Woodstock Quarries Ltd

Attention Darryn Shepherd

12 May 2022

Woodstock Quarry RFI - response to geological questions (Revised)[1]

A number of geological and/or hydrogeological questions have been raised by Ecan's reviewers. As requested, I have considered these questions and have summarised the questions and my responses below.

Item 1.1 (a) Please provide responses to all question in Section 5 of the attached *CRC214073 Landfill Compliance Review Woodstock Quarries Limited* letter, dated 31 May 2021, and address all the issues identified, particularly in relation to the recommendation to reconsider or further justify the proposed cut slope profile.

Q21 Section 62 of the AEE application states that fresh greywacke would be suitable for use as a low permeability liner and for capping or drainage layers. This is unlikely to be the case. Possibly the author should be referring to the overlying weathered greywacke which is likely to be more soil-like and may prove suitable as a low permeability layer? Fresh greywacke material is likely to be a crushed rock and to form a high permeability product, which would also not be compatible with the proposed geosynthetic liners.

Response: The first sentence of Section 62 should be reworded to read "Weathered rock occurs in the upper 10-15m below ground level." Remainder of Section 62 is then OK.

Q22 Several sections of the report suggest that the proposed bench with of 2 m in the cut highwalls may prove insufficient to control the release of rockfall from a safety perspective. Those sections of the report referring to the cut slope design and require clarification or amendment are provided below:

a. The Geology report, Figure 6, shows greywacke bedding, which the caption states is dipping "approximately 40-45 degrees to the right" into the face with conjugate joints dipping at 45-50 degrees into the pit. This seems at variance with statements in Section 3.1.3 of the report where the bedding dip is "(commonly > 80°)" which would give a conjugate joint set dip set of 10 degrees. Drawing 02 and 03 in Appendix 2 show cut slopes on the section that are much steeper than 45 degrees with minimal bench width. Figure 13 in the Geology report shows cut batter slopes in fresh greywacke that appear to be dictated by the bedding angles. Later comment suggests the issue of the cut highwall designs needing further work to confirm the proposed design profiles in each wall. As the angle that the slopes can be cut at is key to landfill airspace, stability and operations, this aspect requires clarification.

Response: The reviewer appears to have mis-read Figure 6. The caption clearly states that the greywacke is steeply dipping and that there are joints dipping 40-45° to the right. For clarification, the bedding dips ~80° to the left in the photo.

b. In Section 5.5 of the Geology Report the first paragraph states that the quarry walls will be cut at an unstated angle (presumably dictated by rock defect dip in each wall) with 10 m high inter-bench heights and a 2 m bench. Firstly, this gives an overall angle of 79 degrees which is steeper than the Joint sets J1 and J3 in Table 1 of the Geology report and those shown in Figure 6. Depending on wall vs Joint orientation rock blocks underlain by J1 and J3 will daylight in the proposed cut face and are likely to be unstable as indicated in Appendix C. This could lead to local cut slope failure and represent a danger of rockfall to site staff. Has this risk been considered in the selection of bench width design?

Response: This is a valid point. Response 23 below provides details of a slope redesign.

[1] The revision to this letter is in the form of a new Attachment providing a revised pit slope design with supporting kinematic assessment and discussion. The original text is unchanged except for a minor addition on page 4.

c. The cross-sections in Drawing B4 illustrate the proposed cut wall slopes. The scale is uncertain but one of the cut walls may be 80 m high if the height intervals are 10 m. This highlights the potential safety issue and the need to ensure the rockfall risk is adequately managed for staff safety. One example from open cast NZ coal mines, is the use of a highwall profile with a 15 m inter-bench height and 8 m bench width to manage rockfall and to provide maintenance access. This gives an overall wall angle of 62 degrees. This angle may better manage both wedge and toppling failure types at Woodstock.

Response: This is a useful comment that has been considered in the slope redesign described below in the response to Q23.

d. The kinematic analyses of the joints and cut slope interactions presented in Appendix C of the Geology report highlight that a high number of failure possibilities for the East and South wall for both wedge sliding and toppling failure modes reinforcing the importance of a sound design cut profile.

Q23 Overall, considering the above points, the applicant should either reconsider or further justify the proposed cut slope profile, particularly with respect to the design cut slope angles and 2 m inter-bench width to ensure consistency with the geological defect orientations, the adequacy of the proposed bench width and its ability to control rockfall from a safety perspective.

Response: Based on the above helpful comments and suggestions, the slope design has been reconfigured to improve safety. The revised proposed design is provided as an attachment. The design philosophy, as noted on the drawing, is

- 10m vertical separation between benches
- Bench widths of 2m and 5m (alternating)
- 5m wide bench within weathered zone (exact base of weathering unknown and expected to vary)
- Overall slope angle ~70°

Q24 Is the stripped overburden material stockpiled around the quarry area an instability threat to the landfill, and to the safety of people working in the pit area?

Response: Management of stripped overburden is not an engineering geological issue. I have recommended that the stockpiled material should be removed to be at least 10m from the top of any long term batter.

Item 1.2. The monitoring wells (MWs) do not appear to have been placed to intercept fault/shear zones. The highest groundwater conductivity (K) values would be expected in the faulted/fractured rock. Groundwater levels may also be most critical near these structures, i.e., if the faults/shears act as drains then the hydraulic gradient may increase significantly near these features. Further, it is understood that drilling of MWs was carried out without extracting a core, which would have been useful to characterise the fractures below the site (i.e., are they clean/infilled, open/tight, etc.?).

Please provide an investigation of fractures and joints of the exposed pit walls to get an understanding of the fracture characterisation for the site.

Response: It is correct that the MW's were not specifically sited to intersect fault/shear zones. A hydrogeologist might do that, an engineering geologist working on a dam investigation would more likely recommend angled holes across known or suspected faults to do packer tests.

Drill core from greywacke typically breaks along joints and it is hard to confidently demonstrate that they are tightly closed from drilling. Generally, below the weathered zone the joints in undisturbed greywacke are kept tightly closed by the weight of the overlying rock.

