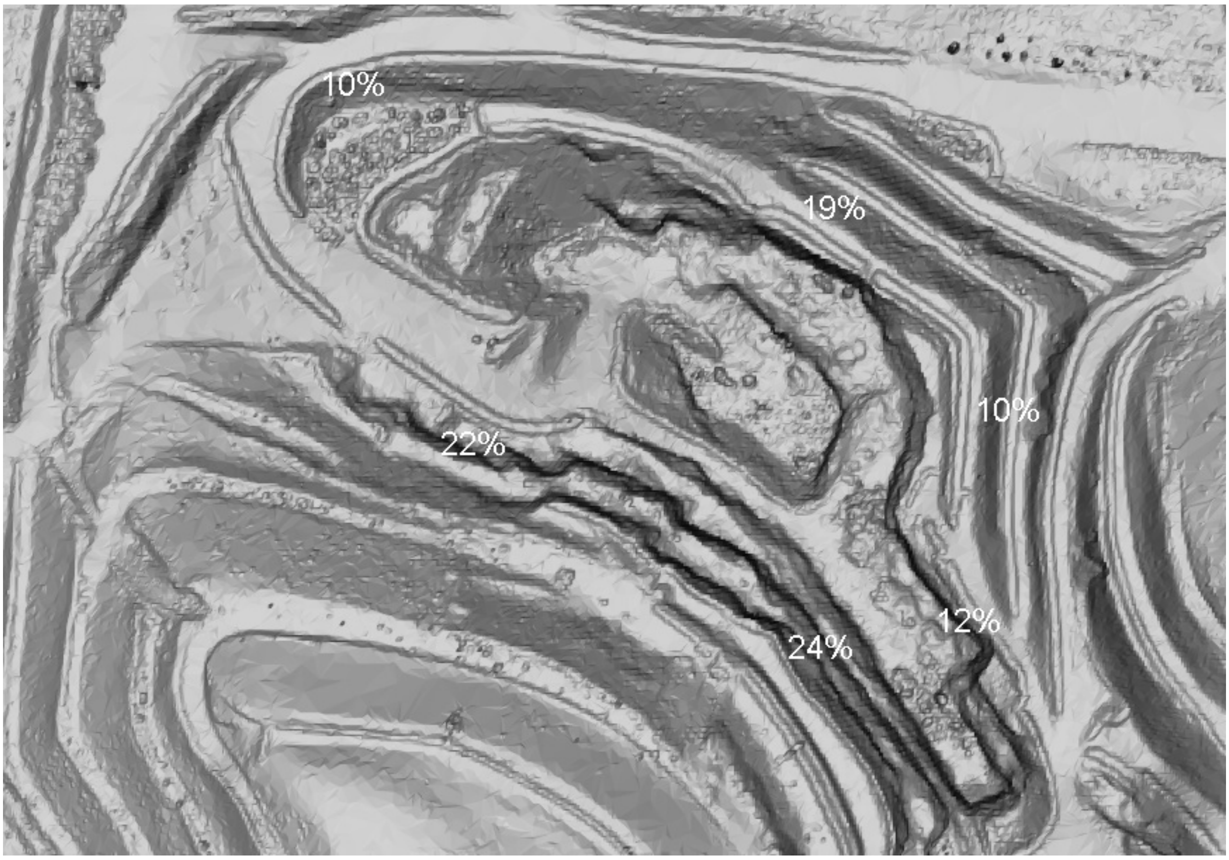


Figure 16. Upper bound overall scale stabilities (PoFs) at the west end of the East-West pit.

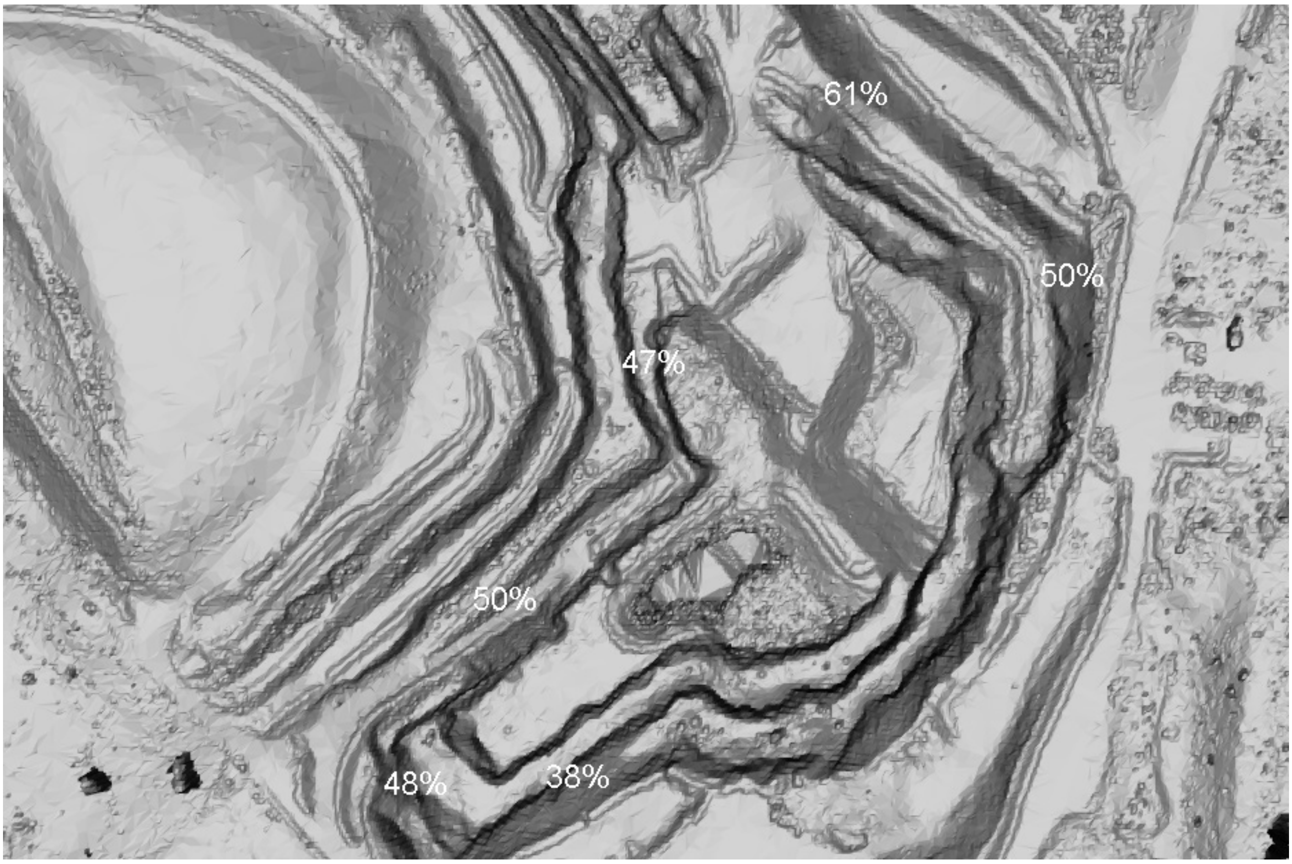


Figure 17. Upper bound bench scale stabilities (PoFs) at the east end of the East-West pit.

