Assessment of the Operating and Post-Closure Stability of the Open Pit at the Proposed Ioneer Rhyolite Ridge Lithium-Boron Mine, Esmeralda County, Southwestern Nevada

Steven H. Emerman, Malach Consulting, 785 N 200 W, Spanish Fork, Utah 84660, USA, Email: SHEmerman@gmail.com, Tel: 1-801-921-1228

Report prepared at the request of the Center for Biological Diversity
Submitted May 29, 2024

ABSTRACT

The Draft Environmental Impact Statement (DEIS) for the proposed Ioneer Rhyolite Ridge lithium-boron mine in Esmeralda County, southwestern Nevada, would involve an open pit only 15 feet from the only population of Tiehm's buckwheat. The stability analyses in the DEIS argue that the Tiehm's buckwheat could not be impacted by slope instability neither during mine operation nor after mine closure (when buttresses would be constructed for additional pit slope stability). The calculated factors of safety cannot be regarded as reliable. Although the raw data that were used to develop the geotechnical parameters show considerable scatter, the geotechnical parameters and factors of safety are stated with no uncertainties and there is no sensitivity analysis. No source has been identified for the buttress material, so that the geotechnical parameters for the buttress are purely hypothetical. The DEIS chose a minimum factor of safety of 1.2 for both the operational and the post-closure periods. However, according to the Guidelines for Open Pit Slope Design (published by the Large Open Pit Project) and the SME Surface Mining Handbook (published by the Society for Mining, Metallurgy and Exploration), based upon the data uncertainty and the consequences of slope failure, the minimum factor of safety should be 1.5 and the maximum probability of failure should be 5% during the operational period (prior to buttress construction). Moreover, according to the Guidelines for Mine Closure (published by the Large Open Pit Project), based upon the same considerations, the minimum factor of safety should be 2.0 during the post-closure period (after buttress construction). Based upon the guidelines for calculating the Zone of Instability by the Western Australian Department of Industry and Resources, the minimum separation distance between the quarry and the Tiehm's buckwheat population ought to be 450 feet before buttress construction and 240 feet after buttress construction along the profile where the proposed quarry would be only 15 feet from the population. The assumption in the DEIS that the slope materials will remain unsaturated indefinitely does not consider the hydrogeological and meteorological processes by which the current state of saturation and over-pressurization was achieved, nor the time period over which re-saturation and re-pressurization could occur. The Adaptive Management plan lacks any specifics or details, and states the mine could be closed in response to an indication of slope instability, although without any apparent commitment on the part of the mining company. The recommendation of this report is that the geotechnical sections of the DEIS should be completely re-written.

EXECUTIVE SUMMARY

The Australian mining company Ioneer has proposed the Rhyolite Ridge Lithium-Boron Project in Esmeralda County, southwestern Nevada. The open-pit mine would operate for 26 years with average annual production of 22,340 metric tons of lithium carbonate in the first three years, 21,951 metric tons per year of lithium hydroxide over the remaining mine life, and 174,378 metric tons per year of boric acid over the entire lifespan. The proven and probable mineral reserves have been estimated at 60.2 million metric tons with average grades of 0.1797% lithium and 1.5418% boron. The Draft Environmental Impact Statement (DEIS) for the project was released by the Bureau of Land Management (BLM) on April 19, 2024. Although the DEIS refers to the open pit as a "quarry," its maximum depth would be 960 feet and "quarry" typically refers to a shallow excavation for the extraction of aggregate. Since this report compares the DEIS with mining industry guidelines, the words "quarry" and "open pit" are used interchangeably.

A central issue regarding the potential environmental impact is the presence of the world's only population of Tiehm's buckwheat only 15 feet from the edge of the proposed quarry on the northern side. Thus, the DEIS includes geotechnical analyses that argue that the Tiehm's buckwheat could not be affected by instability of the mine pit slopes. The DEIS chose a value of 1.2 as the minimum factor of safety for both the operational and post-closure periods. The factor of safety is the ratio of the resistance to the load, so that a factor of safety of 1.0 indicates a slope at the cusp of failure, equivalent to 50% probability of failure. A report by Geo-Logic Associates, which was an attachment in the DEIS, updated previous stability analyses by considering six sections across the quarry, including TR02E-11, which is close to the population of Tiehm's buckwheat that has a separation distance of 15 feet from the quarry. The limit equilibrium method was used to show factors of safety for the operational period ranging from 1.20 to 1.26, thus satisfying the minimum value set by the DEIS. By adding buttresses to promote slope stability for the post-closure period, the factors of safety increased to the range 1.25 to 1.57. The stability analyses assumed that, after depressurization and dewatering, the slope materials would remain unsaturated indefinitely. The Adaptive Management plan called for the cessation of mining activity if monitoring indicated instability near Tiehm's buckwheat habitat.

The objective of this report was to answer the following questions regarding the geotechnical analysis in the DEIS:

1) Are the calculated factors of safety reliable?
2) Was the choice of 1.2 for the minimum factor of safety appropriate for the operational period?
3) Was the choice of 1.2 for the minimum factor of safety appropriate for the post-closure period?
4) Was the Zone of Instability for open pits as specified in Western Australian guidelines properly taken into account?
5) Was the assumption that slope materials will remain unsaturated justified?
6) Is the proposed Adaptive Management plan adequate?

To facilitate reading by non-specialists, this report includes a tutorial on key geotechnical concepts, including the limit equilibrium method, factor of safety, and probability of failure.

Some information in the DEIS is inconsistent with information in other sources and the BLM has indicated that other information is already out of date. For example, the Tiehm's buckwheat population map in the DEIS, which was created by Ioneer, is not the same as the map used by the Center for Biological Diversity (CBD). In particular, the CBD map shows the closest separation distance between the Tiehm's buckwheat and the quarry to be 17 feet. According to the CBD map, subpopulations of Tiehm's buckwheat are found 380 feet, 332 feet, 283 feet, and 177 feet from the quarry on the western side. The Ioneer map places those same subpopulations 208 feet, 329 feet, 281 feet, and 165 feet, respectively, from the edge of the quarry. From a geotechnical standpoint, a critical issue is that BLM has stated that the position of the haul road is going to change, although the quarry as mapped has the exact dimensions to accommodate the haul road as currently mapped. Thus, if the position of the haul road changes, then the location of the quarry will also change, even though the location as shown in the DEIS was the basis for the stability analyses in the DEIS. No attempt was made in this report to document all inconsistencies or outdated information in the DEIS.

The factors of safety that are calculated in the DEIS cannot be regarded as reliable. The geotechnical parameters for each geologic unit that are the input data for the stability analysis are stated with ultra-precision, sometimes with five significant digits, and with no range of uncertainty. Some of the geotechnical parameters were obtained from another consulting report that is not available for public review, while other parameters were simply the judgment of Geo-Logic Associates. The DEIS does not specify which parameters were developed from data and which were based on "judgment." The DEIS presents some of the raw data that were used to develop the geotechnical parameters, which show a very small number of measurements for each rock sample with a high degree of scatter. The calculated factors of safety are also stated as single values with no range of uncertainty. In particular, there is no sensitivity analysis that would show the range of possible factors of safety that could result from reasonably possible alternative values for the geotechnical parameters and there is no distribution of possible values for the factor of safety that would make it possible to estimate the probability of failure. In the same way, there is no sensitivity analysis that would show the range of possible locations of the critical failure surface that could result from reasonably possible alternative values for the geotechnical parameters. The DEIS does not identify any source or type of material for the buttress, so that the geotechnical parameters of the buttress should be regarded as strictly hypothetical.

Failures of mine pit slopes are incredibly common in comparison with other types of industrial accidents. The mean annual probability of failure of a mine pit slope is about 6% with a range of 2-20%. The high failure frequency of mine pit slopes was part of the motivation for the writing of the Guidelines for Open Pit Slope Design by the Large Open Pit Project. According to the Guidelines for Open Pit Slope Design, for mine pit slopes with High consequences of failure, the minimum factor of safety should be in the range 1.3-1.5 and the maximum probability of failure over the entire design life (as opposed to an annual probability) should be 5%. Since the Adaptive Management plan calls for the cessation of mining activity as a response to slope instability affecting sensitive habitat, the consequences of slope failure at the Rhyolite Ridge mine should be placed into the High category (on a three-level scale of Low, Medium, and High). Another five-level scale for consequences of slope failure places closure of pit production for a significant period as Major consequences and permanent closure as Catastrophic consequences. The SME Surface Mining Handbook (published by the Society for Mining, Metallurgy and Exploration) has confirmed the recommendations of the Large Open Pit Project. The range of 1.3-1.5 for the minimum factor of safety depends upon the uncertainty in the input data with the upper end corresponding to high uncertainty. Based upon both the high data uncertainty and lack of attention to data uncertainty addressed above, the appropriate minimum factor of safety during the operational phase should be 1.5, which is significantly greater than the value of 1.2 that was chosen in the DEIS.

The appropriate minimum factor of safety should increase in the transition from the operational to the post-closure period. Some industry publications have argued that the post-closure factor of safety should be greater than 2.0 or as high as credible with the probability of failure reduced to the ALARP (As Low as Reasonably Practicable) level. There are two principal reasons for the need to increase the minimum acceptable factor of safety. After pit closure, there will be a long-term degradation in the strength of the adjacent rock masses due to rewetting of the pit and the time-delayed responses to blasting and the radical changes in topography and stress levels that accompanied construction of the pit. For example, the removal of the weight of overlying rock could result in the slow opening of joints (cracks). Thus, the first reason is that there is considerable uncertainty as to the rate or degree to which the rock masses will degrade. There is even considerable theoretical uncertainty regarding the coupled interactions of erosion and slope instability and how those interactions are coupled with climate change. The second reason is that the post-closure period will see a reduction in or a complete lack of slope monitoring and trained on-site personnel, thus limiting the ability to detect and respond to changes in slope stability. It should be noted that, in addition to raising the minimum value of the factor of safety for the post-closure period, the factor of safety should be calculated based upon the anticipated future reduced rock strength, not the rock strength that exists during the operational period.

In response to the above concerns, the Large Open Pit Project published the Guidelines for Mine Closure, which describe a procedure for determination of the appropriate minimum factor of safety for the post-closure period. The procedure involves the calculation of a Relative Stability Guideline (RSG), which is the product of the score for the Pit Wall Condition Class (on a scale of 1 to 7 with lower scores indicating more competent slopes), the Adjacent Impact Consequence (on a scale of 1 to 5 with higher scores indicating more severe consequences), and the Existing Design Confidence (on a scale of 1 to 5 with higher scores indicating less design confidence or greater data uncertainty). Since the pit slopes at the Rhyolite Ridge mine would have factors of safety slightly greater than 1.2 (although those calculations are highly unreliable, as explained above), the pit slopes would be placed into Pit Wall Condition Class C, corresponding to a score of 5. Pit Wall Condition Class C is described in the Guidelines for Mine Closure as "unvegetated slopes with uncontrolled rockfall risk and undesirable risk of failure" with a "high level of concern." In terms of failure consequences, the Guidelines for Mine Closure do not address the irreplaceable loss of biological resources, but other five-level consequence classifications, such as the Global Industry Standard for Tailings Management place accidents with "catastrophic loss of critical habitat or rare and endangered species" into the most severe category of Extreme consequences. Thus, a score of 5 for Adjacent Impact Consequences, corresponding to Very High consequences would yield an RSG score of 25 multiplied by the score for Existing Design Confidence.

The Guidelines for Mine Closure require a minimum factor of safety greater than 1.5 for RSG in the range 20 to 50 and a minimum factor of safety greater than 2.0 for RSG in the range 50 to 100. On that basis, the minimum post-closure factor of safety of 1.2, which was assumed by the DEIS, would not be appropriate even if the Existing Design Confidence could be raised to the level of Very High (corresponding to a score of 1). The Existing Design Confidence is certainly not at the level of Very High, based on the low-quality geotechnical data that are currently available. If the Existing Design Confidence could be raised to a level of Medium with a score of 3, then the RSG score would be 75, which would demand a post-closure factor of safety greater than 2.0. In summary, the appropriate minimum factor of safety for the post-closure period would be 2.0 with the factor of safety calculated based on the anticipated future degraded rock strengths.

The Department of Industry and Resources (Western Australia) has detailed guidelines for calculating the post-closure Zone of Instability. There is no application of these or similar guidelines or any corresponding discussion of the width of the unstable zone anywhere in the DEIS. The Western Australian guidelines specify that a safety bund wall with a width of 5 meters should be constructed at least 10 meters outside of the Zone of Instability, so that the safe region begins 15 meters (roughly 50 feet) beyond the Zone of Instability. The calculation involves connecting a line from the toe of the pit to the surface with an angle of 45° for unweathered (strong) rocks and an angle of 25° with respect to the horizontal for weathered (weak) rocks. Some studies have shown the calculation procedure to be insufficiently conservative (insufficiently protective) because some pit slope failures have resulted in breakback angles significantly less than 25°. In the application of the Western Australian guidelines to the Rhyolite Ridge mine, all rock units at the stratigraphic level of geologic unit B5 of the Cave Spring Formation or higher were regarded as weak based on the description of the units in the DEIS. In the absence of any information, the unknown buttress material was also regarded as weak or weathered.

The widths of the Zones of Instability were calculated for the same six sections for which stability analyses were updated in the DEIS. All widths were reduced when a buttress was added to the section, except in the single section in which there was no Zone of Instability even without a buttress. Thus, the widths ranged from 0 to 450 feet without a buttress and from 0 to 225 feet with a buttress. Adding 50 feet to establish a safe region resulted in safe regions ranging from 50 to 500 feet upslope from the edge of the quarry without a buttress and 50 to 275 feet upslope from the edge of the quarry with a buttress. It is most important that Section TR02E-11, which is closest to the population of Tiehm’s buckwheat that has separation distance of 15 feet from the quarry, has a Zone of Instability of 400 feet, with the safe region beginning 450 feet from the edge of the quarry. In other words, the Zone of Instability at Section TR02E-11 would extend far into the population of Tiehm’s buckwheat. It should be noted that, according to the Western Australian guidelines, the Tiehm’s buckwheat population that has a separation distance of 15 feet from the quarry could not be in the safe region even if there were no Zone of Instability (setting the safe region at 50 feet beyond the edge of the quarry).