Field mapping has shown that the greywacke rock at the site is (as is typical of Canterbury greywacke) highly jointed with multiple joint sets and variable spacing. In exposures within the quarry, the joints below the weathered zone are typically either clean and tightly closed except for superficial opening due to blast damage and rockmass relaxation, or they are healed with quartz (forming veins).

Please also consider whether or not further investigations are necessary to confirm conductivity of the underlying rock and whether there are fault/shear zones within the site of the proposed landfill.

Response: This matter is addressed in Appendix 4A Hydrogeology Report 2, which forms part of the response to the RFI.

Item 1.5. The Geology Report notes “minor rock types that may be found interbedded with, or faulted into, the greywacke include limestone, chert, and conglomerate, none of which have been observed on site”. The geologist confirmed in the site visit that there is no limestone onsite.

Please confirm this in writing and whether this statement applies to all areas and depths to be quarried and filled.

Response: There is no evidence of other rock types interbedded with the greywacke in exposures at the site. A review of the literature found no reference to limestone within greywacke anywhere in the South Island.

We will never know for certain until the rocks are excavated and we can see the quarry walls and floor. This is true of any excavation in any material – we can be 99% sure but never 100% of what we will find in the ground. I'm happy to say I'm 99% sure and that the depositional environment suggests deep water sediments (limestone only forms in shallow water).

Please confirm whether or not the argillite beds are calcareous as carbonates can dissolve in weak acids such as rainwater over long periods of time, or very quickly with stronger acids (i.e. potential leachate from the landfill).

Response: I have never come across calcareous argillite and found no reference to it in a review of the literature. We tested this concern by putting a few drops of 10% hydrochloric acid onto unweathered argillite exposures at 10 locations in the existing quarry. The rocks would fizz if they contain calcite. None of the test sites indicated any response suggestive of calcite. From this I conclude that the rocks at the site are non-calcareous and at worst may contain only trace amounts of calcite as secondary minerals in veins.

Item 1.7. We agree with the description given for the expected groundwater behaviour, i.e. the intact rock has a low conductivity, and groundwater flow is likely to be dominantly fracture flow or along bedding planes. However, to predict where potential contaminant may flow, it is recommended that structural mapping of faults/shear zones in the area (local to pit, not just regional). This would help with placement of monitoring wells (also see Question 5.9 below).

Please provide a conceptual model of the groundwater system specific to this site, considering local structure, geology, recharge, and specifically discharge mechanisms.

Response: As indicated in the Geology report, in addition to bedding shears in the pit, I observed one sheared zone near MW3/MW4 (in the side of the pond – see Figure 11) and inferred two others from the topography, one of them passing very close to MW7/MW8 (as shown on Drawings G-02 and G-03)

Item 1.8. Blasting is currently used as part of pit excavation. This is expected to increase fracturing and potentially increase permeability in the rock surrounding the pit.

Please confirm how fracturing and increase in permeability in surrounding rock will be monitored and managed throughout the quarrying operation and how the proposed landfill cell design will be informed by this information.

Response: Blasting may loosen rock to shallow depth (generally less than 1 m) in the side walls or base of the excavation. In my experience the degree of damage depends on the blast design and can easily be controlled.

T+T Review

Q30 The geological report describes a high groundwater level surrounding the landfill. Please provide details of the expected groundwater inflow through the unlined side slopes of the landfill and the expected impact of this on the liner system, leachate containment, leachate quantities and the overall design of the leachate management system.

Response: This is separately addressed by the hydrogeologist. The geology report was a 'first pass' that inferred a groundwater table based on the topography and streams. As stated on page 12 in the report, the monitoring data appears to show that the unweathered and slightly weathered rock is virtually impermeable and that groundwater infiltration and flow occurs within the upper weathered rock zone where it will be recharged by rainfall and runoff.

T+T Review, Appendix A

Item 17 The geology reporting highlights the risk of rockfall both small and large scale. Please provide further clarification on how this will be managed in terms of landfill worker safety, overall slope stability, adopted benching profiles and protection of the landfill liner.

Item 18 Weathered rock is located above the hard greywacke rock, however proposed excavation profiles do not appear to take into consideration this weather rock with the same 10 m high 2 m width benching profiles adopted. Please provide technical justification and analyse for this design.

Response: The proposed bench widths, batter slope angles and height between benches are conservative and are designed based on kinematic analysis (presented in the report – p16-17 and Appendix C). Following initial review comments by T+T, the bench widths were increased to 5m, thus reducing the overall slope angle, as detailed above, to improve overall stability and reduce the risk of rockfall to workers.

May 2022 Update: Attachment 1 to this letter details revised slope designs and replaces the attachments to the letter dated 14 February 2022.

Closing

I trust that these notes provide sufficiently detailed responses to the geological questions raised by ECan. Please do not hesitate to contact me if additional explanation is required.

Yours faithfully

Don Macfarlane
Consultant Engineering Geologist

2 Attachments

Woodstock Quarry – Updated Pit Slope Design

Background

In relation to the design of the pit slopes at Woodstock Quarry, which it is proposed to progressively backfill as a landfill, Environment Canterbury's external reviewers have raised concerns relating to

1. The steepness and stability of the proposed excavated slopes in the greywacke rock, and
2. The safety of workers during the landfill placement activities.

These concerns are partly driven by the duration of the time between excavation of the slope and the placement of landfill which could be tens of years in some parts of the site. This allows time for the slopes to deteriorate, potentially increasing the risk of rockfall to workers.

This memo outlines how the slopes have been assessed and how the concerns noted above have been addressed.

Pit Slope Design

Design considerations

In quarrying, a critical factor is often the ability to maximise resource recovery, which means cutting slopes as steeply as possible. However, it is also essential that the excavations can be undertaken safely. To this end, Matheson & Duthie (2010)[1] discuss techniques that can be used to design and excavate quarry faces and form slopes that will satisfy both the safety and the excavation objectives. These involve:

1. designing faces which optimise stability;
2. designing benches that will capture rockfall from the faces (which acknowledges that optimising the stability does not mean eliminating rockfall from the batter slopes); an
3. using excavation techniques that minimise disturbance of the rockmass and hence minimise the extent and magnitude of rockfall so that it is manageable.