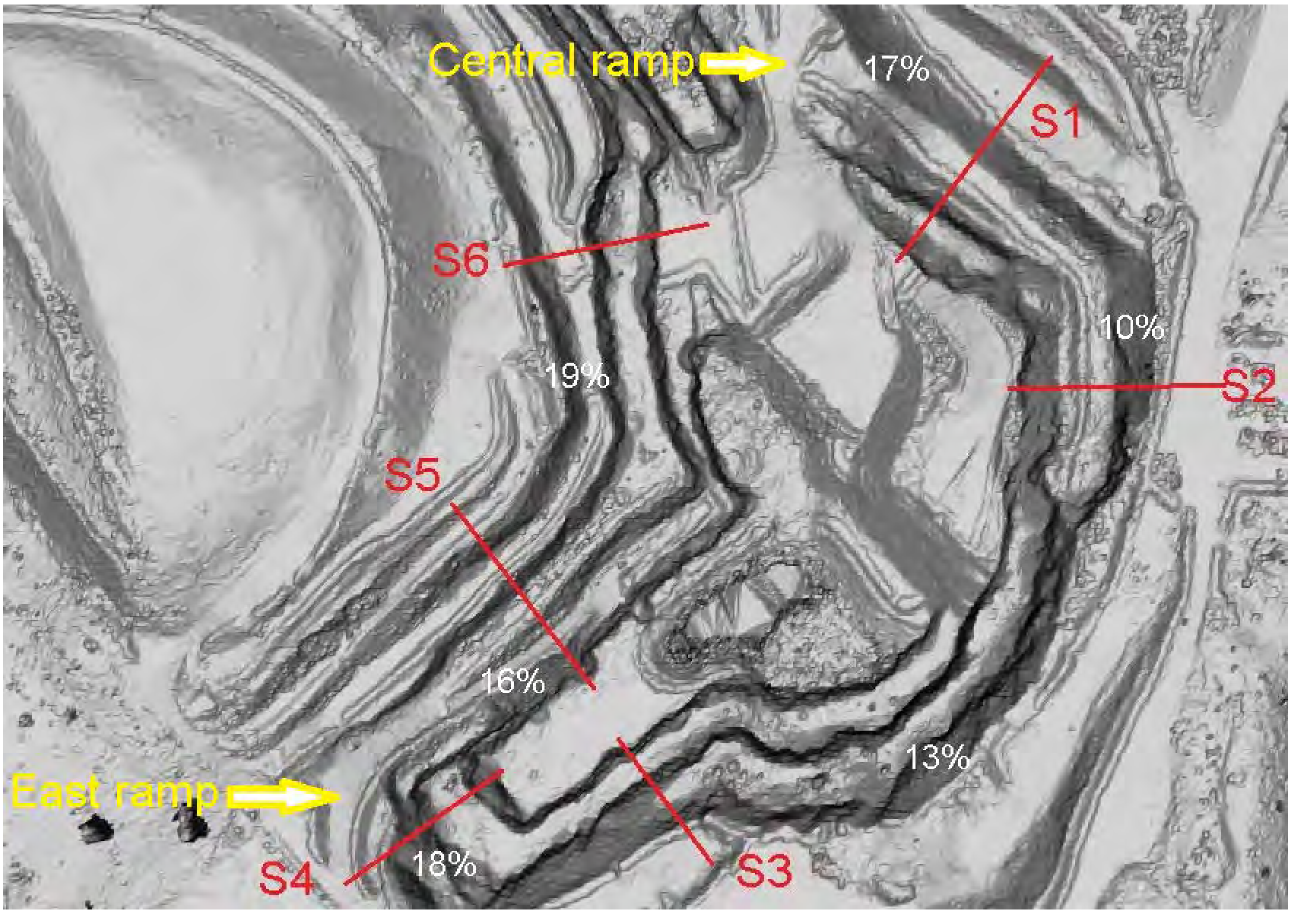


Figure 18. Upper bound overall scale stabilities (PoFs) at the east end of the East-West pit.

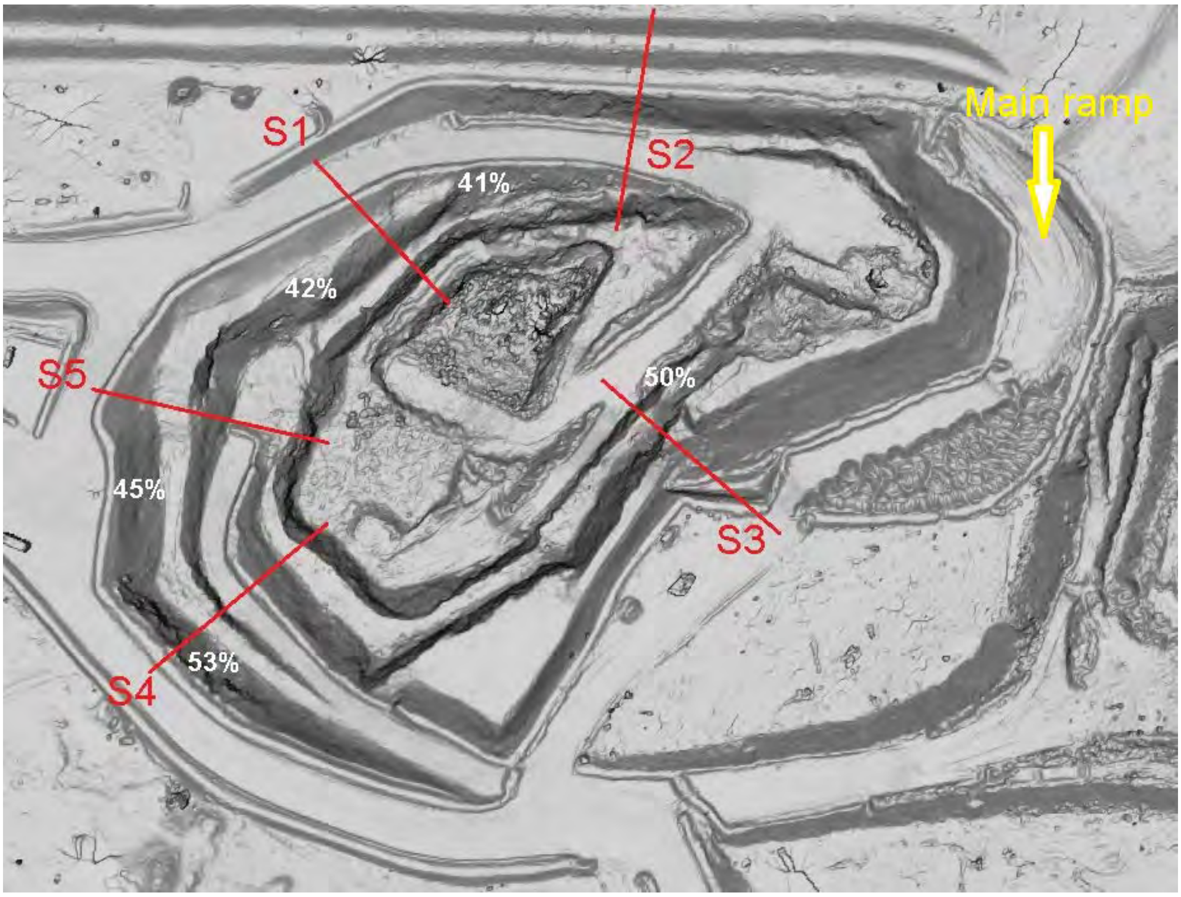


Figure 19. Upper bound bench scale stabilities (PoFs) around the Phoenix pit.

Figure 20. Upper bound overall scale stabilities around (PoFs) the Phoenix pit.