The mining plan involves the depressurization and the dewatering of the geologic units prior to construction of the quarry. The DEIS expresses the opinion that the slope materials will not be rewetted even by extreme precipitation or snowmelt events because the water will infiltrate to a very shallow depth and then evaporate. The preceding is only an opinion because it is not accompanied by any data, calculations or modeling. In particular, there is no consideration as to the hydrogeological and meteorological processes by which the geologic units became saturated and then pressurized in the first place. Thus, it should be assumed that the relevant geologic units will eventually become re-saturated and re-pressurized and there should be some consideration as to the time period over which this will occur. In addition, there should be some consideration as to the localized impact of the large volume of water that will be applied to the haul roads for dust suppression. Along the same lines, there should be some consideration as to the impact of the weight of vehicular traffic on the haul roads on slope stability.

At the present time, nearly all large-scale mining projects involve the application of an Adaptive Management plan (also called the Observational Method). For complex projects, not all actions can be planned in advance. Instead, a monitoring program is set up together with a set of pre-planned actions ready for execution as a response to every possible adverse observation. The DEIS does describe a plan for monitoring slope instability, but only in terms of the particular instruments that will be used. The description of pre-planned responses to indications of instability consists of a single sentence that states that the mining activity could cease in response to any evidence of slope instability that could affect sensitive habitat. It is difficult to determine whether the assertion is meant to be taken literally, since it is found in a report by Geo-Logic Associates that is an attachment to the DEIS, and certainly does not represent a binding commitment by the mining company.

The recommendation of this report is that the geotechnical sections of the DEIS be completely rewritten with special attention to the following:

1) A specific source should be identified for the buttress material with estimation of the geotechnical parameters for that particular source.
2) All of the raw geotechnical data should be presented with a complete explanation as to how those data were used to develop the geotechnical parameters.
3) The DEIS should specify which parameters were developed from data and which were based on judgment. Parameters that were based on judgment should be rigorously defended.
4) The discussion of the geotechnical parameters should include the uncertainty in the parameters.
5) The calculated factors of safety should include the uncertainty, such as the standard deviation.
6) A sensitivity analysis should be carried out in which the factor of safety for each section is re-calculated based on the entire range of reasonable values for the geotechnical parameters, such as the lowest reasonable values for cohesion and friction angle. If the factors of safety vary significantly for the reasonable range of input data, the results should be used with great caution.
7) A sensitivity analysis should be carried out in which the critical failure surface for each section is re-calculated based on the entire range of reasonable values for the geotechnical parameters, such as the lowest reasonable values for cohesion and friction angle. If the positions of the critical failure surfaces vary significantly for the reasonable range of input data, the results should be used with great caution.
8) It should not be assumed that all slope materials will remain unsaturated. The factors of safety should be re-calculated for a range of possible pore pressures and water tables, including the eventual possibility that pore pressures and the water table will return to pre-mining levels. If the factors of safety are strongly dependent upon the assumption that all slope materials will be unsaturated, then the results for unsaturated materials should be used with great caution.
9) The localized re-saturation of slope materials that could result from the surface application of water for dust suppression on the haul roads should be calculated and the potential impact on slope stability should be assessed.
10) The weight of vehicular traffic on the haul roads should be taken into consideration for analyses of slope stability.
11) The distribution of possible values of the factor of safety should be developed for each section, so that the probability of failure can be calculated.

12) The stability analyses should be carried out in accordance with the most up-to-date map for the intended quarry.
13) The DEIS should adhere to the recommendations of Guidelines for Open Pit Slope Design (published by the Large Open Pit Project) and the SME Surface Mining Handbook (published by the Society for Mining, Metallurgy and Exploration) that the minimum factor of safety should be 1.5 and the maximum probability of failure should be 5% during the operational period (prior to buttress construction).
14) The DEIS should adhere to the recommendations of the Guidelines for Mine Closure (published by the Large Open Pit Project) that the minimum factor of safety should be 2.0 during the post-closure period (after buttress construction).
15) The factors of safety and the critical failure surfaces for the post-closure period should be calculated based on reasonable expectations for the rock mass degradation that will occur during the post-closure period.
16) For each section, the Zone of Instability should be calculated according to the guidelines of the Western Australian Department of Industry and Resources. The connecting lines for the geologic units that are at the stratigraphic level of Unit B5 of the Cave Spring Formation or higher should have an angle of 25° with respect to the horizontal. Local and regional outcrops should be investigated to determine whether some geologic units show breakback angles less than 25°, in which case, the connecting lines should be assigned the lower angle for those units.
17) Unless it can be convincingly argued to the contrary, the quarry should be designed so that the Tiehm's buckwheat population is at least 50 feet beyond the Zone of Instability, as specified in Western Australian regulations.
18) The Adaptive Management plan for the response to indications of slope instability should be specific and detailed with intermediate steps that would occur prior to a cessation of mining activity. Any claims that the mine will be closed in response to evidence of slope instability should be supported by a binding commitment from the mining company.

TABLE OF CONTENTS

ABSTRACT	1
EXECUTIVE SUMMARY	2
OVERVIEW	9
TUTORIAL ON KEY GEOTECHNICAL CONCEPTS	20
Limit Equilibrium Method and Factor of Safety	20
Probability of Failure	21
SUMMARY OF STABILITY ANALYSIS FOR RHYOLITE RIDGE OPEN PIT	23
METHODOLOGY	32
RESPONSES	40
The Calculation of the Factor of Safety is Unreliable	40
The Choice of the Minimum Operating Factor of Safety is too Low	43
The Choice of the Minimum Post-Closure Factor of Safety is too Low	49
The Post-Closure Zone of Instability has not been Taken into Account	56
The Assumption that Slope Materials will remain Unsaturated is Unjustified	70
The Adaptive Management Plan is Inadequate	71
SUMMARY CONCLUSIONS	72
RECOMMENDATIONS	73
ABOUT THE AUTHOR	74
REFERENCES	75

OVERVIEW

The Australian mining company Ioneer has proposed the Rhyolite Ridge Lithium-Boron Project in Esmeralda County, southwestern Nevada (see Fig. 1). The open-pit mine would operate for 26 years with average annual production of 22,340 metric tons of lithium carbonate in the first three years, 21,951 metric tons per year of lithium hydroxide over the remaining mine life, and 174,378 metric tons per year of boric acid over the entire lifespan. The proven and probable mineral reserves have been estimated at 60.2 million metric tons with average grades of 0.1797% lithium and 1.5418% boron (Mining Technology, 2024). The Draft Environmental Impact Statement (DEIS) for the project was released by the Bureau of Land Management (BLM) on April 19, 2024 (Bureau of Land Management, 2024a).

A portion of the open pit would be left permanently open after the closure of the mine, while the remainder would be backfilled with overburden and referred to as the "Quarry Infill OSF [Overburden Storage Facility]" (see Fig. 2). Additional Overburden Storage Facilities, called the North OSF and South OSF would be constructed to the north and southwest, respectively, of the open pit (see Fig. 2). Although the DEIS refers to the open pit as a "quarry," its maximum depth would be 960 feet (Bureau of Land Management, 2024b) and "quarry" typically refers to a shallow excavation for the extraction of aggregate. Since this report compares the DEIS with mining industry guidelines, the words "quarry" and "open pit" are used interchangeably.

A central issue regarding the potential environmental impact of the Rhyolite Ridge mine is the presence of the world's only population of Tiehm's buckwheat only 15 feet from the edge of the proposed quarry on the northern side (see Figs. 2 and 3a-b). A subpopulation of Tiehm's buckwheat also occurs 208 feet from the western edge of the proposed quarry, while three subpopulations are found 329 feet, 281 feet, and 165 feet from the western edge of the Quarry Infill OSF (see Figs. 4a-b). The critical habitat for Tiehm's buckwheat (based on a 500-meter buffer) occurs well within both the quarry and the Quarry Infill OSF (see Fig. 2). The preceding distances were measured from the population map created by Ioneer and used in the DEIS, and for which the GIS shapefile was provided to the Center for Biological Diversity by the BLM. The Ioneer map is not identical to the map that has been in use by the Center for Biological Diversity (compare Figs. 3a and 4a with Figs. 3b and 4b). The issues of information in the DEIS that is inconsistent with information in other sources and of information in the DEIS that has already been acknowledged to be out-of-date will be discussed in the "Methodology" section.

Based on the close proximity of the proposed quarry to Tiehm's buckwheat, the DEIS includes two attachments by the consulting company Geo-Logic Associates (2022, 2023) that argue that the Tiehm's buckwheat could not be impacted by instability of the mine pit slopes. The purpose of this report is to review the conclusions in the attachments and to address the following questions with regard to the Rhyolite Ridge mine:

1) Will the mine pit slopes be stable during the period of operation of the mine?
2) Will the mine pit slopes be stable after the closure of the mine?

To facilitate reading by non-specialists, this report includes a tutorial on key geotechnical concepts, including the limit equilibrium method, factor of safety and probability of failure. The preceding questions will be refined following the tutorial and a summary of the stability analyses by Geo-Logic Associates (2022, 2023).

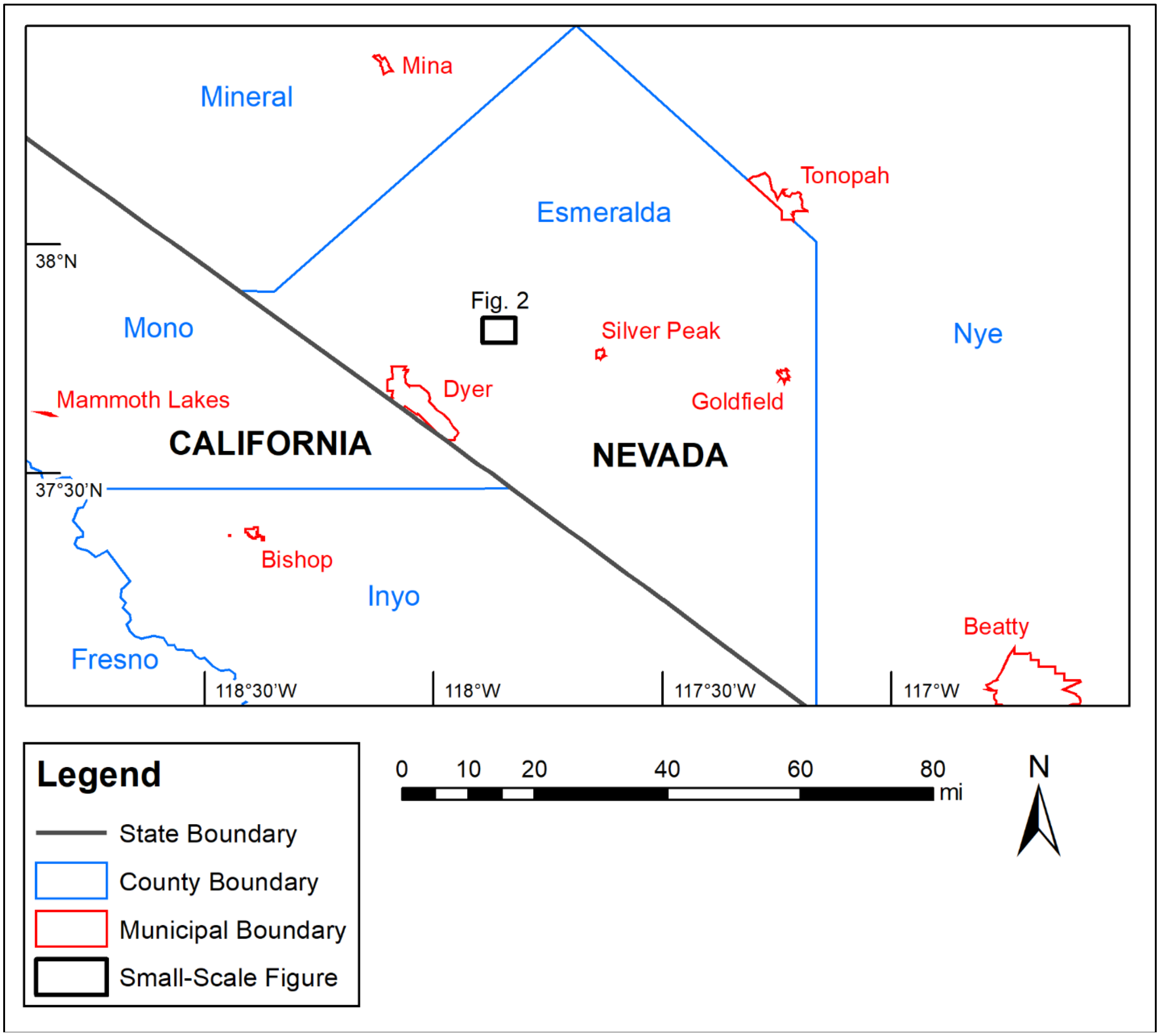

Figure 1. The site of the proposed Rhyolite Ridge Lithium-Boron Project is located in Esmeralda County in southwestern Nevada, close to the border between California and Nevada.