Using this approach, ongoing risk assessment is carried out using hazard appraisals and geotechnical assessments on the faces immediately following excavation to confirm that the bench design is capable of containing rockfalls and that the risk to people is minimised or, if it is not, maintenance and/or risk management is carried out and the design is updated accordingly. Rockfalls are therefore avoided or contained, no access to benches above is needed, and risk is effectively managed.

The result is final quarry slopes that are virtually maintenance free, not because of the absence of instability in the faces but due to the fact that the risk to people has been effectively managed.

However, where the quarry is to be backfilled as a landfill, the long term stability of the slopes and the risk of rockfall during fill placement operations are future issues that must also be taken into account.

Pit slope design

The proposed design of the rock slopes to be excavated during the quarrying operation has been based on kinematic analysis. The kinematic analysis of rock slopes involves three- dimensional graphical analysis of the rock mass discontinuities to identify those that will (singly or in combination) act to control the stability of the slope. The analysis techniques are well documented in many textbooks and published papers, and computer software programs such as *Rocscience DIPS* have been developed to facilitate analysis. Such software allows rapid checks to be carried out varying slope angles and the shear strength of the rock mass discontinuities to determine stable

[1] Matheson, G.D.; Duthie, B. (2010). The design of quarry faces and slopes. *Geotechnics* Nov 2010, p21-23

slope angles under static conditions and to assess the effect of variability in the orientation of the rock mass discontinuities[2].

Kinematic analysis does have limitations. It does not take into account the persistence of the individual defects included in the analysis (this can dictate the size of unstable rock blocks), nor does it consider groundwater conditions or earthquake effects.

As described in the *Engineering Geological Assessment Report* dated 2 February 2021 that formed Appendix C of the consent application documents, mapping in the site area identified the dominant discontinuities to be bedding (dipping steeply to the north), with associated bedding plane shears, and three sets of joints - but also identified other less prominent joint sets and the potential for other sheared zones to be exposed during quarrying.

Previous slope designs

The initial slope stability assessments for the consent application were based on the mean orientations of the discontinuity sets and considered two slope orientations on the north wall and one on the west wall. The analyses identified toppling failure as the dominant failure mode in the north face with potential for wedge and planar failures in both the north and west slopes of the pit. The report concluded that the rock structure was favourable for pit slope design but did not specify slope designs. However, the geological drawings in the report showed very steep cut slopes with narrow benches on cross sections. The stability of such slopes was queried by ECan's reviewers and a revised design was provided in February 2022.

The revised design provided for alternating 2m and 5m wide benches which provided an overall slope angle of about 70° but assumed vertical batters between benches due to bedding control (which would only apply to parts of the north face of the quarry). ECan's reviewers questioned the vertical batters and the potential risk to workers during landfill construction works against such slopes.

Revised slope design

The revised proposed slope designs have also been developed by kinematic analysis, in this case using sensitivity checks that considered a range of batter slope angles between the benches and the same two friction angles (30° and 40°) used in the previous analyses.

The results are summarised in the following Attachments:

1. **Attachment 1** provides a series of tables summarising which defect sets drive each potential failure type for each of four slope orientations. Two of these are based on sensitivity analyses and great circle (mean orientation) plots, and two just on the great circle plots. Slightly different batter slopes have been considered in different places; this does not seem to affect the outcomes.
2. **Attachment 2** is a "sensitivity review" for the east-facing and south-facing slope orientations which is colour-coded to indicate the relative likelihood of each type of failure in those slopes. This is based on the kinematic analysis outputs and provides an arbitrary (but we believe reasonable) "Relative Likelihood" qualitative assessment based on the % of intersections or poles that DIPS identified as "critical".
3. **Attachment 3** includes stereonets that show the slopes and discontinuity sets evaluated in graphical form.

[2] Rock mass defects such as bedding planes, joints and sheared zones commonly occur in 'sets' with similar orientation and characteristics. There is always natural variability that can easily be analysed using software such as DIPS. Previously, the analyses were done manually base don the mean orientation of the sets of defects, and this is still a good way of undertaking a 'sanity check' on the outcomes of the analyses.

In summary, this review shows that

1. Toppling failure away from bedding is the likely to be the most significant form of slope instability on the north side of the quarry (i.e. in south-facing slopes) and that there is some potential for wedge instability (controlled by joints and/or bedding).
2. In the east-facing slopes (which will be temporary slopes for most of the life of the quarrying work) the most significant potential failure mode is wedge failure controlled by joints and bedding.
3. Slope stability is not generally greatly sensitive to slope angle. This is because the relative orientation of the discontinuities (bedding and joints) in relation to the slope is generally helpful for stability.

Two revised slope designs are shown in Figures 1 and 2:

For the north wall (south, southeast and southwest facing slopes) the interbench batters are proposed to be cut at 85°, and for the east-facing slopes (west wall and temporary faces) 75° batters are proposed. For all slopes, the two top benches are planned to be 5m wide, and the lower benches 3.5m. These can be widened during excavation if the conditions encountered require a design change.

The proposed 3.5m bench width is based on design charts developed by Alejano et al (2007)[3]. We used the charts for an 8-bench slope as this is the maximum expected in the quarry. As shown by Figure 3, the bench width indicated as necessary to capture 95% of any ongoing rockfall is 2.5m.

Although there are modelling tools that predict rockfall trajectories and runout distances for rock slopes, the reality is that the variable nature of both rockfalls and slopes makes it almost impossible to reliably estimate rockfall parameters.

For this reason, Alejano et al (2007) further recommend that the bench width should be increased to allow for breakback (partial loss) of the outer edges of the benches and other uncertainties; they suggest this 'backbreak correction' should be 0.5 m for pre-split benches, 1 m for carefully blasted good-quality rock masses, and 2 m for less carefully blasted average-quality rock masses. We have assumed an additional 1m for the Woodstock Quarry benches, making the minimum bench width 3.5m.