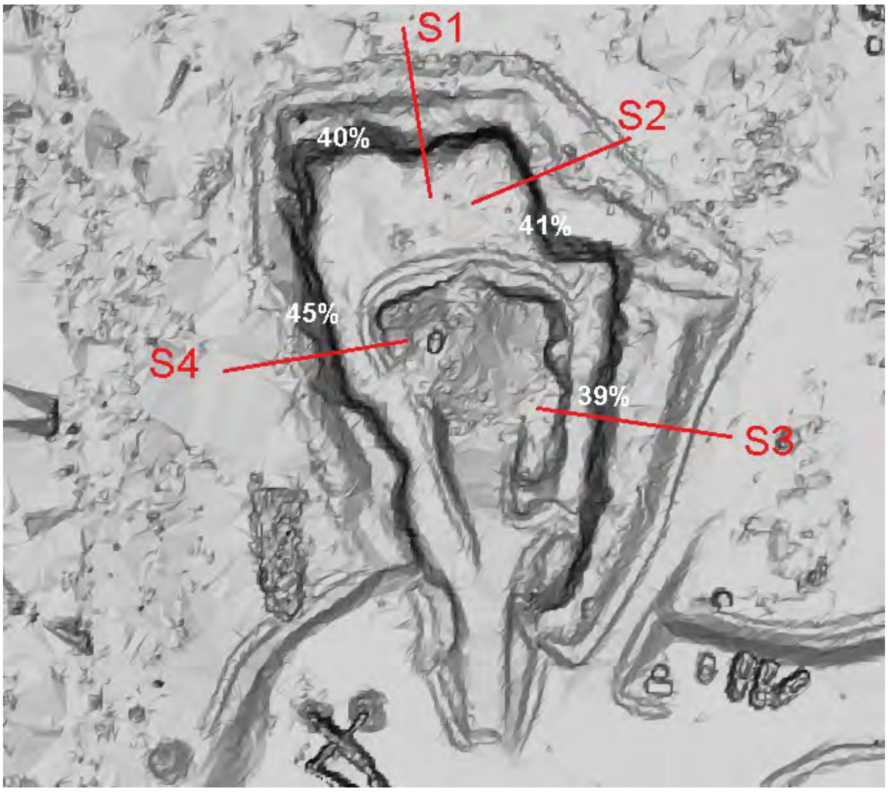


Figure 21. Upper bound bench scale stabilities (PoFs) around the Aspinal pit.

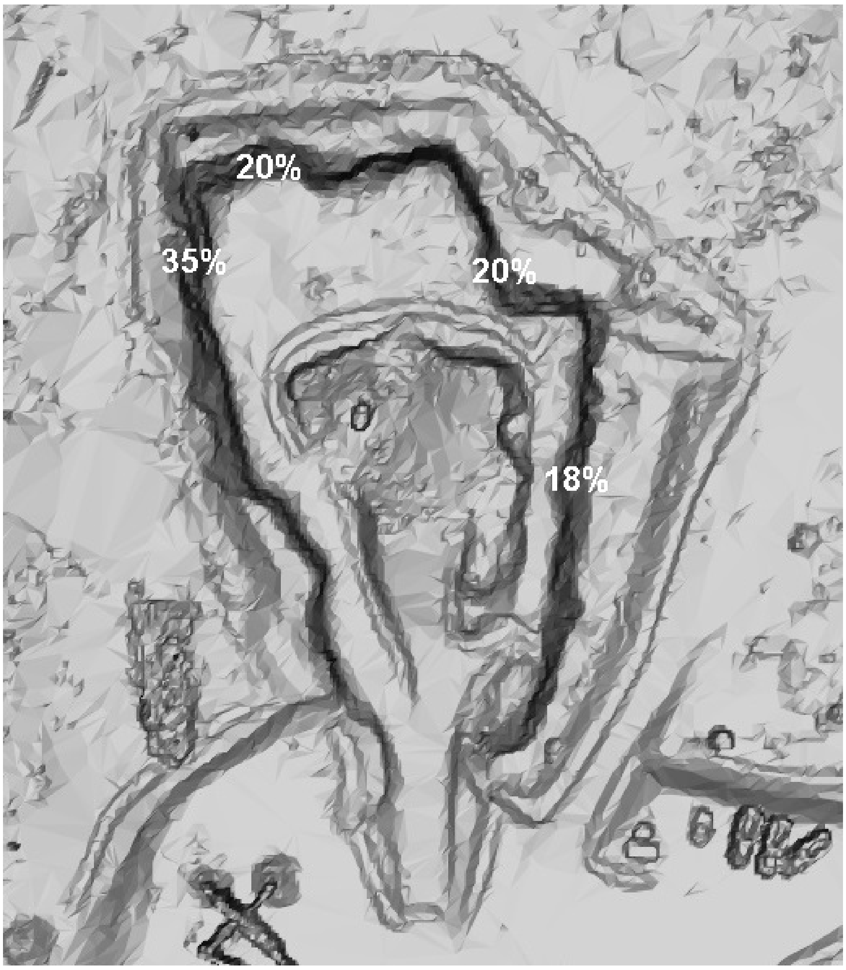


Figure 22. Upper bound overall scale stabilities (PoFs) around the Aspinal pit.

Figure 23. Loose and overhanging rocks (highlighted) on the batters of the north wall at the west end of the East-West pit.

Figure 24. Scree filled berms, loose rocks on batters and overhanging rocks (highlighted) on the northeast wall at the east end of the East-West pit.

Figure 25. Loss of widths of some sections of some berms, loose rocks on batters (highlighted) on the southwest wall at the east end of the East-West pit.

Figure 26. Loss of widths on some berms and scree filled sections of berms, loose rocks on batters and overhanging rocks (highlighted) on the north wall of the Phoenix pit.

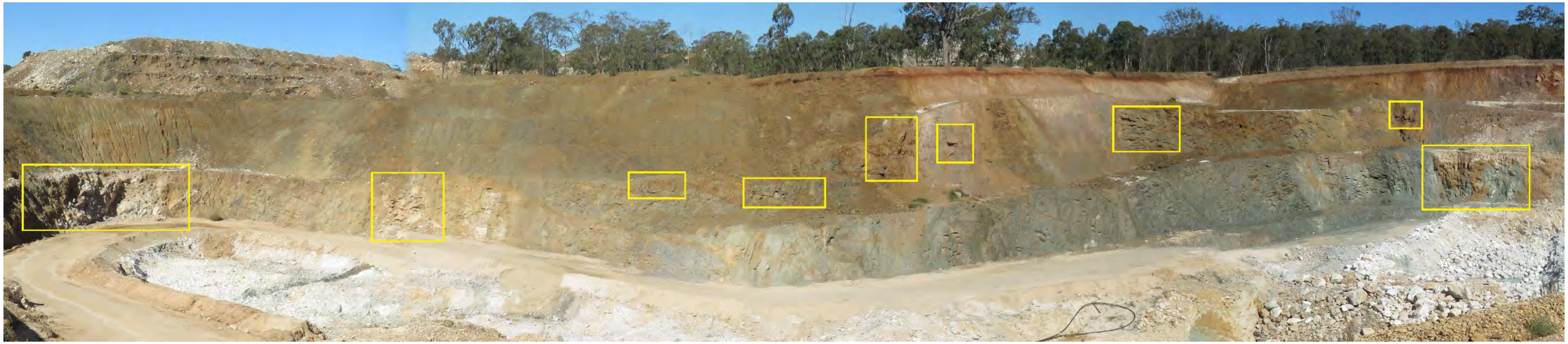


Figure 27. Loose rocks on the batters and overhanging rocks (highlighted) on the south wall of the Phoenix pit.