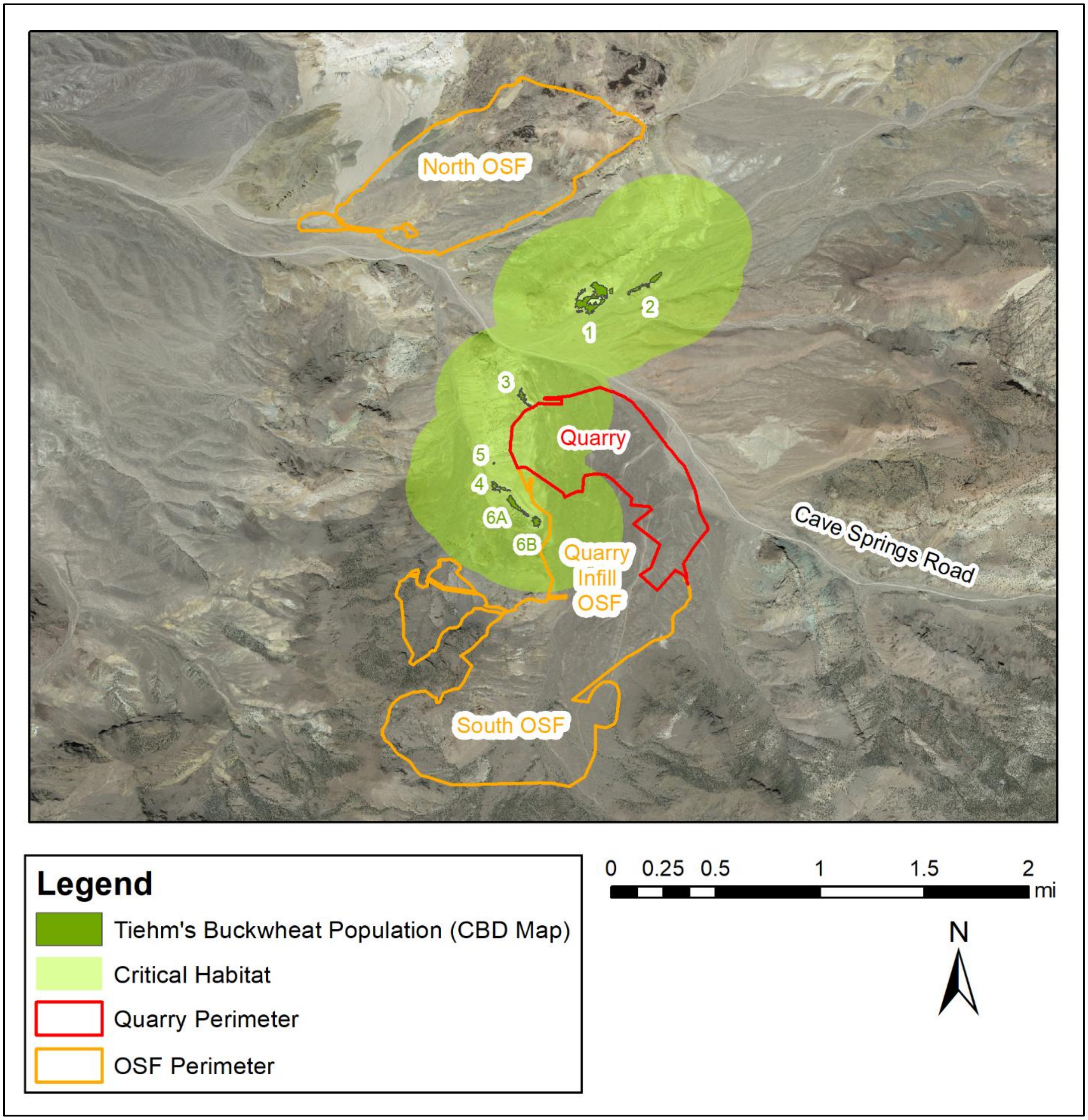

Figure 2. The quarry for the Proposed Ioneer Rhyolite Ridge Lithium-Boron Project would be constructed in close vicinity to the only existing population of Tiehm's buckwheat. The purpose of this report is to evaluate geotechnical analyses by Geo-Logic Associates (2022, 2023) that argue that instability of the quarry walls could not impact the Tiehm's buckwheat population either during mine operation or after mine closure. Maps of Tiehm's buckwheat population and critical habitat were provided by the Center for Biological Diversity. Maps of the quarry and Overburden Storage Facilities (OSF) were provided to the Center for Biological Diversity by the Bureau of Land Management. The green numbers refer to the Tiehm's buckwheat subpopulations. Figs. 3a-b and 4a-b show smaller-scale views. Background is Google Earth imagery from August 9, 2013. The map is projected onto the WGS84 coordinate system.

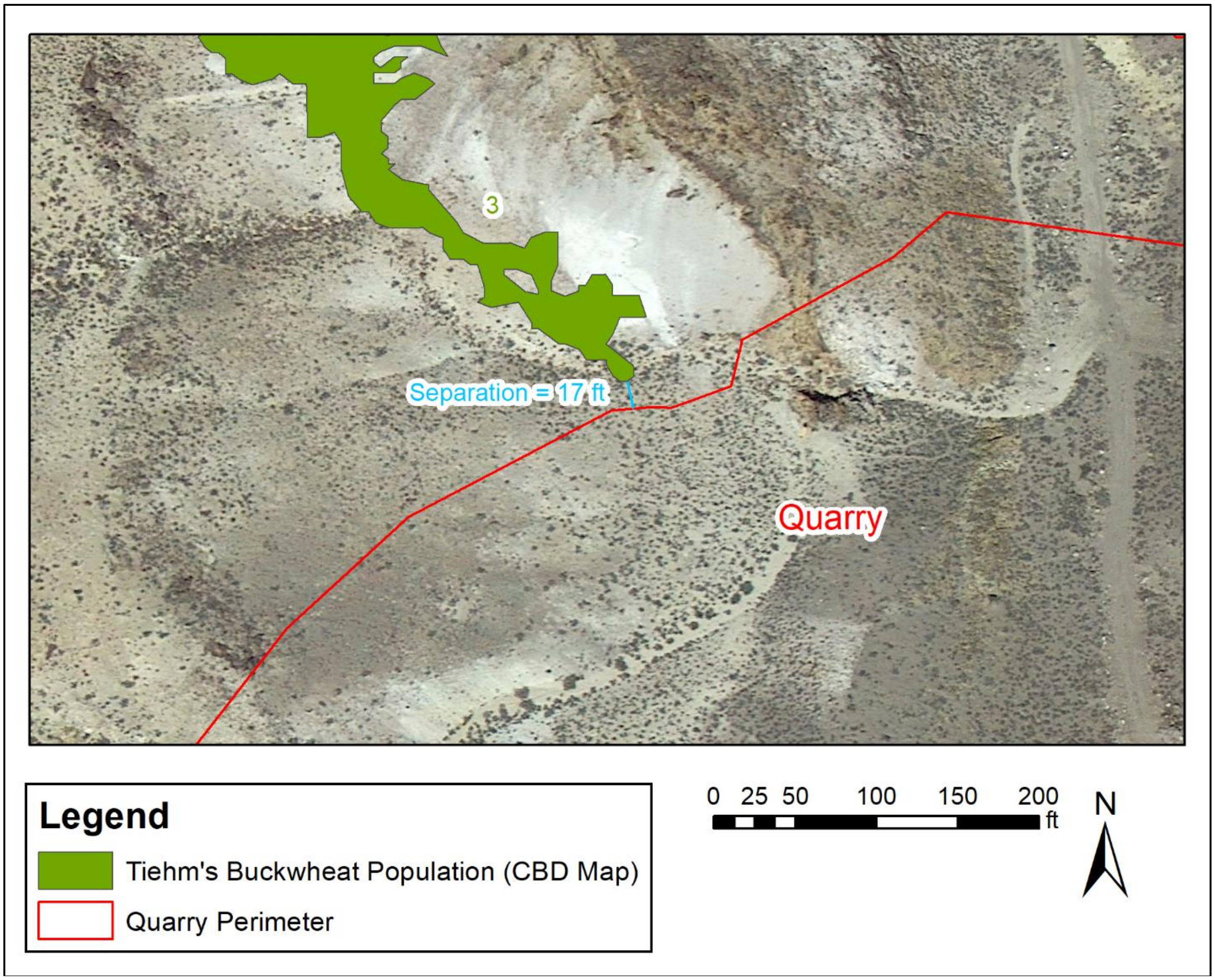

Figure 3a. According to the map of Tiehm's buckwheat that is used by the Center for Biological Diversity (CBD), the edge of the quarry would be 17 feet from the Tiehm's buckwheat population (see Figs. 3b and 16a for a different map that is used by Ioneer). The quarry map was provided to the Center for Biological Diversity by the Bureau of Land Management. The green number refers to the subpopulation. Fig. 2 shows a larger-scale view with labeled subpopulations. Background is Google Earth imagery from August 9, 2013. The map is projected onto the WGS84 coordinate system.

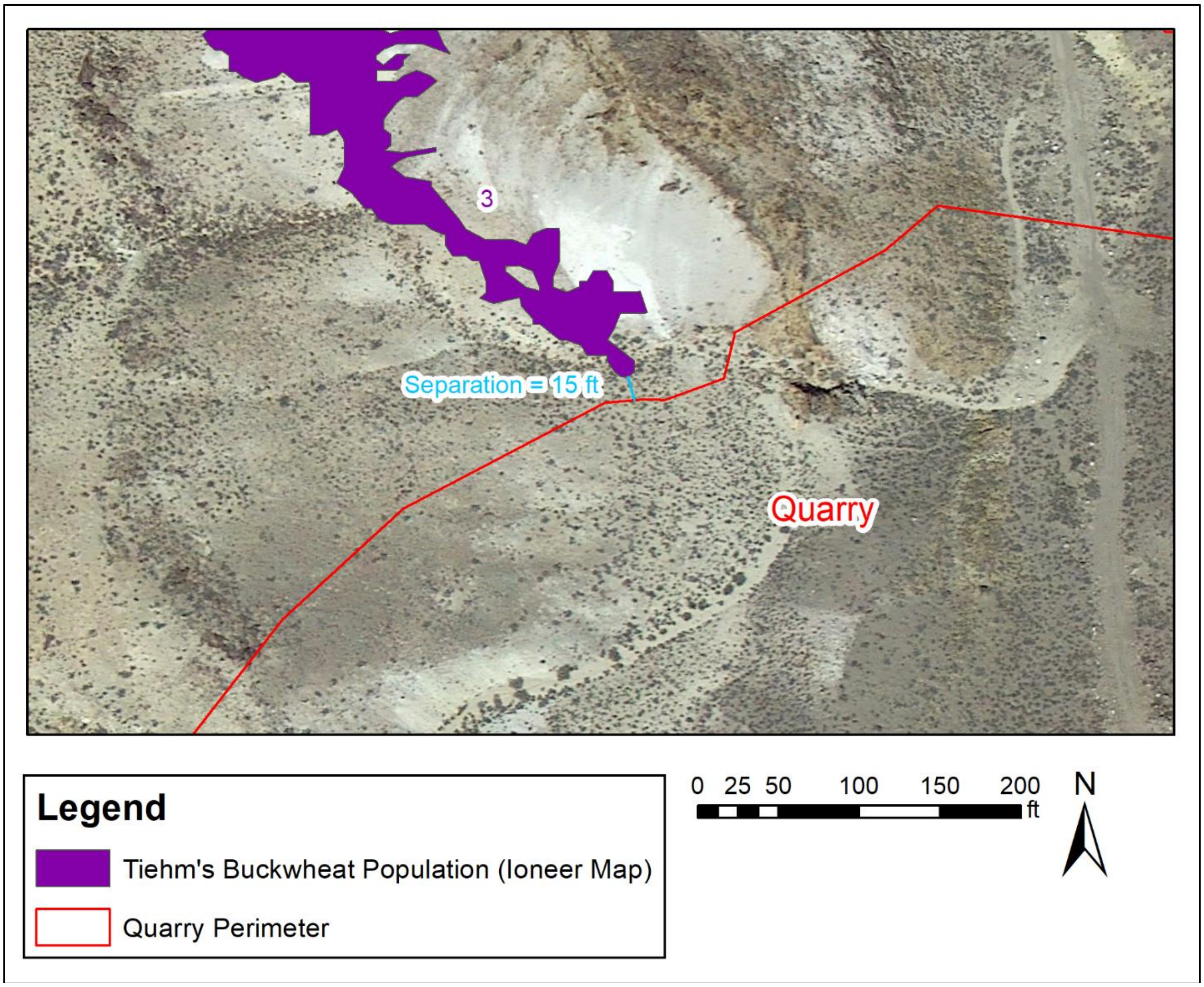

Figure 3b. According to the map of Tiehm's buckwheat that is used by Ioneer, the edge of the quarry would be 15 feet from the Tiehm's buckwheat population (see Figs. 3a and 16a for a different map that is used by the Center for Biological Diversity). The quarry map was provided to the Center for Biological Diversity by the Bureau of Land Management. The purple number refers to the subpopulation. Fig. 2 shows a larger-scale view with labeled subpopulations. Background is Google Earth imagery from August 9, 2013. The map is projected onto the WGS84 coordinate system.