The effect of adding the backbreak correction is a final minimum catch-bench width capable of reasonably controlling rockfall from the batters. The effectiveness of the benches can be increased by placing a covering able to cushion rockfall from the face(s) above and/or incorporating a bund along the outer edge of the bench if the backbreak allows it.

Implications for landfill construction

The proposed overall slopes of ~60-65° with 75-85° batters and 3.5m or 5m wide benches are judged acceptable for the quarry slopes as the designs are based on the geology and kinematic assessments, and it is recognised that unforeseen ground conditions will almost certainly require adjustments during excavation.

However, these slopes may not be entirely suitable for the landfill operations. Other factors that must be considered in the design of the slopes for the landfill construction may include:

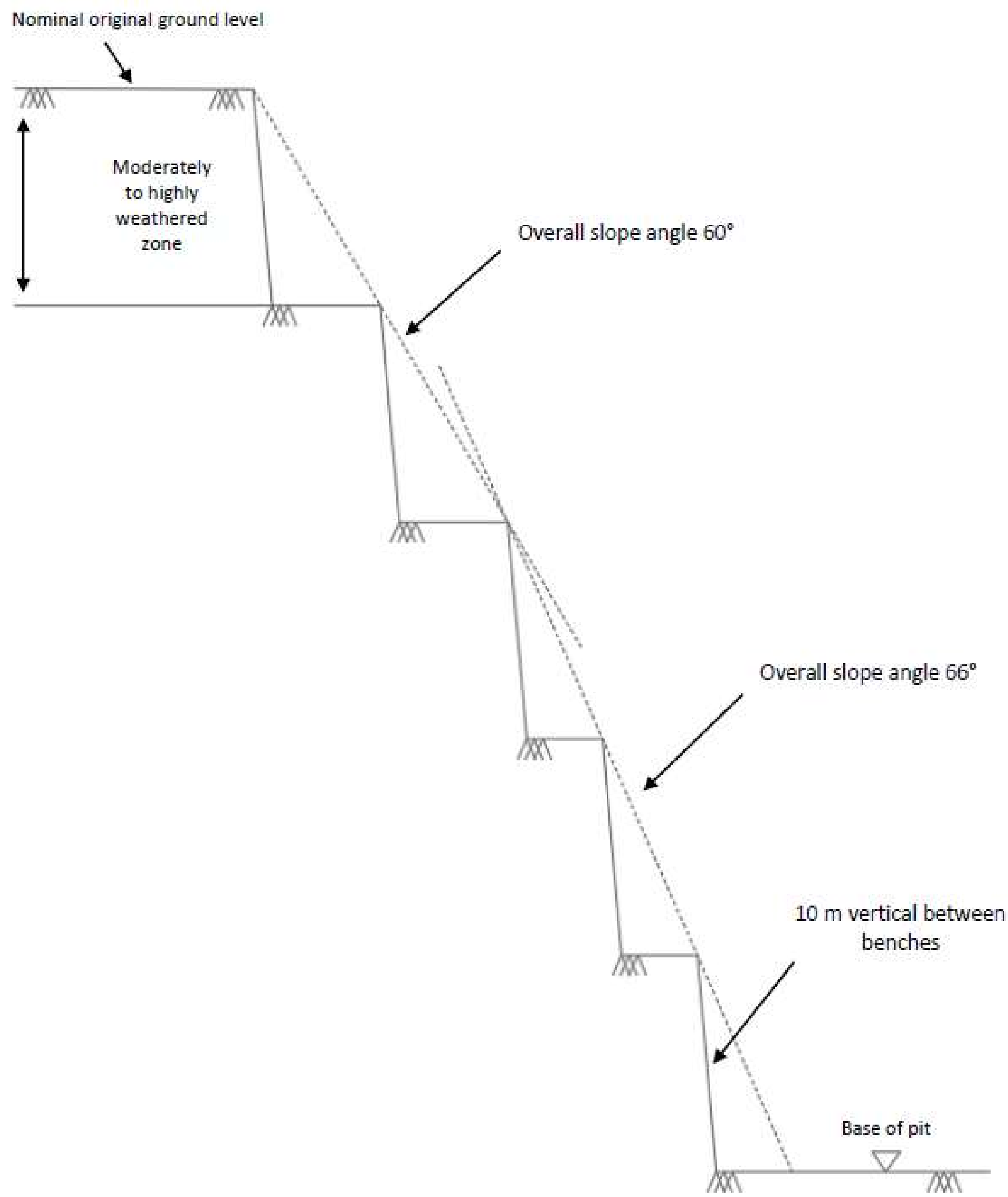
1. setback from the property boundary for
    a. access/inspection

[3] Alejano, L.R. et al (2007). Slope geometry design as a means for controlling rockfalls in quarries. *International Journal of Rock Mechanics & Mining Sciences* 44, pp903-921

    b. allowance for slope instability during excavation requiring additional layback