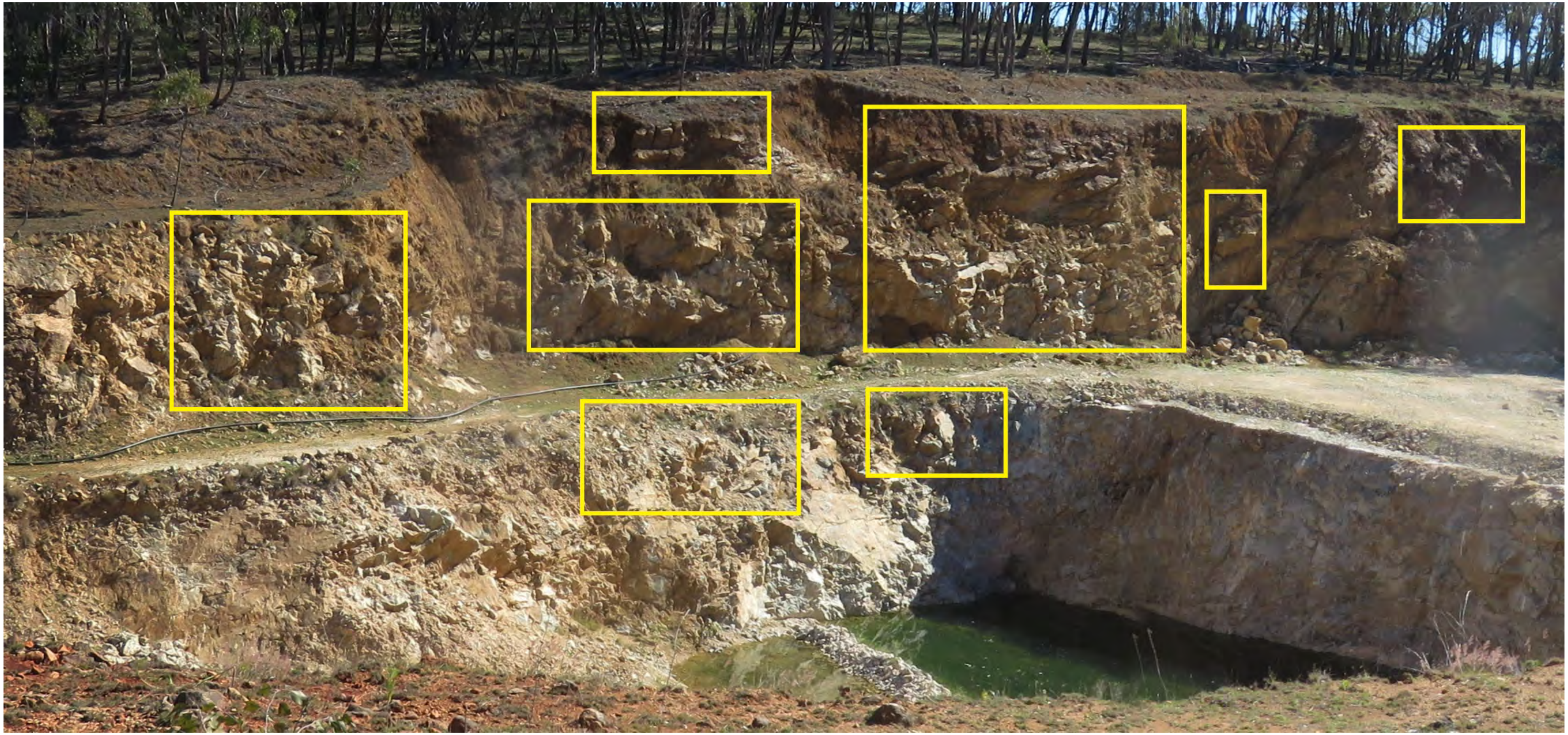


Figure 28. Loose rocks on the batters and overhanging and toppling rocks (highlighted) and scree on the berms on the west wall of the Aspinal pit.

Figure 29. Loose rocks on the batters and overhanging rocks (highlighted) and loss of berm widths and scree on the berms on the east wall of the Aspinal pit.

Figure 30. Sawtooth profile on the lower batter of the north wall of the east pit in the East-West pit due to multiple wedges sliding.

Figure 31. Toppling rocks on an east dipping batter on the upper bench of the Phoenix pit.

Figure 32. Loose rocks (highlighted) within soil and weathered siltstones near the crest of the batter adjacent to the central ramp in the East-West pit are currently hazards for users of the ramp. Batter should be draped in rockfall mesh, debris removed from the toe and drainage installed across and down the ramp. Flows of water from the overlying 550-mRL berm are not be modified with berm and batter drain and crest bunds.

Figure 33. Erosion on the batters adjacent to the main ramp in the Phoenix pit. If not controlled will increase the likelihood for instabilities. Batter is to be hydroseeded

Figure 34. Loss of widths of most sections of the berms and scree filled berms, loose rocks on batters and overhanging rocks on the south wall at the west end of East-West pit. If the adjacent western ramp is to be retained, the height and continuity of the current toe bund are to be increased. Otherwise the ramp will be removed.

.

Figure 35. Two deep gullies cut in the haul-road and ramp at the west end of the East-West pit by water shedding off the ramp require remediation.

Figure 36. Deep gully cut by water shedding off the west end of WRD 1 is contributing to erosion of the ramp at the west end of the East-West pit. Drain will be remediated when the ramp is removed.

Figure 37. Gully cut by water shedding off the central ramp on the north wall of the East-West pit requires lining and sediment traps.

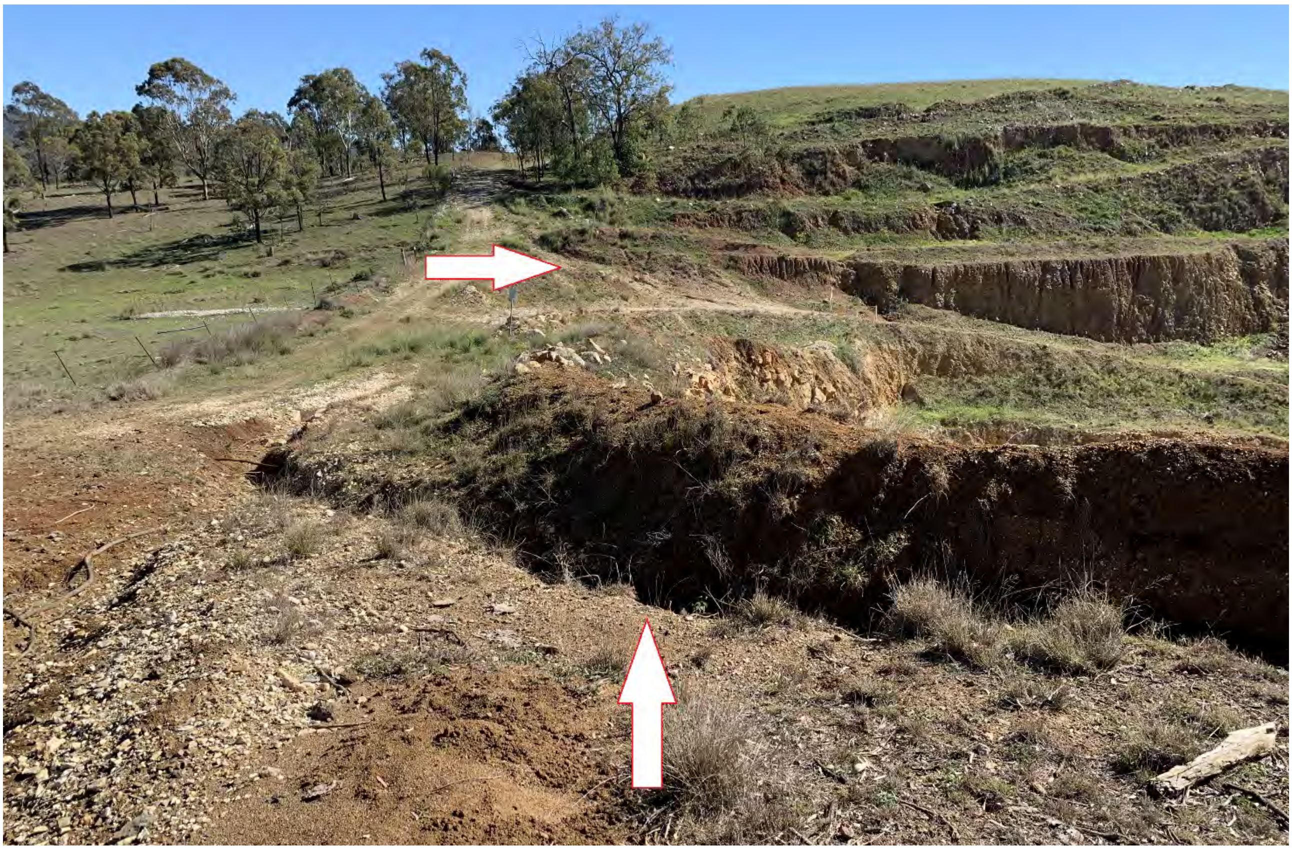


Figure 38. 2 x deep gullies cut by water shedding off the haul-road along the east end of the East-West pit requires repair. Haul-road to be graded to shed water to the east and ripped.

Figure 39. The haul-road along the east end of the Phoenix pit is to be graded to shed water to the east, removed by ripping and hydroseeded.