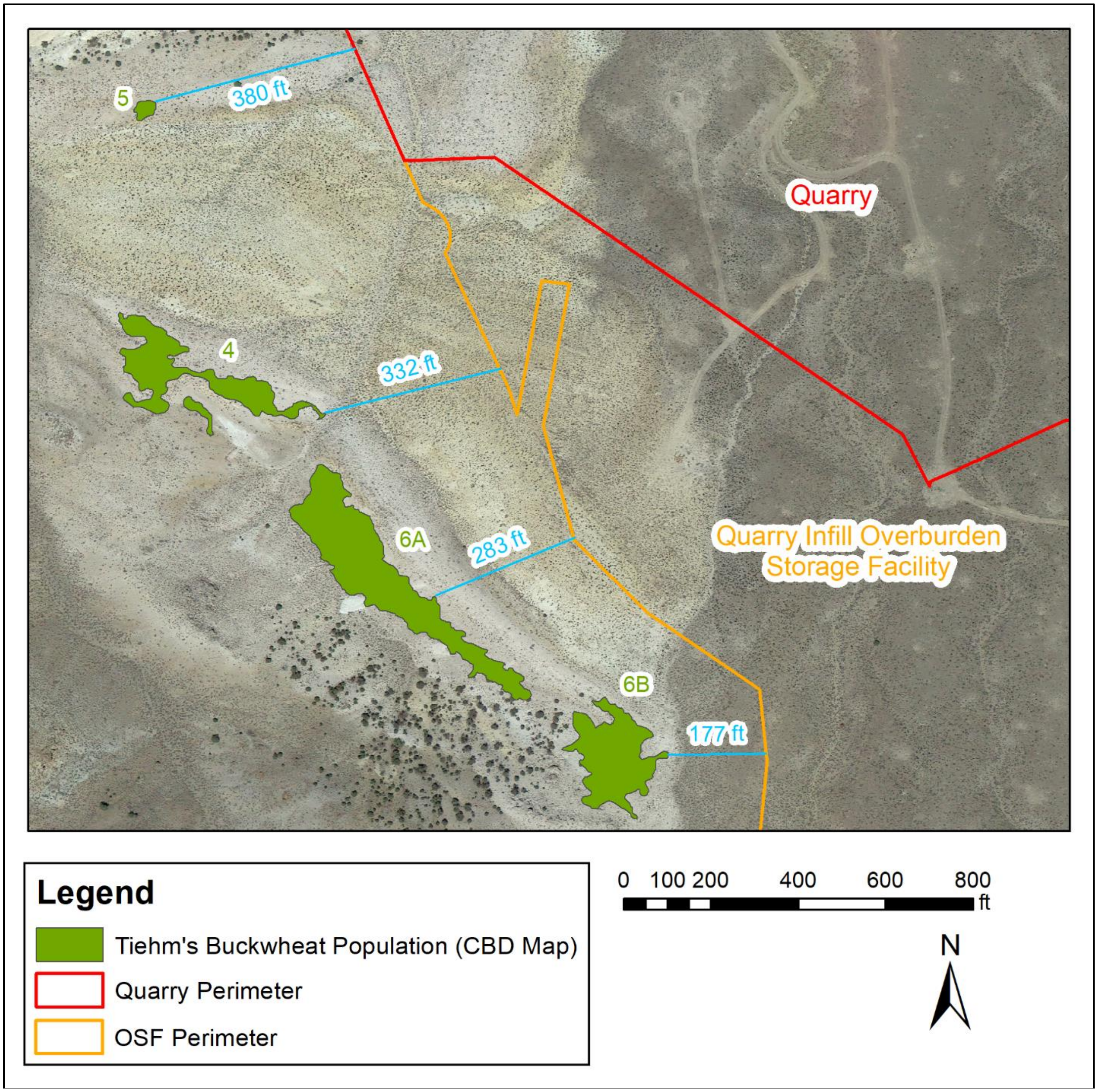

Figure 4a. According to the map of Tiehm's buckwheat that is used by the Center for Biological Diversity (CBD), subpopulations 5, 4, 6A, and 6B would be 380 feet, 332 feet, 283 feet, and 177 feet, respectively, from the edge of the quarry (see Figs. 4b and 16b for a different map that is used by Ioneer). The perimeters of the quarry and Overburden Storage Facility (OSF) were provided to the Center for Biological Diversity by the Bureau of Land Management. The green number refers to the subpopulation. Fig. 2 shows a larger-scale view with labeled subpopulations. Background is Google Earth imagery from August 9, 2013. The map is projected onto the WGS84 coordinate system.

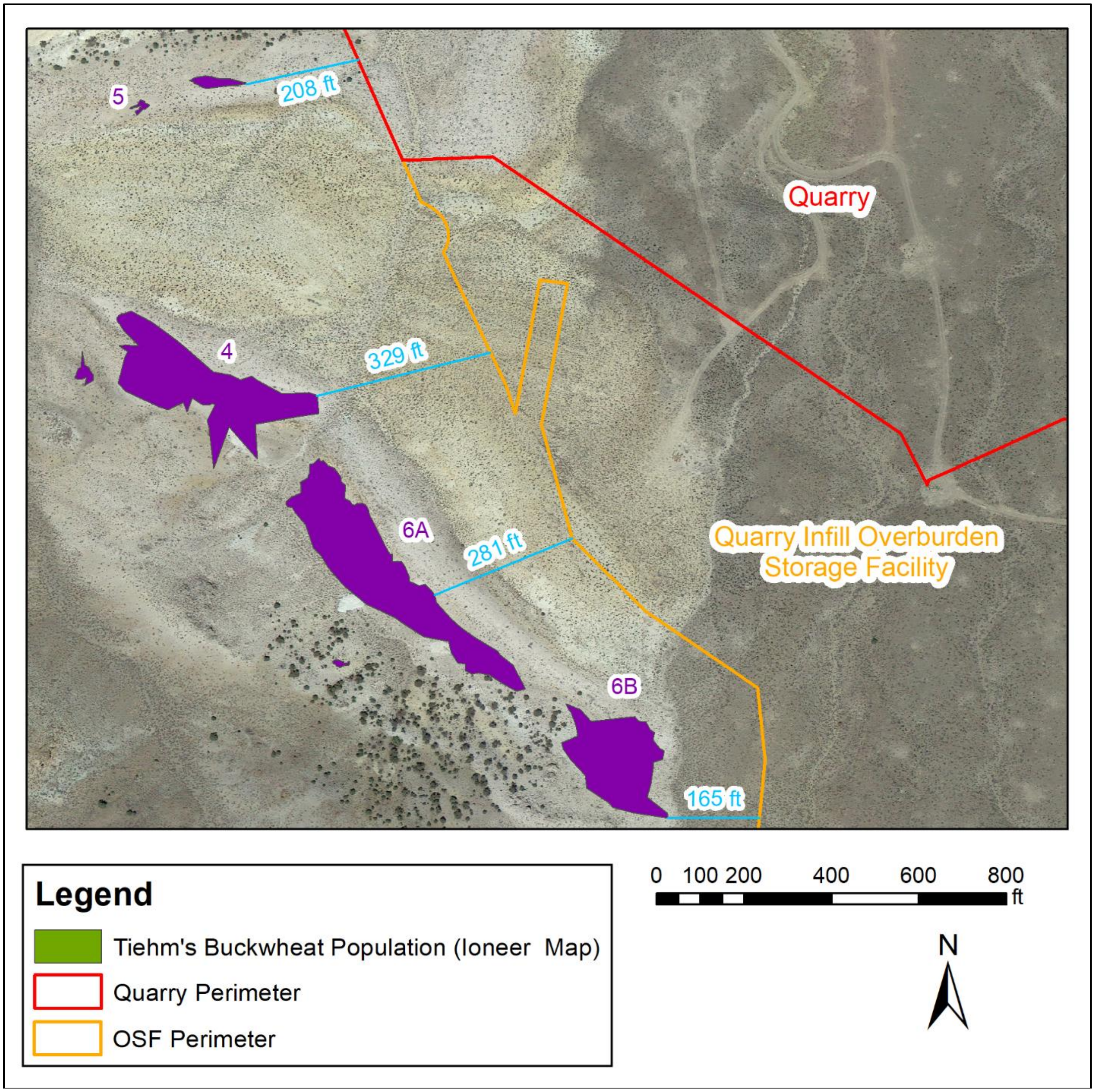

Figure 4b. According to the map of Tiehm's buckwheat that is used by Ioneer, subpopulations 5, 4, 6A, and 6B would be 208 feet, 329 feet, 281 feet, and 165 feet, respectively from the edge of the quarry (see Figs. 4a and 16b for a different map that is used by the Center for Biological Diversity). The perimeters of the quarry and Overburden Storage Facility (OSF) were provided to the Center for Biological Diversity by the Bureau of Land Management. The purple number refers to the subpopulation. Fig. 2 shows a larger-scale view with labeled subpopulations. Background is Google Earth imagery from August 9, 2013. The map is projected onto the WGS84 coordinate system.

It is important to consider the different issues that arise regarding pit slope stability during mine operation and after closure of the mine. During mine operation, the key issue is that failures of mine pit slopes are incredibly common, especially in comparison with other types of industrial accidents (Steffen et al., 2006; Wesseloo and Read, 2009; see Fig. 5). The mean annual probability of failure of a mine pit slope is about 6% with a range of 2-20%, which is considerably more common than failure rates of critical infrastructure in such high-risk industries as merchant shipping and offshore drilling (see Fig. 5). Steffen et al. (2006) pointed out that one would need to look at an ultrahigh-risk enterprise such as the Space Shuttle program to see a comparable failure rate (see Fig. 5). According to Steffen et al. (2006), in order to bring the failure rate of mine pit slopes into line with other types of industrial accidents, the annual probability of failure ought to be 1-10% for failure of a pit slope with a probability of one fatality of 1% and 0.1-1% for failure of a pit slope with a probability of one fatality of 10% (see Fig. 5).

The high failure rate of mine pit slopes was part of the motivation for the creation of the industry-funded Large Open Pit Project in 2005 (LOP, 2024) and the subsequent publication of the Guidelines for Open Pit Slope Design (Read and Stacey, 2009). Some of the key recommendations of the Guidelines for Open Pit Slope Design have been incorporated into other mining industry guidance documents, such as the SME Surface Mining Handbook (Darling, 2023), which was published by the US-based Society for Mining, Metallurgy and Exploration in March 2023. Therefore, part of the approach of this report will be the comparison of the safety criteria selected by Geo-Logic Associates (2022, 2023) with the recommendations of the preceding and other mining industry standards. It should be noted that there is no information as to whether adherence to the preceding standards has reduced the failure rate of mine pit slopes over the past 15 years.

A discussion of the comparative definition and significance of "failure" among different high-risk industries goes beyond the scope of this report and has been reviewed elsewhere (e.g., Whitham, 1984; Steffen et al., 2006; Wesseloo and Read, 2009). However, it is essential to respond to the assertion by Geo-Logic Associates (2023) that weaker safety criteria should be applied to open pit slope design in comparison to other industries. According to Geo-Logic Associates (2023), "The design criteria applied to mine pit slopes is complex and can vary depending on circumstances and consequences. Criteria applied to civil engineering structures are poor surrogates for mining applications." Geo-Logic Associates (2023) then quotes from Guidelines for Open Pit Slope Design in writing, "In open pit mining slope failure is not easily defined. Whereas in some engineering systems failure occurs immediately and is not reversible (e.g. the buckling of a structural column or the failure of a dam), in an open pit mine slope failure may take place gradually so that determining the stage at which the pit wall ceases to perform adequately may be highly subjective" (Wesseloo and Read, 2009). The statement is correct and it is fortunate that the vast majority of mine pit slope failures are sufficiently minor or sufficiently slow that they do not result in mineworker fatalities. However, it is still the case that the probability of an expected fatality resulting from a mine pit slope failure is about 4% (see Fig. 5), which would certainly correspond to a major, rapid and irreversible failure. At this point, it suffices to point out that Geo-Logic Associates (2023) and the Guidelines for Open Pit Slope Design reach very different conclusions, although relying on the same interpretation of a mine pit slope failure.

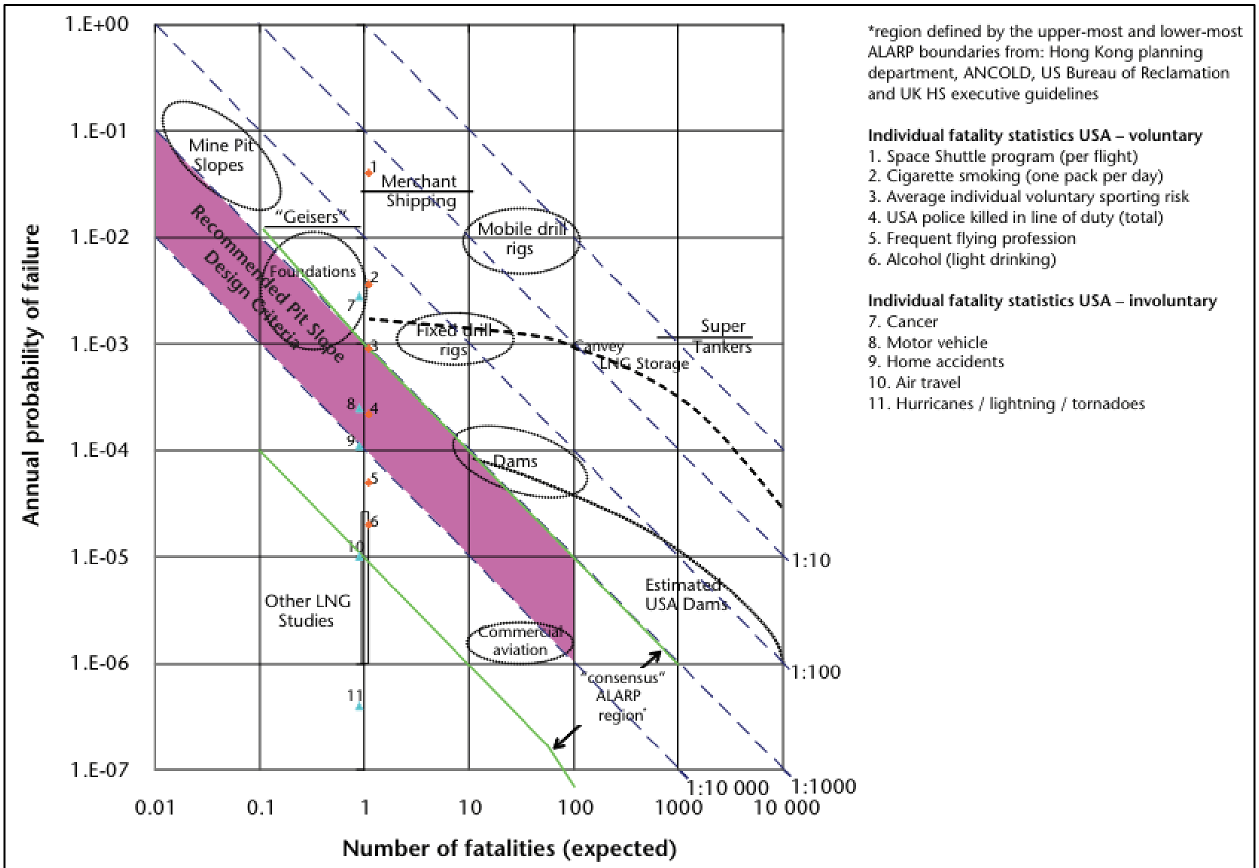

Figure 9.10: Comparison of risk acceptability criteria with statistics
Source: Steffen et al. (2006)

Figure 5. Failures of mine pit slopes are incredibly common in comparison with other types of industrial accidents. The mean annual probability of failure of a mine pit slope is about 6% with a range of 2-20%. Note that other figures related to probability of failure in this report refer not to the annual probability, but the probability of failure over the entire design life. The high failure frequency of mine pit slopes was part of the motivation for the writing of the Guidelines for Open Pit Slope Design (Read and Stacey, 2009) by the Large Open Pit Project (LOP, 2024). According to Steffen et al. (2006), in order to bring the failure rate of mine pit slopes into line other types of industrial accidents, the annual probability of failure ought to be 1-10% for failure of a pit slope with a probability of one fatality of 1% and 0.1-1% for failure of a pit slope with a probability of one fatality of 10%. There is no available data as to whether the annual probability of failure of a mine pit slope has changed since the release of the Guidelines for Open Pit Slope Design. Figure from Wesseloo and Read (2009).