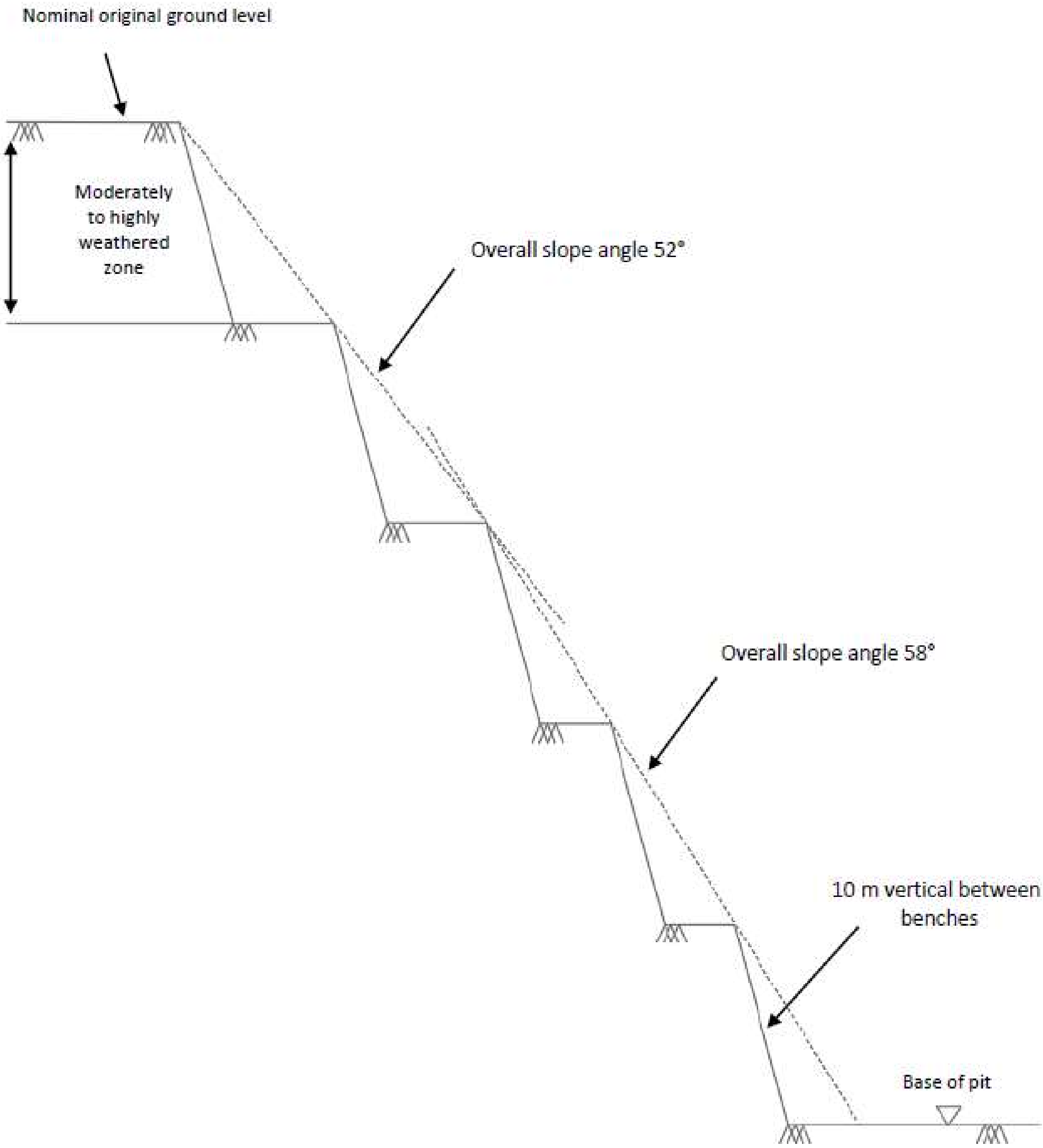
2. groundwater and runoff control
3. personnel safety during landfill construction close to the rock slopes
4. practicalities of liner installation depending on adopted design
5. shape correction of benches and batters if required for liner placement. This may affect quarrying techniques (eg. smooth wall/presplit blasting v production blasting)
6. bench width for access for liner construction (if required) may need to address the allowance for backbreak/loss of bench width or continuity.

These issues are addressed in the *Engineering Report* addendum.



Pit slope	Bench width (m)	Overall slope (°)
85° batters	3.5 m (lower benches) 5 m (top two benches)	66 60

Figure 1: Woodstock Quarry pit slope design concept for south-facing rock slopes



Pit slope	Bench width (m)	Overall slope (°)
75° batters	3.5 m (lower benches) 5 m (top two benches)	58 52