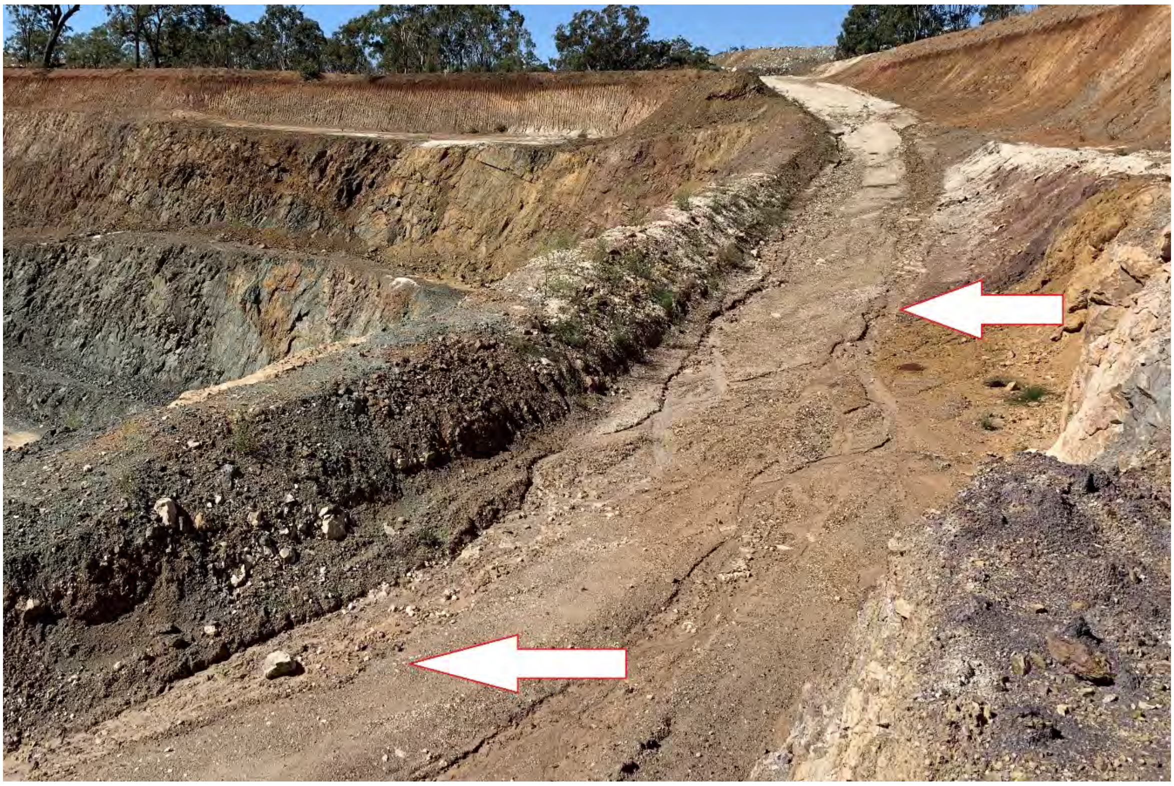


Figure 40. The ramp along the west end of the Phoenix pit requires ripping and drainage control to prevent shallow gullies cut by water from triggering instabilities.

(a)

(b)

Figure 41. Overland flows are eroding topsoil, karst fill and extremely weathered limestones and siltstones in the upper bench at the east end of Phoenix pit (b) The bund along the crest of the is likely sufficiently high to prevent overland flows of water from flowing from behind the crest.
Removal of the haul-road and hydroseeding is required.

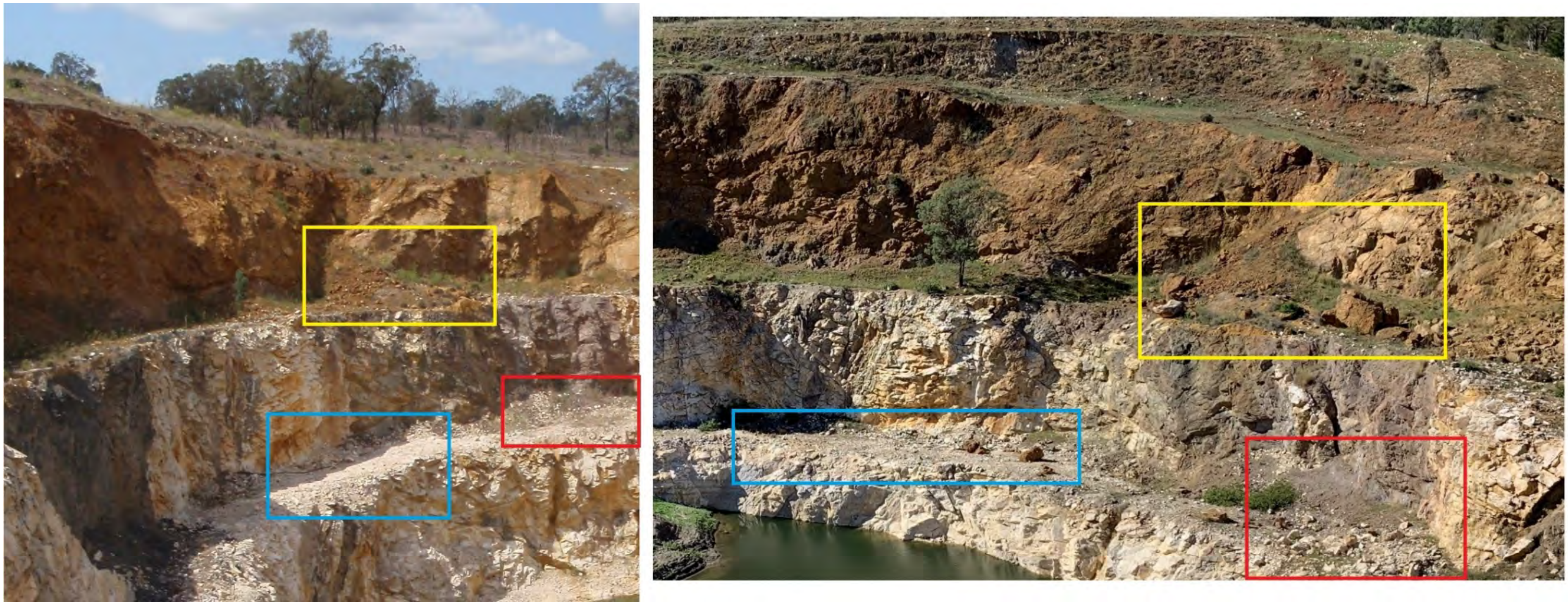


Figure 42. No significant differences in the volumes of rockfall debris on berms on the northeast wall at the east end of East-West pit in (left) 2004 and (right) currently.

Figure 43. No significant differences in the volumes of rockfall debris on berms and the loss of berm widths on the south wall at the west end of East-West pit in (left) 2004 and (right) currently.