After closure of an open-pit mine, the key issues become the reduction in or complete lack of slope monitoring and on-site trained personnel who could detect and respond to signs of slope instability, as well as the typical long-term degradation of the strength of the rock masses adjacent to the open pit (see Figs. 6-7). Strength reduction can result from the rewetting of rock masses that eventually takes place after the cessation of dewatering and depressurization that accompanies open-pit mining. Other causes of long-term strength degradation are weathering of newly exposed slope materials and time-delayed responses to blasting and the radical changes in topography and stress levels that resulted from pit excavation. For example, the loss of the weight of overlying rocks and the loss of confinement by the rocks that were extracted from the open pit could allow the opening of vertical and horizontal joints (cracks), which could then lead to rockfalls (de Bruyn et al., 2019).

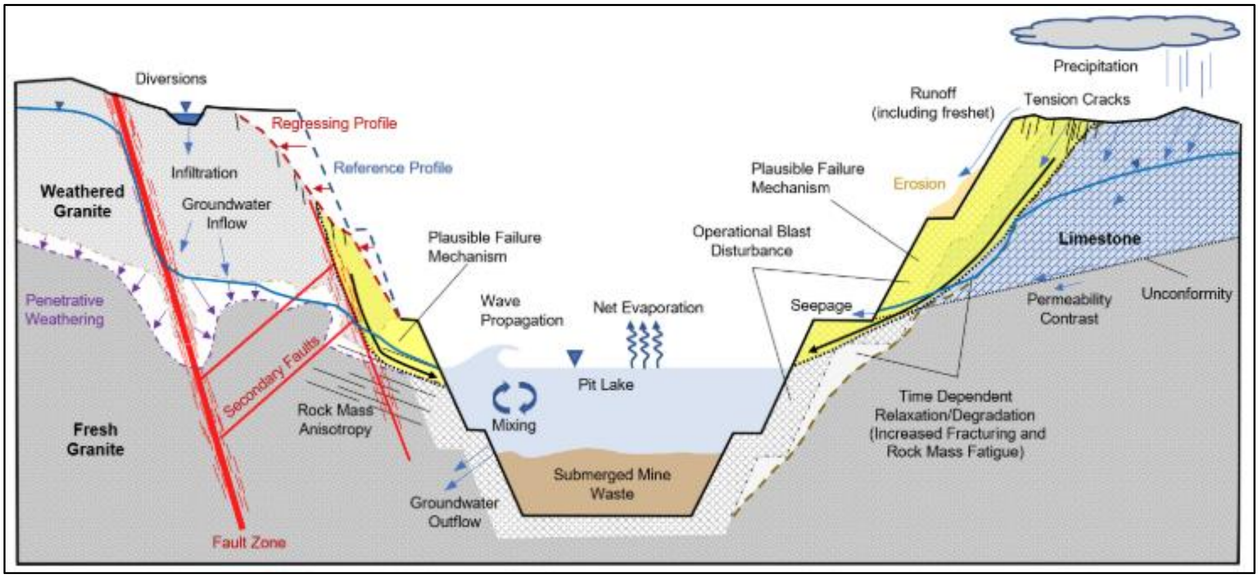

Figure 6. The strength of the adjacent rock mass typically decreases after closure of an open pit. This decrease results from time-delayed responses to blasting and the radical changes in topography and stress levels that accompanied the excavation of the open pit, as well as the eventual rewetting of the pit. For example, the removal of the weight of overlying rock could promote the opening of pre-existing joints (cracks) and there could be a slow creep of the adjacent rock faces toward the open pit. Figure from de Graaf et al. (2024).

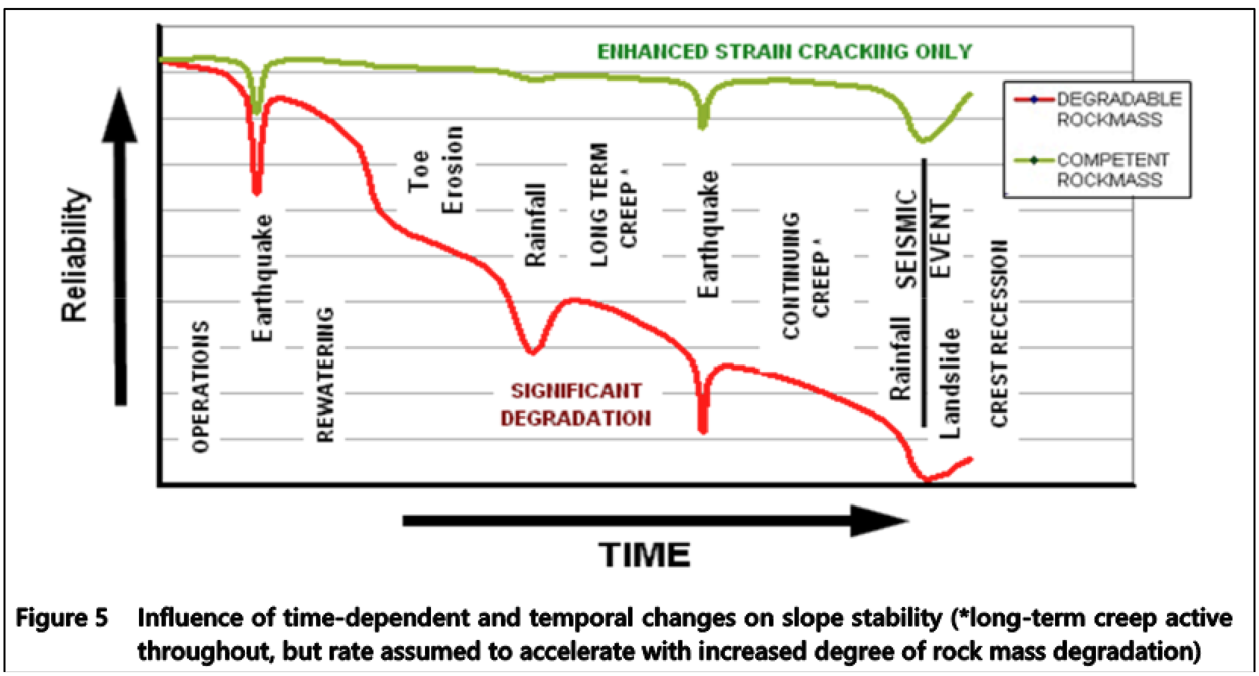

Figure 7. The decrease in the strength of the adjacent rock mass can be moderate for a competent rock mass, but can be profound for a degradable rock mass. In any event, the strength (called the "reliability" on the y-axis) of the adjacent rock mass tends to decrease with time since pit closure. Figure from Carter et al. (2022).

Although the long-term strength degradation of rock masses adjacent to open pits is generally acknowledged, there is still a lack of theoretical knowledge regarding the geologic and climatic controls on strength degradation. For example, there is a lack of knowledge in terms of the coupling between slow erosional processes and rapid incidents of slope instability (see Fig.

8) and how the erosion-slope stability interaction is then driven by climate change. According to de Graaf (2024), "There is no tool for assessing the interdependency between erosion and slope stability: where progressive undercutting can destabilise local and overall slope stability. Typical erosion modelling assumes ongoing denudation and deposition of material (until equilibrium is achieved), but doesn't consider slope instability (which might accelerate the process to reaching a long term equilibrium profile – but could be very different from the 'erosion only' model). There currently isn't a process to integrate this feedback loop into the erosion and stability models … This is of most significance for highly erodible materials and for quasi stable long-term slopes … Future research should consider a coupled erosion-stability-climate analysis tool with quantification of time-dependent material strength degradation."

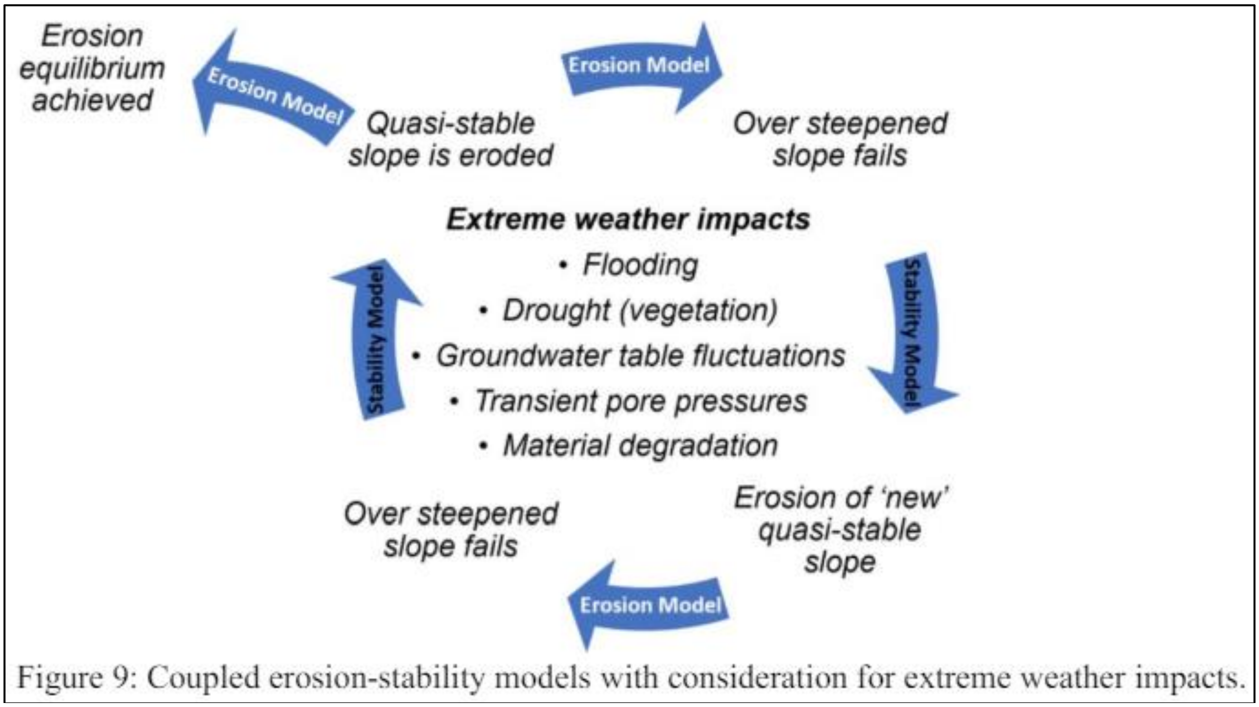

Figure 8. At the present time, there is a lack of conceptual or theoretical knowledge regarding the coupled processes of erosion, slope instability and climate change that will drive a long-term reduction in the strength of the rock masses adjacent to open mining pits during the post-closure period (see Figs. 6-7). Figure from de Graaf et al. (2024).

In light of the additional issues that occur for mine pit slopes in the post-closure period, the Large Open Pit Project has prepared the Guidelines for Mine Closure, which is scheduled for release in 2024 (LOP, 2024). Although the full guidelines have not yet been released as of the date of this report, the key recommendations are already present in a series of conference proceeding papers by the principal authors (de Graaf et al., 2021, 2024; Carter et al., 2022). Just as this report compares the safety criteria selected by Geo-Logic Associates (2022, 2023) with the recommendations of the Guidelines for Open Pit Slope Design for the operational period, it also compares the safety criteria selected by Geo-Logic Associates (2022, 2023) for the post-closure period with the recommendations of the Guidelines for Mine Closure. In terms of the revision of the DEIS or the preparation of a Supplemental Environmental Impact Statement (SEIS) or Final Environmental Impact Statement (FEIS), it would certainly be appropriate for the BLM to either wait for the release of Guidelines for Mine Closure or to consult with the authors of that volume.

TUTORIAL ON KEY GEOTECHNICAL CONCEPTS

Limit Equilibrium Method and Factor of Safety

The limit equilibrium method evaluates the stability of a mass of rock or soil by assessing the tendency of a slope or structure to fail by one rigid block sliding over another (see Fig. 9). The output of the limit equilibrium method is the factor of safety, which is the ratio of the resistance to the load, or the ratio of the shear strength to the shear stress. Thus, a factor of safety equal to 1.0 indicates a slope on the cusp of failure, while higher factors of safety indicate slopes with increasing stability. The limitation of the limit equilibrium method is that not all failures involve the sliding of one rigid block over another. For example, the limit equilibrium method does not assess the tendency of a slope to fail by slow creep that could accelerate into more rapid motion, by rockfall, or by structurally-controlled failures along pre-existing joints or faults. In summary, the limit equilibrium method is a useful starting point, but should not be the totality of a slope stability analysis.