Figure 2: Woodstock Quarry pit slope design concept for east-facing rock slopes

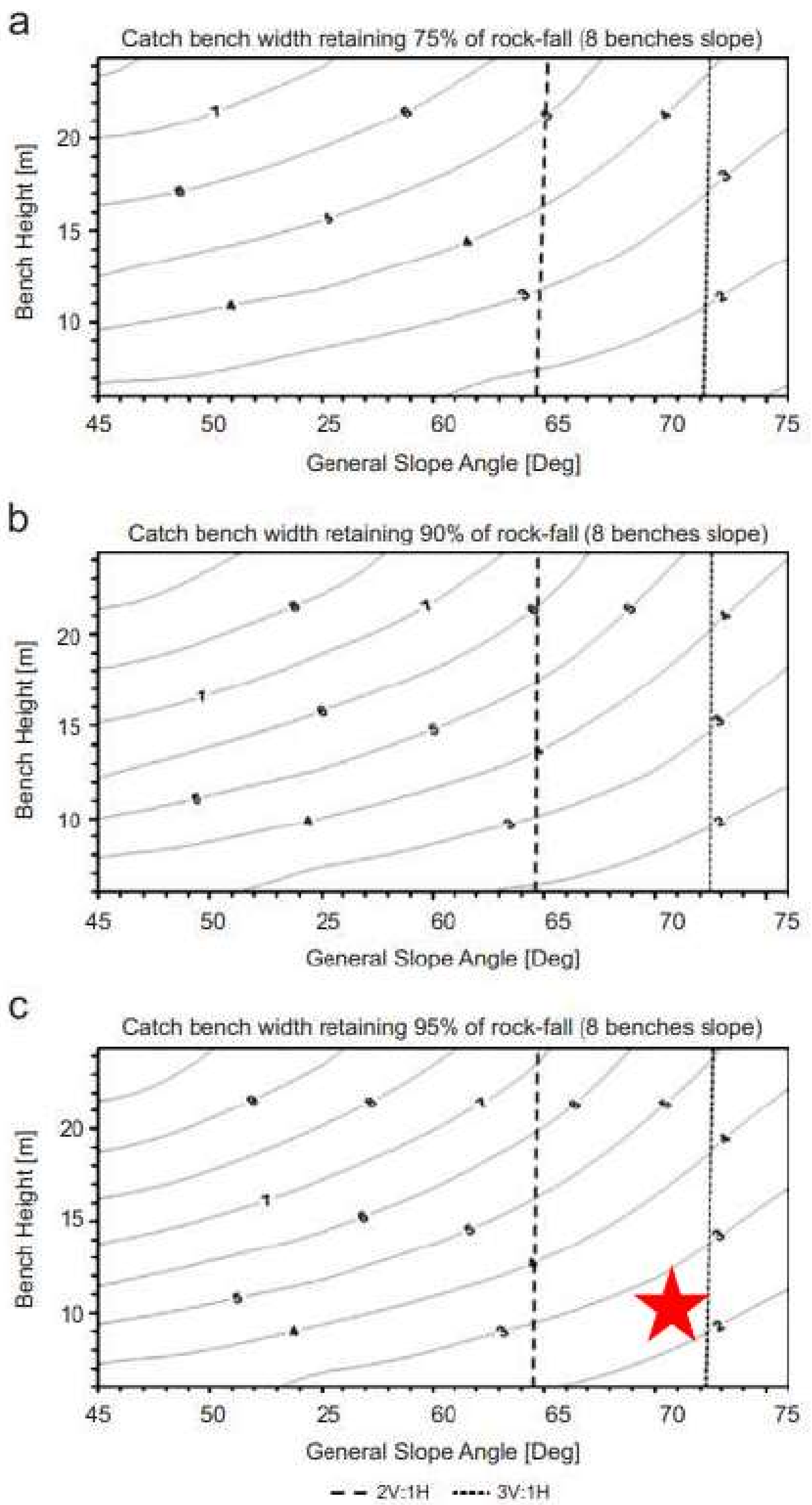


Figure 3: **Catch bench design charts for 8-bench hard rock quarry to catch (a) 75%, (b) 90% or (c) 95% of rocks. [From Alejano et al (2007) Figure 16]**

Attachment 1

Woodstock Quarry Kinematic Assessment Summary

1. From kinematic analyses and great circle plots

East-facing (090) slopes

Failure type	Relative Likelihood	Controlling Defects	Comments
Planar	Low to V Low	Random/minor joints. None of the main joint sets control planar failure	Likelihood is slightly lower at higher friction angle
Wedge	Low to Mod Mod to High	J2/J3 joints Bedding and J3 joints	Likelihood reduces with slope angle and is lower with higher friction angle
Flexural Topple	Moderate	J1 joints	Likelihood reduces with slope angle and increased friction angle
Direct topple	Moderate	J1/Bedding wedge topple	Likelihood reduces with slope angle. Not sensitive to friction angle
Oblique topple	Low Moderate	30 deg friction 40 deg friction	Not sensitive to slope angle but likelihood is indicated to be higher at higher friction angle

South-facing (180) slopes

Failure type	Relative Likelihood	Controlling Defects	Comments
Planar	Low	Random/minor joints. None of the main joint sets control planar failure	Likelihood is slightly lower at higher friction angle
Wedge	 High to Moderate Low to Moderate	J2/J3 joints 30 deg friction 40 deg friction	Likelihood reduces with slope angle and is lower with higher friction angle
Flexural Topple	High	Bedding	Likelihood reduces with slope angle and increased friction angle
Direct topple	Low	Bedding with random/minor joints	Likelihood reduces with slope angle. Not sensitive to friction angle
Oblique topple	Mod to High	B/J1 and B/J2 wedges	Not sensitive to slope angle

2. **from great circle plots only**

Southeast-facing (140) slopes

Failure type	**Relative Likelihood**	**Controlling Defects**	**Comments**
Planar	Low to V Low	J3 joints	Likelihood is slightly lower at higher friction angle
Wedge	Low to Mod Mod to High	J2/J3 joints Bedding and joints	Likelihood reduces with slope angle and is lower with higher friction angle
Flexural Topple	Moderate	Kinematic data indicates moderate likelihood that reduces with slope angle and increased friction angle. Not supported by great circle plot	
Direct topple	Moderate	J1/Bedding wedges	Likelihood reduces with slope angle. Not sensitive to friction angle
Oblique topple	 Low Moderate	J2/Bedding wedges 30 deg friction 40 deg friction	Not sensitive to slope angle but likelihood is indicated to be higher at higher friction angle

Southwest-facing (215) slopes = current wall

Failure type	Relative Likelihood	Controlling Defects	Comments
Planar	Low	Random/minor joints.	None of the main joint sets control planar failure
Wedge	Low	J2/J3	Marginal potential
Flexural Topple	Moderate	Bedding	Bedding >20° off strike of face
Direct topple	High?	Bedding/J2 joints	Intersection within the critical zone so potential exists and evident as dropouts in field
Oblique topple	Moderate?	Bedding/J1 joints	Not sensitive to slope angle

Attachment 2

Woodstock Quarry Kinematic Analysis
Sensitivity Assessments

Batter Slope Angle	East Facing Slopes			Friction Angle (degrees)	South Facing Slopes				
	85	75	65		85	75	65	55	45
Planar	Low (7%)	V Low (2%)	V Low (2%)	30	Low (10%)	Low (9%)	Low (8%)	Not Assessed	
	Low (7%)	V Low (2%)	V Low (2%)	40	Low (8%)	Low (7%)	Low (7%)		
Wedge	High (29%)	High (22%)	Mod (18%)	30	High(25%)	Mod (16%)	Mod (14%)	Low (10%)	Low (7%)
	Mod (19%)	(Mod 12%)	Low (8%)	40	Mod (17%)	Low (8%)	Low (6%)	V Low (3%)	V Low (<1%)
Flexural Topple	Mod (17%)	Mod (16%)	Mod (16%)	30	High (28%)	High (28%)	High (28%)	High (26%)	High (22%)
	Mod (16%)	Mod (16%)	Low (10%)	40	High (28%)	High (28%)	High (25%)	High (22%)	Low (9%)
Direct Topple	Mod (17%)	Mod (13%)	Mod (12%)	30	Low (10%)	Low (9%)	Low (7%)	V Low (4%)	V Low (4%)
	Mod (16%)	Mod (13%)	Mod (12%)	40	Low (10%)	Low (9%)	Low (7%)	V Low (4%)	V Low (4%)
Oblique Topple	Low (8%)	Low (8%)	Low (8%)	30	Mod (19%)	Mod (19%)	Mod (19%)	Mod (19%)	Mod (19%)
	Mod (12%)	Mod (12%)	Mod (11%)	40	High (24%)	High (24%)	High (24%)	High (24%)	High (24%)