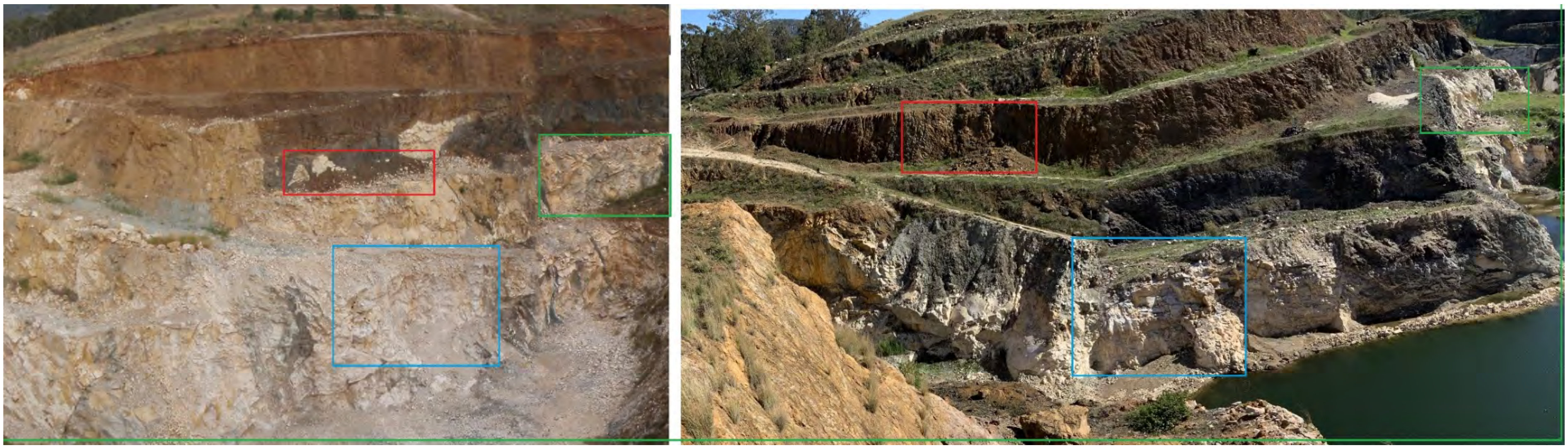
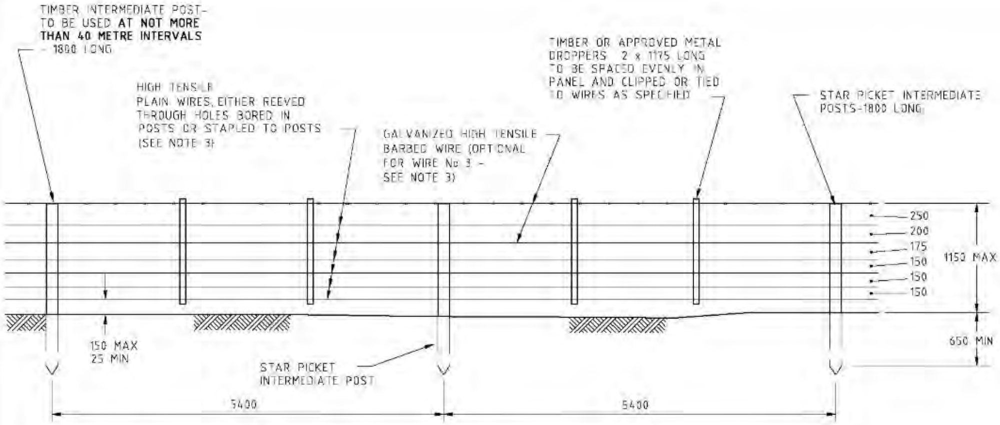


Figure 44. No significant differences in the volumes of rockfall debris on berms and the loss of berm widths on the southwest wall at the east end of East-West pit in (left) 2004 and (right) currently.

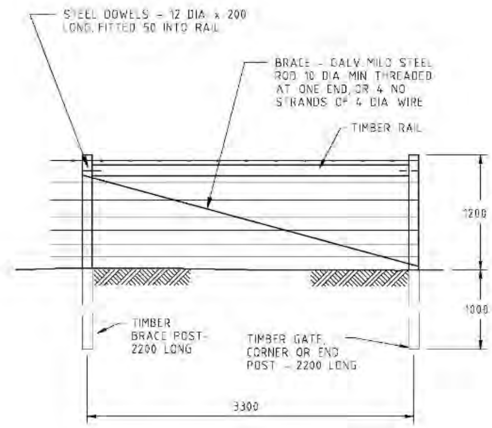
Figure 45. Upper surface of waste rock dump 1 (WRD 1) to the west of the East-West pit. The surface has been contoured and topsoil spread enabling a low to moderate density of grasses to establish.

Figure 46. Upper surface of the southern section of waste rock dump 2 (WRD 2) to the southeast of Phoenix pit. The surface shaping, grading, crowning, topsoil and hydroseed.

Figure 47. A section of the 3.5-m high bund placed 8-m behind the crest of the east wall of Phoenix pit. Although the offset is less than the 10-m requirement, it is considered acceptable at this location. The haul-road is to be graded to the east, ripped and hydroseeded.



GENERAL ARRANGEMENT



SINGLE STRAINER ASSEMBLY

FOR USE AT GATEWAYS, ENDS, ANGLES, ETC.

NOTES:

1. INTERMEDIATE STRAINER ASSEMBLIES SHALL HAVE TWO BRACE POSTS AND BOTH DIAGONALS BRACED, AND SHALL BE PROVIDED ON STRAIGHTS AT INTERVALS NOT EXCEEDING 200 METRES.
2. ELECTRICAL INSULATION DETAILS FOR FENCES IN THE VICINITY OF TRANSMISSION LINES AND TOWERS REFER SD 3171
3. **FENCE TYPES:**

   TYPE B1 1 No 1.6 DIA HIGH TENSILE BARBED WIRE AT THE TOP AND 6 No 2.5 DIA HIGH TENSILE PLAIN WIRE.

   TYPE B2 - 2 No 1.6 DIA HIGH TENSILE BARBED WIRE (THE TOP AND THIRD WIRE) AND 5 No. 2.5 DIA HIGH TENSILE PLAIN WIRE.
4. POST AND WIRE FENCES TYPE B ARE USUALLY INSTALLED IN RURAL AREAS ALONG ROAD RESERVATION BOUNDARIES.

SCHEDULE OF MATERIALS

	INTERMEDIATE POSTS	GATE, CORNER OR END POSTS	BRACE POSTS	RAIL	DROPPERS
UNTREATED TIMBER - SPLIT HARDWOOD	175 x 100	150 x 150 OR 300 DIA	175 x 100	150 DIA	50 x 38
TREATED TIMBER - HARDWOOD OR PINE	100 DIA MIN	150 DIA MIN	125 DIA MIN	125 DIA MIN	42 x 35 PINE OR 40 x 19 HARDWOOD
CONCRETE	REFER SD 3161				
STEEL - POSTS - WIRE	STAR PICKET	REFER SPECIFICATION REFER NOTE 3			

AMEND.	Appd	Date	AMENDMENTS
E			
D			
C			
B			
A	J.C.	1-7-95	GEN NOTES 2 & 3, NOTES 3 & 4, FENCE TYPES CHANGED.

GENERAL NOTES / CROSS REFERENCES

1. FENCE - DOUBLE STRAINER ASSEMBLY SD 3151
2. ALL DIMENSIONS ARE IN MILLIMETRES
3. THIS DRAWING IS PROVIDED AS A GUIDE FOR GOOD FENCING PRACTICE. PROPERTY OWNERS MAY AGREE TO THE ERECTION OF A STANDARD FENCE OF SIMILAR TYPE TO THE EXISTING FENCE AS AN ALTERNATIVE

vicroads

PRINCIPAL ROAD DESIGN ENGINEER'S DEPARTMENT

STANDARD DRAWING
FENCE (TYPE B)
B1 AND B2
POST AND WIRE

APPROVED	DATE	SPEC. REF. No	SHEET No.	DRAWING No	AMENDMENT
PRINCIPAL RD ENGINEER	1-7-95	707		SD 3111	A

Figure 48. Example of Type B fences suitable for limited use as an abandonment barrier where an abandonment bund cannot be used.

Figure 49. Batter adjacent to the central ramp in the East-West pit requires draped rockfall mesh and improved drainage on the ramp and 550-mRL berm above the ramp.

(a)

(b)

Figure 50. (a) If the western ramp in the East-West pit is to be retained, the heights of (b) the current toe bunds are to be increased. If the ramp is not to be retained, the surface is to be ripped and a series of low bunds are to be installed at regular intervals along contour down the inclined surface to reduce flow rates.

Figure 51. Example of concrete canvas liner for ramp drains

Figure 52. Water shedding off the 550-mRL berm is destabilising the 540-m to 550-mRL batter adjacent to the central ramp. Lined drains are required above and along the berm and down the batter.

Figure 53. Example of a batter draped in high tensile strength rockfall mesh.