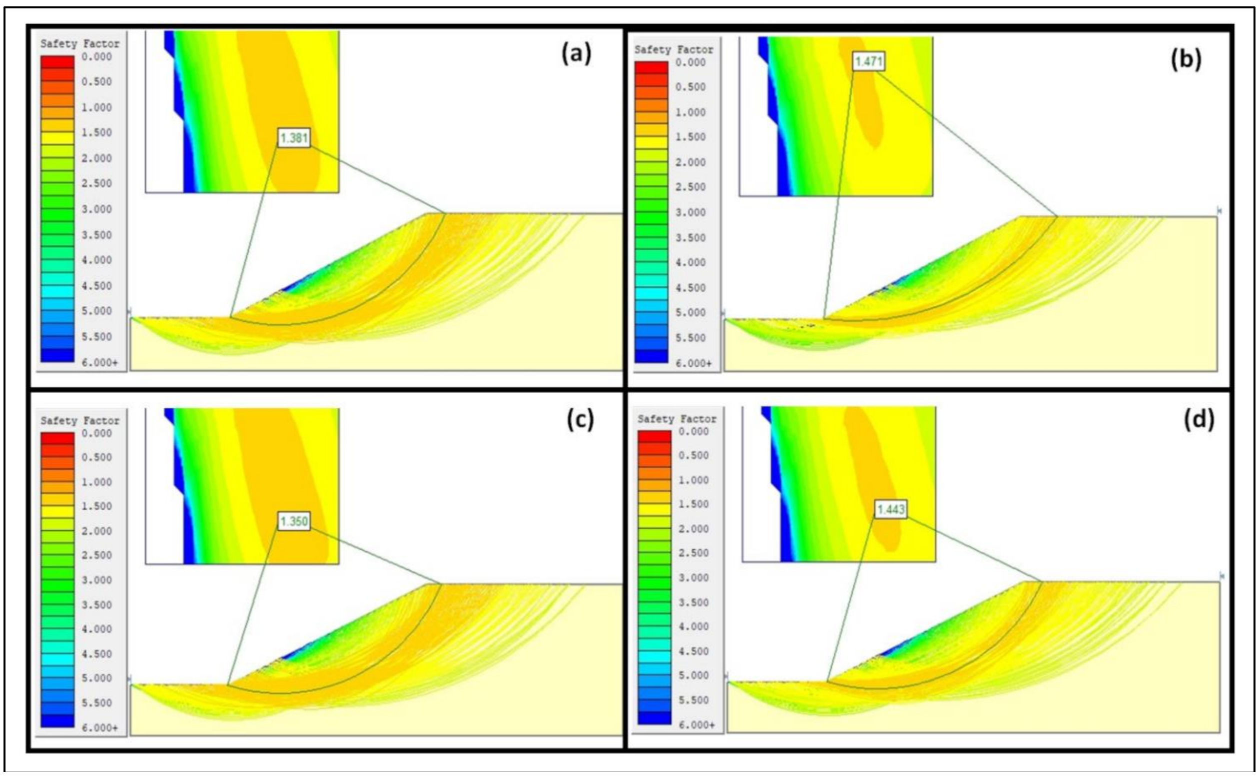

Figure 9. The factor of safety is the ratio of the shear strength to the shear stress (ratio of the resistance to the load) at some point within a slope, embankment or other type of earthen structure. The limit equilibrium method uses the unit weight, the shear strength parameters (cohesion and friction angle), pore water pressure, and position of the water table to calculate the factor of safety as averaged along every possible failure surface. The failure surface with the minimum factor of safety is called the critical failure surface. The factor of safety of the critical failure surface is regarded as the factor of safety of the structure. A factor of safety equal to 1.0 indicates that a structure is on the cusp of failure or, more precisely, that the probability of failure is 50% (see Fig. 10). It should be noted that the limit equilibrium method does not address all possible modes of failure, such as rockfall or structurally-controlled failures (movement along joints, faults, or other pre-existing planes of weakness). Figure from Sengani and Allopi (2022).

The input data for the limit equilibrium method are the topography (geometry), the unit weights (densities), shear stress parameters (cohesion and friction angle), and pore water pressures throughout the slope or structure and its foundation, as well as the position of the water table. The precise meanings of cohesion and friction angle are not necessary for this report, except that higher cohesion and higher friction angle correspond to greater shear strength. Materials that are saturated (below the water table) have lower shear strength and materials that are over-pressurized with water have even lower shear strengths. The limit equilibrium method considers all possible failure surfaces and calculates the factor of safety at each point along a possible failure surface (see Fig. 9). The factor of safety of a failure surface is the average of the factors of safety along every point of a surface. The failure surface with the lowest factor of safety is called the critical failure surface and the factor of safety of the critical failure surface is regarded as the factor of safety of the slope or structure (see Fig. 9).

It cannot be overemphasized that a factor of safety is not a measurement that is made, but the outcome of a model that depends upon a wide range of measurements, estimates and assumptions. There can be considerable uncertainty in the factor of safety as a result of uncertainty in the measurements of the input data and the incomplete sampling of structures for which the geotechnical parameters can have considerable spatial variability. There are also multiple computational methods for carrying out the limit equilibrium method for a given set of input data, each with its advantages and disadvantages, so that there is uncertainty as to whether the correct computational method has been used (Fell et al., 2015). As a consequence of the uncertainty in the data and the computational method, the calculated factor of safety cannot be assumed to be the same as the true factor of safety.

A slope should be stable as long as the true factor of safety is greater than 1.0, although it should be kept in mind that the limit equilibrium method and its resulting factor of safety are evaluating only a narrow class of types of slope failures. However, because of the uncertainty in the calculated factor of safety, the engineering practice is to require a calculated factor of safety significantly greater than 1.0 in order to ensure that the true factor of safety (which could be less than the calculated factor of safety) is actually greater than 1.0. There are numerous publications, industry guidance documents, and regulations regarding the appropriate minimum factor of safety. These minimum factors of safety depend upon the application and the context, but a minimum factor of safety of 1.5 is common for many geotechnical applications (ANCOLD, 2012, 2019; Fell et al., 2015).

Probability of Failure

Based on the preceding subsection, the factor of safety should not be understood as a single value, but as the mean of a distribution of possible values, each of which corresponds to a possible set of input data (see Fig. 10). The area under the distribution curve is then the probability that the true factor of safety is less than 1.0, that is, the probability of slope failure (see Fig. 10). This probability of failure is the probability over the entire design life of the slope or structure, which is different from the annual probability of failure that was discussed in the “Overview” section (see Fig. 5). For example, an annual probability of failure of 0.1% corresponds to a probability of failure of 5% in at least one year over a 50-year period. In other words, a mine pit slope with a probability of failure of 5% over a 50-year life of active operation would have a stability that was quite close to the annual probability of failure of 0.1% that has been recommended to bring the safety of mine pit slopes into line with other types of industrial infrastructure (Steffen et al., 2006; Wesseloo and Read, 2009; see Fig. 5). From another perspective, the annual probability of failure is the probability that the true factor of safety is less than 1.0 (see Fig. 10) multiplied by the annual probability of an event that could trigger slope failure, such as blasting, vehicular traffic, an earthquake, or a precipitation event.

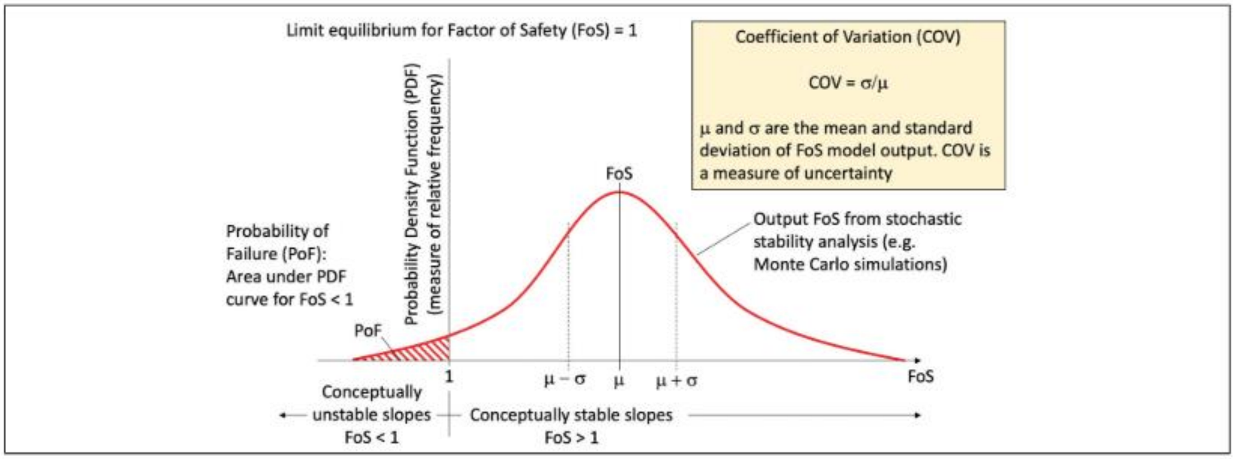

Figure 2. Conceptual representation of FoS distribution and PoF

Figure 10. The factor of safety is not a measurement, but the outcome of an model that involves input data of unit weight, shear strength parameters (cohesion and friction angle), pore water pressure, and position of the water table, together with a computational method, such as one of the computational variations on the limit equilibrium method (see Fig. 9). For that reason, the factor of safety should not be regarded as a single value, but as the mean of a distribution of values that reflects the uncertainty in the input data. The area under the distribution curve for which the calculated factor of safety is less than 1.0 is the probability of failure, that is, the probability that the true value of the factor of safety is less than 1.0. Thus, a calculated factor of safety equal to 1.0 indicates that the probability of failure is 50%. The standard deviation is a measure of the spread of the distribution curve or the uncertainty in the input data. The coefficient of variation (COV) is the ratio of the mean to the standard deviation, so that a high COV indicates a high level of data uncertainty, and a high probability of failure for a given factor of safety (see Figs. 11-12). Figure from Macciotta et al. (2020).

For a given mean factor of safety, the probability that the true factor of safety is less than 1.0 depends upon the spread in the distribution of possible values of the factor of the safety (see Fig. 10). One measure of the spread is the standard deviation, in which the range between one standard deviation less than the mean and one standard deviation greater than the mean includes 67% of the possible values of the factor of safety, assuming that the distribution follows a bell-shaped or normal curve (see Fig. 10). The ratio of the standard deviation to the mean is called the coefficient of variation (COV) (see Fig. 10). The important point is that a slope or structure with a large mean factor of safety and large standard deviation can have a greater probability of failure than a slope or structure with a small mean factor of safety and small standard deviation (see Fig. 11). The preceding point emphasizes the danger of an excessive reliance on achieving a target factor of safety without regard for the standard deviation, which reflects the uncertainty in the data that were used to calculate the factor of safety. Fig. 12 illustrates the same point, in which, for a given mean factor of safety greater than 1.0, the probability of failure increases as the standard deviation increases (left-hand side), while, for a given COV, the probability of failure increases as the factor of safety decreases (right-hand side).

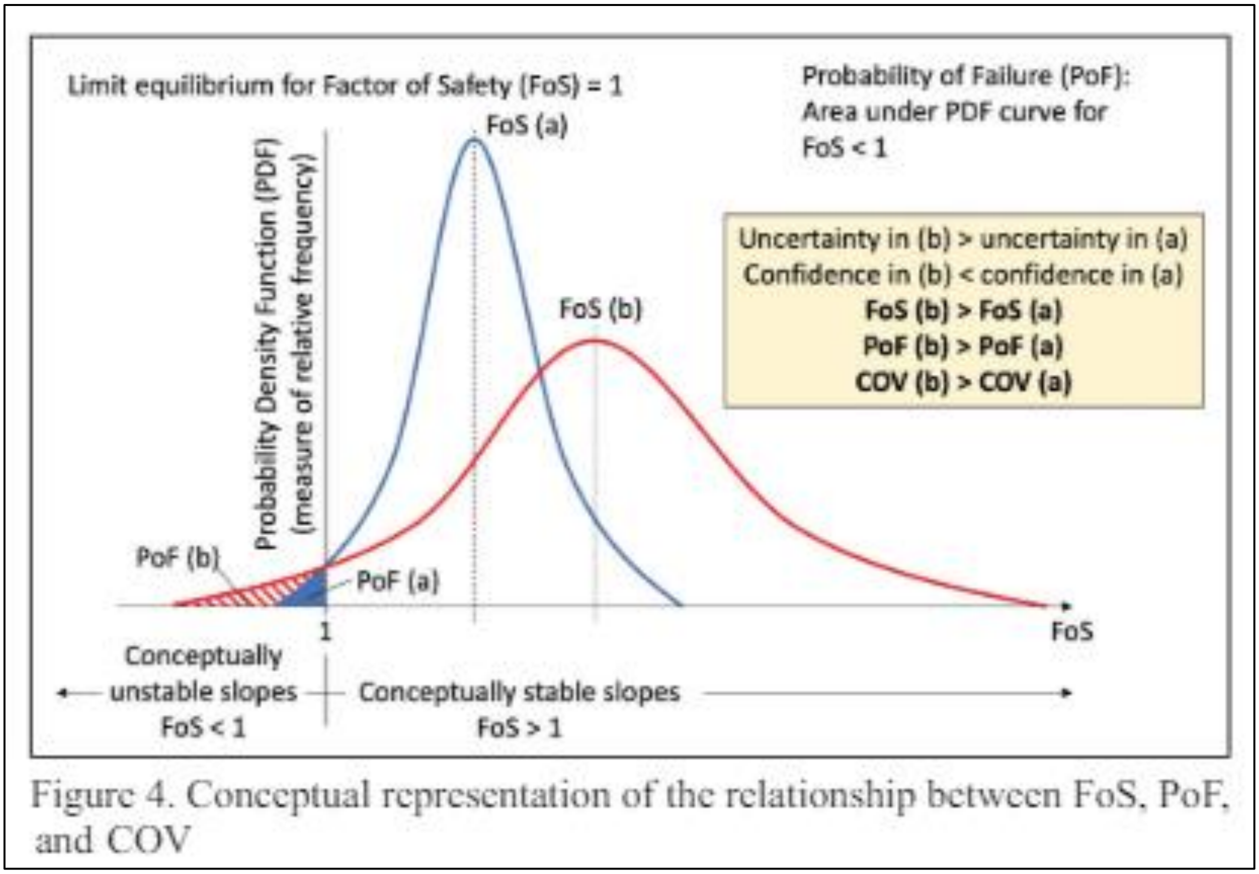

Figure 11. The blue curve (a) represents a structure or slope with a low factor of safety and low data uncertainty, equivalent to low coefficient of variation (COV) (see definition of COV in Fig. 10). The red curve (b) represents a structure or slope with a high factor of safety and high data uncertainty, equivalent to high COV. The structure or slope corresponding to the red curve has a greater probability of failure, that is, a greater area under the distribution curve in the region for which the factor of safety is less than 1.0 (see a different way to show the same concept in Fig. 12). The diagram indicates the danger of excessive reliance on meeting a minimum factor of safety without giving due consideration to the uncertainty in the factor of safety. Thus, modern guidelines on open pit design require meeting requirements for both a minimum factor of safety and maximum probability of failure (see Figs. 20a-b and 22) or on basing the required minimum factor of safety on the uncertainty in the input data (see Figs. 23a and 26a-c). Figure from Macciotta et al. (2020).