Notes

1. % value cited is the proportion of poles or intersections assessed as critical by DIPS
2. This table summarises stability sensitivity to batter slope angle and friction angle for failure mechanisms listed
3. Relative likelihoocd classes listed below are informal only
4.Indicated likelihood only identifies type of instability that may occur, not magnitude

Relative Likelihood Assessment

Class	Likelihood	% Range	Implications
1	V Low	0-5	Only minor instability/ravelling expected
2	Low	6-10	Ongoing minor instability/ravelling possible
3	Moderate	11-20	Potential for ongoing rockfalls
4	High	21-30	Ongoing rockfalls are likely
5	Very High	31-100	Potential for significant instability requiring redsign and/or engineering works

Qualitative Assessment

(green)	Acceptable
(yellow)	Tolerable
(pink)	ALARP*
(red)	Unacceptable

*ALARP: *Manage risk to be as low as practicable*

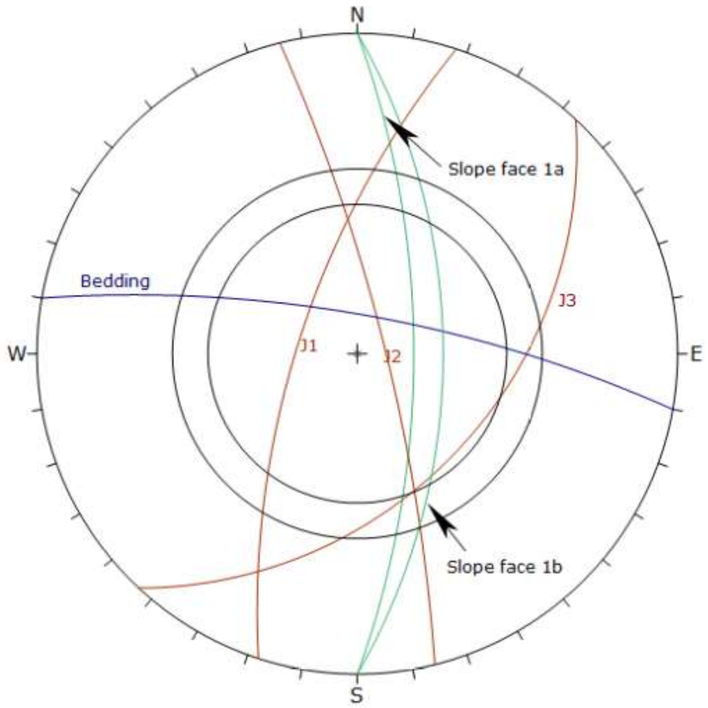
Attachment 3

Kinematic Analysis for Woodstock Quarry Slope Design

Kinematic analyses of batter slope stability for east, south-east, south and south-west facing slopes are shown and discussed below.

1. **East-facing slopes:**

Batters: Slope 1a = 70°, Slope 1b = 60°



	Color	Dip	Dip Direction	Label
User Planes				
1		70	90	Slope face 1
3		69	288	J1
4		80	76	J2
5		43	133	J3
6		76	10	Bedding
7		60	90	Slope face 1b

Plot Mode	Pole Vectors
Vector Count	58 (58 Entries)
Hemisphere	Lower
Projection	Equal Angle

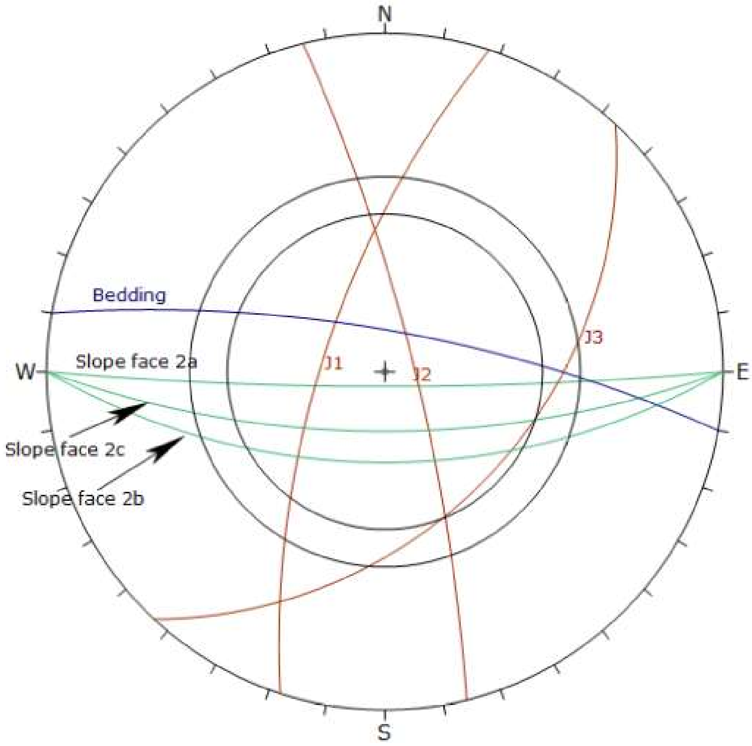
These slopes are formed perpendicular to bedding. Kinematic assessment shows potential for J2/J3 controlled wedge instability in slopes steeper than 60° and for B/J3 wedges in slopes steeper than 30°.

Reducing the slope angle by widening the benches reduces the potential for wedge failures controlled by the J2 and J3 joints. Wedges between J3 joints and bedding remain a potential failure mode for small scale instability of batters.