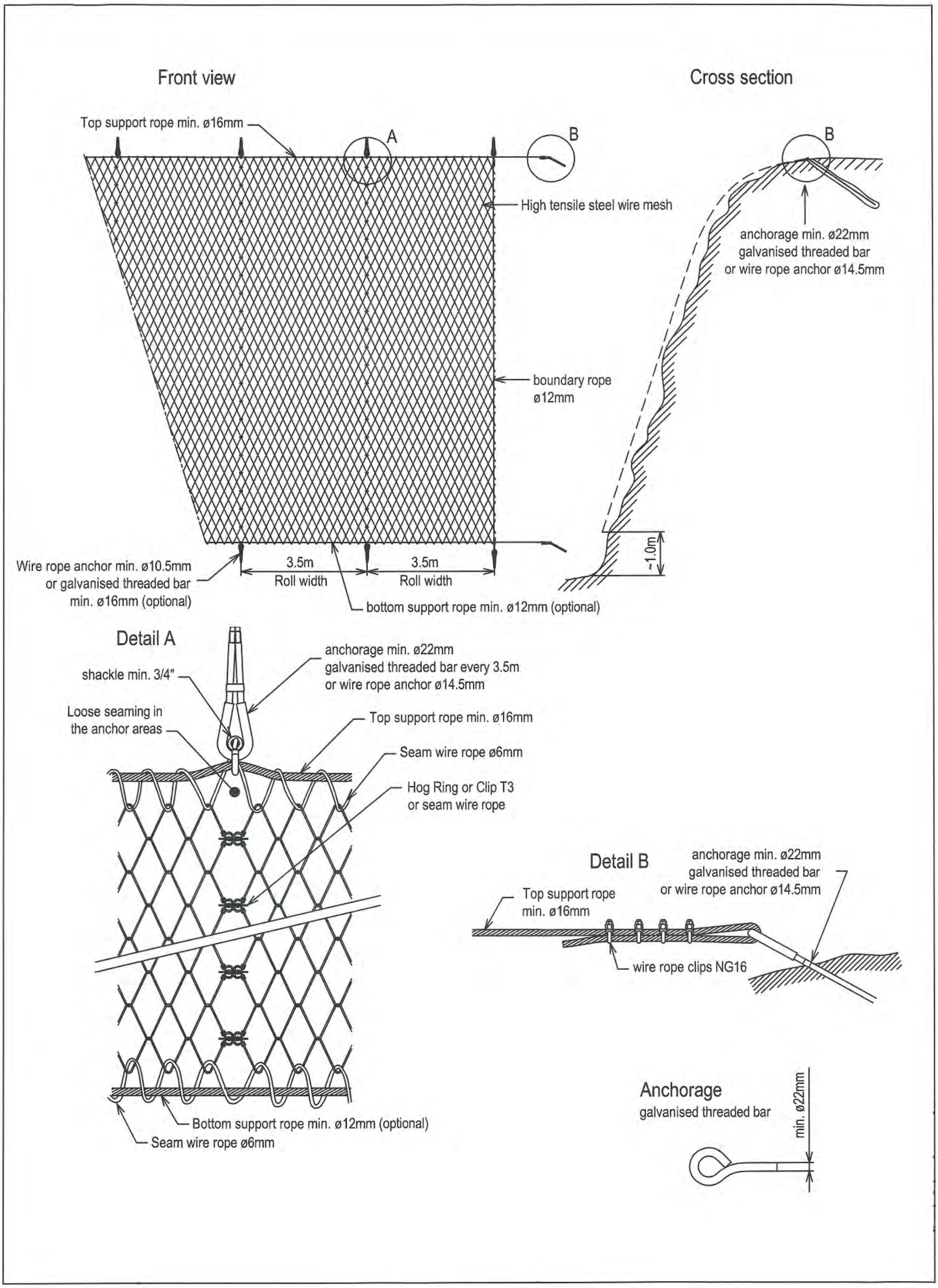


Figure 54. General characteristics of a mesh "drape" rockfall control system

Figure 55. Hydroseeding, and desirably hydromulching, are recommended for the batter adjacent to the main ramp along the east wall of the Phoenix pit and for spraying topsoil on WRD 2.

Figure 56. The ramp at the west end of WRD 1 on the south wall of the East-West pit is to be removed by ripping after an abandonment bund has been being installed along the north crest of the dump.

APPENDICES

APPENDIX 1 RISK ASSESSMENT CLASSIFICATIONS

Table A1.1 Quantitative Measures of Likelihood

Level	Descriptor	Description
A	Almost certain	Will occur, is of a continuous nature, or the likelihood is unknown. Expected to occur in most circumstances
B	Likely	Will probably occur in most circumstances
C	Possible	Might occur at some time.
D	Unlikely	Could occur at some time but is not expected to occur.
E	Rare	Has almost never occurred but conceivably could. May occur only in exceptional circumstances

Table A1.2. Quantitative Measures of Consequence: Health and Safety

Severity Level	Descriptor	Description
5	Insignificant	No injuries. No medical treatment required.
4	Minor	Objective but reversible disability requiring hospitalisation. First Aid treatment.
3	Moderate	Moderate irreversible disability or impairment to one or more persons. Medical treatment required.
2	Major	Extensive injuries. Severe irreversible disability to one or more persons.
1	Catastrophic	Fatality

Table A1.3 Risk Matrix

		Consequence of Event				
		5	4	3	2	1
Likelihood of Event		Insignificant	Minor	Moderate	Major	Catastrophic
A	Almost certain	L	H	H	E	E
B	Likely	L	M	H	H	E
C	Possible	L	M	M	H	H
D	Unlikely	L	L	M	M	H
E	Rare	L	L	L	M	M

Table A1.4. Risk Level Implications.

Extreme (E)	Do not proceed with task until risk is reduced. Go back and review controls to include more effective measures. Detailed action plan required, allocation of resources and effective monitoring. Controls should involve Elimination, Substitution or Isolation.
High (H)	Reduce risk urgently. Controls should involve Elimination, Substitution or Isolation. Senior management consultation. May be tolerable in special circumstances only.
Medium (M)	Take reasonable steps to mitigate the risk. Until elimination, substitution, isolation or engineering controls can be implemented, institute administrative or PPE controls. Management responsibility must be specified.
Low (L)	Reduce risk when/if convenient. Manage by routine procedures. Review by supervisor. Proceed with activity.

APPENDIX 2 KINEMATIC STABILITIES OF THE PITS WALLS

This study used the stereographic method, as implemented in the software Dips[46], to assess whether the kinematics[47] applicable to the walls of the pits are conducive to instabilities. The method calculates the proportions of the logged discontinuities that are conducive to:

- masses of rocks sliding along single (planar) or multiple (wedge) discontinuities and
- individual rocks or masses of rocks toppling.

Although significant limitations in the analysis method limit the veracities of the results, they are of a standard suitable for the scope and purpose of this study.

Analyses

The assessments assumed conducive to the following:

- The sets of discontinuities have the orientation characteristics listed in Table 1.
- Batters dip at the average angles listed in Table 3.
- Walls dip at the overall slope angles listed in Table 6.
- Batters and walls dip towards the means of the ranges listed in Table 4.
- Discontinuities have conservative peak shear strengths of 21^{o} as discussed in Section 2.4.5.

The propensity for a failure mode to develop was defined as follows:

- For planar sliding and toppling, the propensity is the percentage (P_f) of the total number of poles[48] to the logged discontinuities that are within the highlighted “critical zones” [49].
- For wedge sliding, the propensity is the percentage (P_f) of the total number of intersections between pairs of discontinuities that are within the “critical zones”.

Figure A2.1 shows an example of a stereonet applicable to wedge sliding.

The results of the analyses are listed in Tables A2. and discussed in Section 4.1.

---

[46] The kinematic analysis software, Dips, is produced by Rocscience Inc, Toronto.