SUMMARY OF STABILITY ANALYSIS FOR RHYOLITE RIDGE OPEN PIT

The mine pit slopes at the proposed Rhyolite Ridge mine have been designed to achieve a minimum factor of safety of 1.2. According to Geo-Logic Associates (2022), “Cross sections that did not meet the project minimum factor of safety criteria of 1.2 or greater were reconfigured by stepping the quarry wall in or out, adjusting bench heights, and/or implementing a system of ground anchors in an iterative process until the slope was stabilized (i.e. until a minimum factor of safety of 1.2 or greater was attained for each cross section).” The justification for the selection of a minimum factor of safety of 1.2 was only that the minimum factor of safety of 1.2 had been set by the client. According to Geo-Logic Associates (2022), “The following scope of services was performed: … ▪ Performed static stability analysis for 19 cross sections around the proposed Quarry TR02- E provided by Ioneers’s subcontractor NewFields. ▪ Developed conceptual recommendations for cross sections, as necessary, in order to stabilize the quarry slope and meet the project’s minimum factor of safety criteria of 1.2 … ”

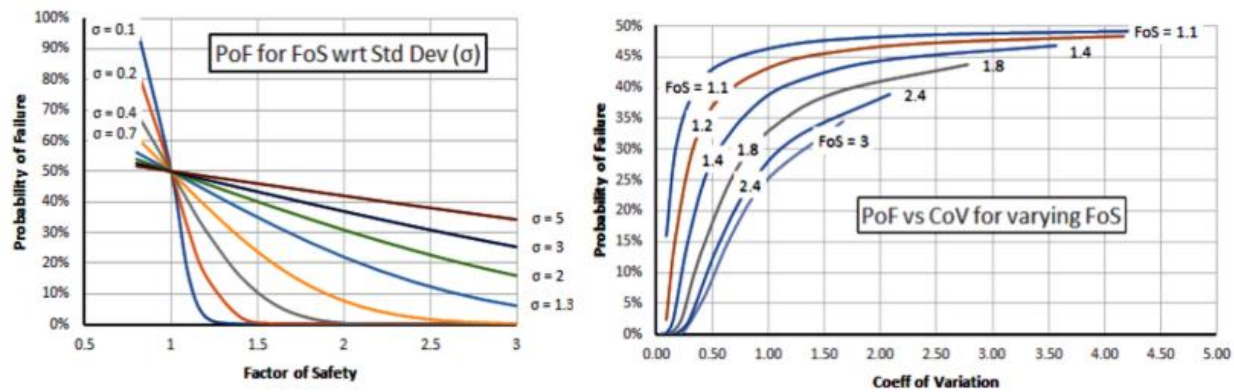

Figure 4 Characteristic relationships between Probability of Failure and Factor of Safety for differing analysis confidences (reliability)

Figure 12. On the left-hand side, for a given mean value of the factor of safety greater than 1.0, the probability of failure (area under the distribution curve for which the value of the factor of safety is less than 1.0) increases for increasing values of the standard deviation, which is a measure of the uncertainty in the input data (see Fig. 10 for a definition of standard deviation). On the right-hand side, for a given value of the coefficient of variation (COV), which is the ratio of the standard deviation to the mean (see Fig. 10), the probability of failure increases as the factor of safety decreases. See a different way to illustrate the same concept in Fig. 11. Figure from Carter et al. (2022).

In a critique of the slope stability analysis, U.S. Fish and Wildlife Service (2022) wrote in an email to BLM, "What has changed to allow for support and stability structures to be developed in the quarry? For years we have heard because of the geology/soils of this area, there was no way to avoid the Tiehm's subpopulations. The geology and soils haven't changed, so what engineering wise makes this structurally sound? The quarry analysis is in Appendix N [Geo-Logic Associates (2022)] and was done by GLA (Geo-Logic Associates Inc.). This is downslope of the Tiehm area. There are no calculations shown or PE (Professional Engineer) stamps on the documents; these items will make the analysis more reliable as they will better fix the responsibility and liability of the engineers involved … One item that stood out to me was the Factor of Safety (FS) being used of 1.2. This is very low. Typically a FS of 1.5 is the minimum for most engineering work, and sometimes much higher depending on the risk. It could be that previous analyses used a higher FS and could not justify the stability; when the FS was lowered, it could be justified." The response of Geo-Logic Associates (2023) was simply that the minimum factor of safety of 1.2 was appropriate without reference to any guidance documents. According to Geo-Logic Associates (2023), "The assignment of a design criteria to any given quarry slope sector is typically a function of the potential consequences of failure and for these analyses is a FOS [Factor of Safety] of 1.20 or greater."

Table 1. Lithology of open pit[1]

Unit Code	Formation	Lithologic Description
Q1	Quaternary Alluvium	Young alluvium; unconsolidated coarse gravels, rounded to subangular clasts, dominant volcanic composition
S3	Cave Spring Fm.	Siltstone, medium bedded, occasional thin sandstone or gritstone, compact, some silicic zones, gray, green-gray and yellow-gray
G4	Cave Spring Fm.	Gritstone; lapilli tuff, fine to coarse, massive to poorly bedded, locally pumice rich, gray to orange, grades upward into siltstone
M4	Cave Spring Fm.	Carbonate and marl, dominant white massive limestone or tufa, some zones laminated stromatolite, dense to porous, minor thin siltstone or gritstone interbeds, irregular silicic zones, white, beige
G5	Cave Spring Fm.	Gritstone, coarse lapilli tuff, often vuggy and very porous from leached pumice, very rough texture, much friable, angular volcanic fragments in lower portion; dominantly orange to yellow oxidized, some leisegang banding, gray when unaltered
M5	Cave Spring Fm.	Claystone and marl, some upper swelling clay locally waxy and friable, thin to medium bedded marl, distinct zone of medium banded gray and white marl, toward base increasing possibility of calcite pseudomorphs after borates; off-white, light gray, beige to tan
B5	Cave Spring Fm.	Marl, minor claystone and siltstone, thin to medium bedded, all very fine grained, dense where dominated by searlesite, occasional calcite pseudomorphs after borate, rare ulexite, sedimentary breccia near base; gray to bluish-gray to white
S5	Cave Spring Fm.	Siltstone, locally interbedded thin marl, sandstone, medium bedded, some pebbly beds bearing ostracods, brown and tan at top, some thin green layers, rest gray to gray-brown
G6	Cave Spring Fm.	Gritstone, sandstone, mostly massive, lapilli tuff and diamictite, locally coarse pumiceous, gray; grades upward into siltstone
L6	Cave Spring Fm.	Marl, minor siltstone and claystone, often finely banded, much medium wavy bedded, locally silicic beds, gray, tan, brown, beige, cream; may include sections of gritstone or diamictite
Lsi	Cave Spring Fm.	Marl, carbonate with abundant silica, medium bedded, siliceous knobs or lenses, gray, white, tan or brown
G7	Cave Spring Fm.	Diamictite, massive, some crude bedded sandstone, mixed angular volcanic clasts of all sizes but mostly coarse, occasional carbonate, dark gray to gray
Tlv	Argentite Canyon Volcanics	Porphyritic latite, massive, dense, commonly large feldspar phenocrysts, often brecciated, may grade into diamictite: gray to dark gray

Tbx	Rhyolite Ridge Tuff	Tuff breccia, massive, lithic angular volcanic fragments in fine tuffaceous matrix, some crystal fragments, cream, pink, light gray; occasional zones welded tuff to vitrophyre
Z	Silver Peak Fm.	Sandstone, siltstone, mostly unsorted, pebbly sandstone or conglomerate, massive to faintly bedded, subrounded clasts, possibly volcanic, brown or gray-brown

[1]Redrawn from Geo-Logic Associates (2023)

Table 1 - Material Properties

Material Name	Color	Unit Weight (lbs/ft3)	Strength Type	Cohesion (psf)	Phi (deg)	Cohesion 2 (psf)	Phi 2 (deg)	Anisotropic Linear A (deg)	Anisotropic Linear B (deg)	Anisotropic Surface	Water Surface	Ru
Q1		120	Mohr-Coulomb	550	37						None	0
S3		124.4	Anisotropic Linear	555.7	23.3	7920	39.42	5	10	Anisotropic Surface 1	None	0
G4		120	Mohr-Coulomb	11376	35.53						None	0
M4		146.7	Anisotropic Linear	476.7	39.77	4608	26.23	5	10	Anisotropic Surface 2	None	0
G5		120	Mohr-Coulomb	4608	31.19						None	0
M5a		110	Mohr-Coulomb	271.85	7.78						None	0
M5		133.4	Anisotropic Linear	567.7	14.92	3168	19.58	5	10	Anisotropic Surface 3	None	0
B5		130.4	Anisotropic Linear	567.7	14.92	8784	40.17	5	10	Anisotropic Surface 4	None	0
S5		123.2	Anisotropic Linear	788.1	33.1	6768	36.18	5	10	Anisotropic Surface 5	None	0
G6		120	Mohr-Coulomb	4464	27.04						None	0
L6		134.3	Anisotropic Linear	496.47	24.6	5904	32.33	5	10	Anisotropic Surface 6	None	0
LSI		130	Anisotropic Linear	496.47	24.6	5904	32.86	5	10	Anisotropic Surface 7	None	0
G7		130.9	Mohr-Coulomb	12384	49.77						None	0
Tbx D=0.7		145	Mohr-Coulomb	14688	45.02						None	0
Buttress		125	Mohr-Coulomb	150	37						None	0

Figure 13. The geotechnical analysis by Geo-Logic Associates (2022, 2023) states the unit weights and shear stress parameters (cohesion and friction angle ("Phi") for each geologic unit with ultra-precision, sometimes with five significant digits. Geo-Logic Associates (2022, 2023) does not provide any information on the uncertainty in the input data that would justify such a high degree of precision. In addition, the factors of safety that are calculated from the unit weights and shear stress parameters are stated as single values with no range of uncertainty (see Fig. 15). In particular, there is no sensitivity analysis that would show the range of possible factors of safety that could result from reasonably possible alternative values for the geotechnical parameters and there is no distribution of possible values for the factor of safety that would make it possible to estimate the probability of failure (see Figs. 10-11). The low degree of uncertainty and high precision that is implied in the above table is quite unlikely in light of the raw data in Geo-Logic Associates (2022) that show a very small number of measurements for each sample with a high degree of scatter (see Fig. 19). Geo-Logic Associates (2022) states that some of the material properties were obtained from a report by the consulting company EnviroMine (2019) that is not available for public review, while other material properties were simply the judgment of Geo-Logic Associates. Geo-Logic Associates (2022, 2023) does not identify any source or type of material for the buttress, so that the geotechnical parameters of the buttress should be regarded as strictly hypothetical. Finally, it was assumed that all geologic units would be unsaturated (see column second from right-hand side) both during mine operation and indefinitely through the post-closure period. Table from Geo-Logic Associates (2022).

Geo-Logic Associates (2023) used the geotechnical properties that were provided by EnviroMine (2019) (see Table 1 and Fig. 13) to update the stability analyses for six sections across the proposed quarry, including TR02E-5, TR02E-6, TR02E-7, TR02E-8, TR02E-9, and TR02E-11 (see Fig. 14). The last five sections are of special interest for this report since they intersect subpopulations of Tiehm's buckwheat. In particular, section TR02E-11 intersects the population of Tiehm's buckwheat that would occur only 15 feet from the edge of the quarry (see Fig. 14 and compare with Figs. 2 and 3a-b). The stability analyses were updated for the slopes without buttresses, corresponding to the pit slopes as they would exist during the operational period (see column "Final Slope Configuration" in Fig. 15), and for the slopes with buttresses, corresponding to the pit slopes as they would exist during the post-closure period (see column "Condition 1" in Fig. 15). The difference between "Condition 1" and "Condition 2" in Fig. 15 is that "Condition 1" includes ground anchors. While there is a plan to construct buttresses for Sections TR02E-5 and TR02E-8, there is no plan to install ground anchors at those sections (see Figs. 14 and 15).

The factors of safety during the operational period (without a buttress) range from 1.20 to 1.26 (see Fig. 15), or just barely above the minimum factor of safety that was selected by Geo-Logic Associates (2022, 2023). The section of greatest concern (TR02E-11) because it would intersect the population of Tiehm's buckwheat that would be only 15 feet from the edge of the quarry, would have a factor of safety of only 1.21 (see Figs. 14-15). The addition of a buttress increases the factor of safety from 1.21 to 1.52, from 1.24 to 1.31, from 1.26 to 1.45, from 1.20 to 1.57, from 1.22 to 1.25, and from 1.21 to 1.33 for Sections TR02E-5, TR02E-6, TR02E-7, TR02E-8, TR02E-9, and TR02E-11, respectively (see Fig. 15). The installation of ground anchors does not appear to have any impact on the factors of safety (see Fig. 15).

"Condition 3" in Fig. 15 refers to the factor of safety that would occur after buttress construction along the critical failure surface that would have existed prior to buttress construction (see Fig. 15). It is not surprising that these factors of safety greatly increase, since failure is no longer predicted to occur along these surfaces. The point is presumably that the addition of a buttress advances the critical failure surface inward toward the quarry, so that failure occurs within the buttress, as opposed to within the pit walls (such as, beneath the population of Tiehm's buckwheat). However, there is no consideration as to how the pit walls will continue to evolve after failure of the buttress. By contrast, the possibility of progressive failure of the buttress followed by failure of the pit walls was taken into account in the post-closure recommendations of de Bruyn et al. (2019). Under the assumption that pit slope buttresses would be constructed out of waste rock (the rock that must be removed to reach the ore body), de Bruyn et al. (2019) wrote, "Consider the stability of the waste rock buttress in the long-term. Although the material used for the buttress will likely be dumped at its current angle of repose, it is possible that this angle will reduce in the long-term as the properties of the waste rock deteriorate. Any significant failure (not merely surficial ravelling) or erosion of the waste buttress in the long-term, reducing its effective width/volume, will reduce its effectiveness as a support measure. This could conceivably result in an increase in the risk of failure of the original slope it is meant to support, such that the acceptance criteria for the closure plan are no longer met."