Proposed overall slope ~60° (75° batters, 3.5m wide benches)

2. **South-facing slopes:**

Batters: Slope 2a = 85°; Slope 2b = 60°; Slope 2c = 70°



	Color	Dip	Dip Direction	Label
User Planes				
2		85	180	Slope face 2a
3		69	288	J1
4		80	76	J2
5		43	133	J3
6		76	10	Bedding
7		60	180	Slope face 2b
8		70	180	Slope face 2c

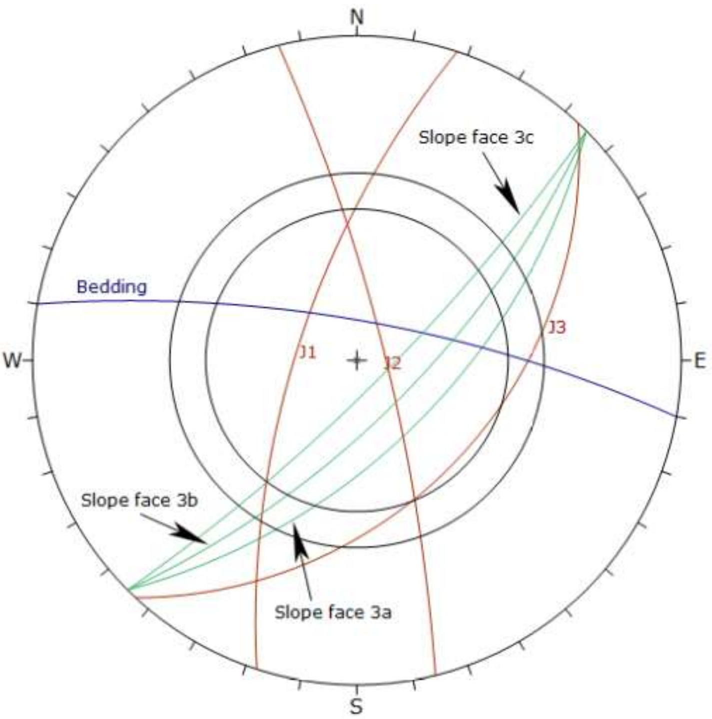
Plot Mode	Pole Vectors
Vector Count	58 (58 Entries)
Hemisphere	Lower
Projection	Equal Angle

The slopes are formed subparallel to bedding and are expected to be controlled by the bedding planes or bedding plane shears. Toppling from bedding is the dominant potential failure mode. A wedge between joint sets J2 and J3 is feasible. Reducing the slope angle makes no significant difference.

Proposed overall slope ~65° (85° batters, 3.5m wide benches)

3. SE-facing slopes:

Batters: Slope 3a = 60°; Slope 3b = 70°; Slope 3c = 80°



	Color	Dip	Dip Direction	Label
User Planes				
2		60	135	Slope face 3a
3		69	288	J1
4		80	76	J2
5		43	133	J3
6		76	10	Bedding
7		70	135	Slope face 3b
8		80	135	Slope face 3c

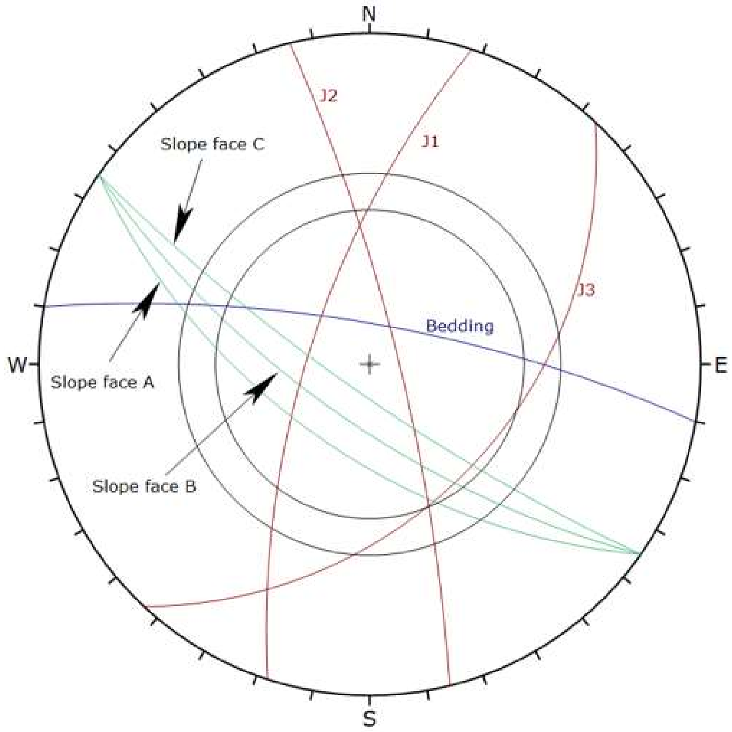
Plot Mode	Pole Vectors
Vector Count	58 (58 Entries)
Hemisphere	Lower
Projection	Equal Angle

All three slopes show potential for localised wedge failures controlled by joint sets J2 and J3 and potential for planar failures controlled by joint set J3. Wedge topple away from bedding and J1 joints is feasible. Reducing the batter slopes has no significant benefit

Proposed overall slope ~65° (85° batters, 3.5m wide benches)

4. SW-facing slopes

Batters: Slope 4a = 60°; Slope 4b = 70°; Slope 4c = 80°



	Color	Dip	Dip Direction	Label
User Planes				
1		69	288	J1
2		80	78	J2
3		43	133	J3
4		76	10	Bedding
5		60	215	Slope face A
6		70	215	Slope face B
7		80	215	Slope face C

Plot Mode	Pole Vectors
Vector Count	1 (1 Entries)
Hemisphere	Lower
Projection	Equal Angle

These slopes were not previously assessed. All three slopes show potential for wedge topple failures controlled by (away from) bedding and joint set J2. Bedding strike is more than 20° different from the strike of the face indicating low potential for direct bedding-controlled topple.

Possibly marginal potential for oblique wedge topples controlled by bedding and joint set J1.

Reducing the batter slope angles does not reduce the potential for wedge toppling.

Proposed overall slope ~65° (85° batters, 3.5m wide benches)