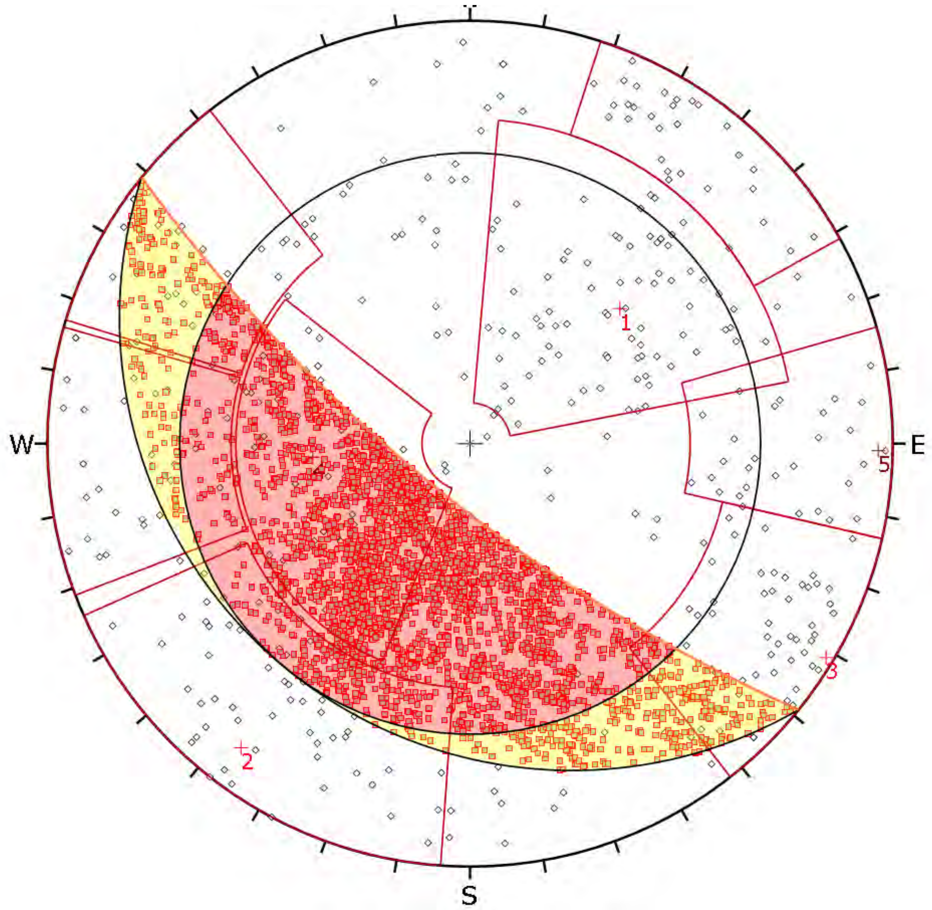
[47] Kinematics describes the motion of rocks without considering their masses nor the forces that may cause the motion. It is primarily concerned with the orientations of discontinuities bounding rocks with respect to the orientations of slopes from which rocks may move.

[48] In a stereonet analysis, a discontinuity is assumed to be a planar feature represented on a stereonet as a “great circle”. The “pole” to a discontinuity is a downward directed line orientated perpendicular to the plane. It is represented on a stereonet as a point.

[49] The propensity for wedge sliding is defined as the proportion (P_f) of the total number of lines representing intersections of pairs of discontinuities that are within the highlighted “critical zone”.

Table A2.1. Results from stability analyses.

					Bench Scale Stability Analysis					Overall Scale Stability Analysis				
					Sliding		Toppling			Sliding		Toppling		
			Dip Dirn	Overall slope angle	Planar	Wedge	Flexural	Block		Planar	Wedge	Flexural	Block	
Pit	Section	Wall	(deg)	(deg)	$PoF_{individual}$				$PoF_{combined}$	$PoF_{individual}$				$PoF_{combined}$
East-West	west pit	1	219	35	12.5	42.2	8.4	13.8	60%	1.6	6.9	3.2	8.7	19%
		2	278	28	8.2	28.9	14.1	10.0	50%	0.1	0.7	2.9	6.9	10%
		3	229	29	15.3	42.4	8.3	12.1	61%	0.4	2.2	1.7	7.9	12%
		4	61	45	4.9	20.5	15.8	15.9	46%	1.2	5.5	5.9	13.9	24%
		5	29	37	3.6	19.2	14.5	27.4	52%	0.5	4.1	5.3	13.4	22%
		6	140	18	4.8	33.6	10.0	13.9	51%	0.0	0.0	0.0	9.6	10%
	east pit	1	223	34	14.1	42.5	9.0	13.1	61%	1.4	5.7	2.8	8.4	17%
		2	275	26	7.8	30.0	14.1	9.8	50%	0.1	0.4	2.9	6.7	10%
		3	320	32	2.1	19.6	8.4	13.7	38%	0.2	1.9	3.4	7.7	13%
		4	57	37	5.3	20.4	16.1	17.7	48%	0.6	2.9	3.4	12.5	18%
		5	148	32	5.4	35.8	4.6	13.4	50%	0.3	3.5	2.8	10.3	16%
		6	85	35	7.7	22.3	14.6	13.3	47%	0.9	1.9	5.7	11.3	19%
Phoenix		1	141	34	4.8	34.0	9.6	13.8	51%	0.0	3.8	6.9	10.8	20%
		2	179	25	4.9	39.7	2.1	14.7	52%	0.0	1.2	0.2	8.6	10%
		3	213	31	11.0	41.2	7.0	14.9	59%	0.8	4.2	2.1	8.5	15%
		4	45	24	5.6	19.4	18.5	24.2	53%	0.0	0.4	0.5	9.6	10%
		5	102	31	9.2	24.0	19.1	14.8	52%	0.0	1.0	8.1	11.1	19%
Aspinal		1	169	15	4.3	39.0	1.9	13.8	51%	0.0	0.0	0.0	8.4	8%
		2	263	27	10.8	34.0	11.6	9.6	53%	0.0	0.4	2.9	7.1	10%
		3	284	28	6.9	26.6	14.1	10.3	47%	0.3	0.9	2.9	6.8	11%
		4	75	35	6.5	20.6	15.0	13.5	45%	0.8	2.2	4.4	11.2	18%



Symbol	Feature
◇	Pole Vectors
▫	Critical Intersection

Kinematic Analysis	Wedge Sliding		
Slope Dip	75		
Slope Dip Direction	219		
Friction Angle	21°		
Weighted Results	Critical	Total	%
Wedge Sliding	232280	550812	42.17%

Plot Mode	Pole Vectors
Vector Count (Weighted)	1051 (420 Entries)
Terzaghi Weighting	Minimum Bias Angle 15°
Intersection Mode	Grid Data Planes
Intersections Count (Weighted)	550812
Hemisphere	Lower
Projection	Equal Angle

Figure A2.1. Example of the results from a wedge sliding stability analysis. This example applies to a bench on the north wall of the west pit in the East-West pit. Each point represents the line formed by the intersection of two discontinuities. The proportion (42%) of points in the red and yellow “critical” zones is a measure of the propensity for a wedge sliding mode of instability to occur.

APPENDIX 3 BARRIER OFFSETS FROM CRESTS

Offsets are based on procedure in Government of Western Australia Department of Industry and Resources (1997) *Safety Bund Walls Around Abandoned Open Pit Mines: Guideline*. MOSHAB Approved. Document No: ZMA048HA. 14 pages.

			Wall							
Pit	Section	Wall	N sth dipping	S nth dipping	W east dipping	E west dipping	Wall height (m)	Overall slope angle (deg)	Depth of weathering (m)	Required Bund offset (m)
East-West	west pit	1	1				42	35	18	10
		2				1	49	28	10	10
		3				1	42	29	10	10
		4			1		40	38	13	14
		5		1			33	21	13	10
		6	1				31	18	18	10
	east pit	1	1				35	34	9	10
		2				1	28	26	2	10
		3		1			34	32	5	10
		4			1		28	39	9	13.7
		5	1				40	32	9	10
		6			1		41	35	9	10
Phoenix		1	1				25	34	5	10
		2	1				21	25	5	10
		3	1				21	31	5	10
		4		1	1		32	24	12	10
		5			1		30	31	13	10
Aspinal		1	1				14	15	15	10
		2				1	12	27	19	20.2
		3				1	18	28	19	15.9
		4			1		13	35	15	21.6