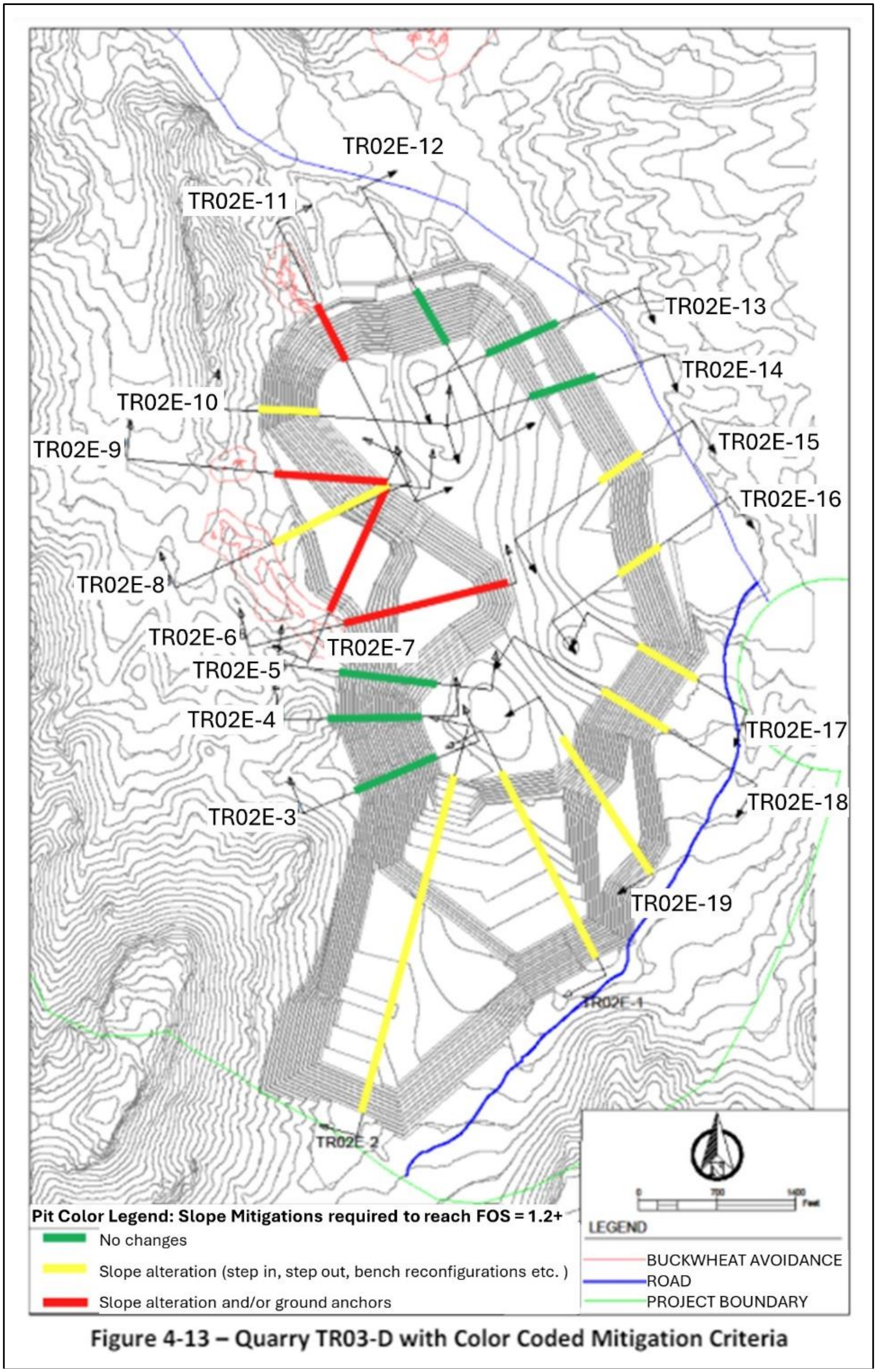

Figure 14. Geo-Logic Associates (2023) updated the design of Sections TR02E-05, TR02E-6, TR02E-7, TR02E-8, TR02E-9, and TR02E-11 with a goal of increasing the factor of safety (see Fig. 15). Figure from Geo-Logic Associates (2022) with overlay of larger labels for ease of reading.

Table 2 - Buttress Slope Stability Results

Section	Ground anchors included in section (yes/no)	Final Slope Configuration FOS (Prior to buttress implementation)	FOS for Condition 1*	FOS for Condition 2**	FOS for Condition 3***
TR02E-5	No	1.21	-	1.52	1.91
TR02E-6	Yes	1.24	1.31	1.31	2.71
TR02E-7	Yes	1.26	1.45	1.45	1.81
TR02E-8	No	1.20	-	1.57	1.84
TR02E-9	Yes	1.22	1.25	1.25	2.15
TR02E-11	Yes	1.21	1.33	1.33	2.45

*Condition 1 – Post-mining buttress is in place covering ground anchors and the critical failure surface is located entirely within the buttress.
**Condition 2 – The same post-mining buttress from Condition 1 is in place and ground anchors are either absent or have become passive (unloaded).
***Condition 3 –The same post-mining buttress configuration from Conditions 1 and 2 is analyzed with the exact same minimum slip surface from the Final Slope Configuration FOS. This result shows how the buttress increases the factor of safety along the Final Slope Configuration slip surface below buckwheat areas.

Figure 15. Without a buttress, the factors of safety for Sections TR02E-5, TR02E-6, TR02E-7, TR02E-8, TR02E-9, and TR02E-11 (see Fig. 14) range from 1.20 to 1.26. The stability analyses for the sections without an added buttress correspond to the operating period of the quarry, since a buttress is constructed as a part of pit closure. Thus, even without a buttress, the factors of safety fulfill the minimum factor of safety of 1.2 that was set by Geo-Logic Associates (2022, 2023), but not the minimum factor of safety of 1.3-1.5 that is recommended by the Guidelines for Open Pit Slope Design and the SME Surface Mining Handbook. The upper range of 1.5 would be preferred for the Rhyolite Ridge mine due to the high degree of uncertainty in the geotechnical data (see Fig. 19). The addition of buttresses for pit closure (Condition 1) increases the factors of safety to the range 1.25-1.57. This again fulfills the minimum factor of safety of 1.2 that was set by Geo-Logic Associates (2022, 2023), but not the minimum factor of safety of 2.0 that would be recommended by the Guidelines for Mine Closure (see Fig. 26a-c) for the pit wall condition, failure consequences, and design confidence of the quarry at the Rhyolite Ridge mine. The right-hand column (Condition 3) states the factor of safety for a surface that is not the critical failure surface, so that its significance is not apparent. Figure from Geo-Logic Associates (2023).

The recommendations by de Bruyn et al. (2019) further considered the need for the buttress to reduce the width of the Zone of Instability as defined in Western Australian guidelines (Department of Industry and Resources, 1997). According to de Bruyn et al. (2019), "These guidelines provide generic design criteria to determine the likely zone of instability (ZoI) for long-term post-mining instability; i.e. the area designated as the potentially unstable pit edge zone … Using the identified critical failure mode(s), determine the position and level of waste material that will need to be dumped against the pit wall to maintain its stability in the long-term (i.e. which will meet the required design acceptance criteria) such that the reduced ZoI allows the abandonment bund to be located at the position required. Verify the stability of the pit slope and dumped in-pit waste material in the long-term to allow for the ZoI to be reduced as necessary." The significance of the Zone of Instability will be further considered in the "Methodology and "Responses" sections.

An additional assumption made in Geo-Logic Associates (2022, 2023) is that, after dewatering and de-pressurization to allow construction of the open pit, all of the relevant geologic units would be above the water table both during mine operation and during the post-closure period (see Fig. 13). According to Geo-Logic Associates (2022), "For stability calculations performed herein, GLA [Geo-Logic Associates] has assumed that the quarry slopes will be dry as a result of dewatering performed during mine operations and pit development." Geo-Logic Associates (2022, 2023) both stated, "Slopes are considered to be dewatered with no excess pore pressures as indicated by Ioneer and their consultant HydroGeoLogica." In other words, as with the assumption of a minimum factor of safety of 1.2, the permanently low position of the water table was an assumption that was supplied to Geo-Logic Associates by their clients.

Geo-Logic Associates (2023) recognized that it was not obvious to everyone that geologic units that had been dewatered for pit construction would remain permanently dewatered. According to Geo-Logic Associates (2023), "The U.S. Fish and Wildlife Service has expressed concerns about the potential effectiveness of the proposed program for dewatering/ depressurization of the quarry at Rhyolite Ridge and the potential impact of surface water infiltration during extreme snowmelt events and/or precipitation events on pore pressures and stability." In an email to the Bureau of Land Management, U.S. Fish and Wildlife Service (2022) expressed in their own words, "Stability calculations were done assuming quarry slopes were dry. What if dewatering the slopes fail or there is an intense rain or snow storm? This page also says that this area because of the type of clay it is, may be challenging to dewater. Why weren't stability calculations done for extreme weather events if there is so much concern about slope stability? … I would request slope stability analyses for wet or saturated soils and whether there is still any FS or whether the slopes will fail."

The response by Geo-Logic Associates (2023) was that, even for extreme precipitation and snowmelt events, the excess water would either become surface runoff or would infiltrate to a shallow depth and then evaporate, but would not reach the geologic units that could result in slope instability. According to Geo-Logic Associates (2023), "As regards the impact of infiltration during snowmelt or precipitation events, as difficult as it may be to depressurize and remove water from these low permeability clays, it is even more difficult to put it back in. The vast majority of the water applied to the surface will simply become surface runoff. The small fraction that does infiltrate will initially form a shallow saturated wetting front at the surface that will continue to grow as long as the source of water at the surface persists and will exhibit small positive pore water pressures. As soon as the surface water source goes away, the water in the wetting front will continue to redistribute at depth, but now as an unsaturated wetting front with negative pore water pressures (soil suction). The depth of penetration in these low permeability soils will remain very near the surface and the effects of potential evaporation at the surface will eventually remove most if not all of the water in the wetting front as long as it remains above the ‘extinction depth’ (the depth below which potential evaporation at the surface is no longer effective). In summary, there is no risk of any significant volume of water from surface infiltration reaching the deep critical failure planes associated with the weak anisotropic clays that present the most serious stability risk in the quarry.”

The final item of particular interest in Geo-Logic Associates (2023) is the Adaptive Management plan for slope stability. Adaptive Management is also called the Observational Method and is the approach used by nearly all large-scale mining and other engineering projects at the present time. For complex projects, it is not possible to determine all actions in advance because some later actions will depend on the unknown outcomes of earlier actions. Instead, a monitoring plan is created together with a set of preplanned actions ready for execution in response to every possible adverse observation. According to the Global Industry Standard on Tailings Management (GISTM), the Observational Method is “a continuous, managed, integrated, process of design, construction control, monitoring and review that enables previously defined modifications to be incorporated during or after construction as appropriate … The key element of the Observational Method is the proactive assessment at the design stage of every possible unfavourable situation that might be disclosed by the monitoring programme and the development of an action plan or mitigative measure to reduce risk in case the unfavourable situation is observed” (ICMM-UNEP-PRI, 2020). The GISTM continues, “Full implementation of the Observational Method shall be adopted for non-brittle failure modes” (ICMM-UNEP-PRI, 2020), referring to failure modes that occur with some warning or precursors, so that there is sufficient time for observations and pre-planned responses.

The GISTM would be strictly applicable only to tailings facilities, not mine pits. Thus, the GISTM should be applicable to the proposed Spent Ore Storage Facility (SOSF) for the Rhyolite Ridge mine (Bureau of Land Management, 2024a), which is not reviewed in this report. The potential relevance of the GISTM to the proposed quarry will be discussed in the “Responses” section. At this point, it suffices to point out that Company Members of the International Council on Mining and Metals (ICMM) have been obligated to fully comply with the requirements of the GISTM since August 5, 2023 (ICMM, 2021). Ioneer is not a Company Member of ICMM, but it is noteworthy that Association Members of ICMM include the Australasian Institute of Mining and Metallurgy (AusIMM), the International Lithium Association (ILiA), the Minerals Council of Australia (MCA), the US-based National Mining Association (NMA), and the US-based Society for Mining, Metallurgy and Exploration (SME) (ICMM, 2024). It is not clear to what industry guidelines Ioneer adheres, since the company is not a member of either the Minerals Council of Australia (MCA, 2024), nor the International Lithium Association (ILA, 2024).

The Adaptive Management plan (Observational Method) in Geo-Logic Associates (2023) consists largely of descriptions and photographs of types of instruments that could be used to monitor slope stability, but without any specific plan as to how those instruments would be used. The set of preplanned actions then consists of the single sentence stating, “Preliminary concepts for adaptive management actions include suspending mining activity, stopping mining activity and implementing mitigation measures in an area if detrimental instability near sensitive habitat is identified, based on monitoring” (Geo-Logic Associates, 2023). There is no clarification as to how or whether “suspending mining activity” and “stopping mining activity” are different concepts. It is most important that the mining company Ioneer has made no apparent commitment to close the mine if there is indication that slope instability could be affecting Tiehm’s buckwheat habitat. Nevertheless, the preceding quote does help to clarify that a slope failure that could impact the Tiehm's buckwheat population would be an accident with very high consequences. The implied consequences of slope failure will form the context in this report for evaluating the statement by Geo-Logic Associates (2023) in the same document that "the assignment of a design criteria to any given quarry slope sector is typically a function of the potential consequences of failure and for these analyses is a FOS of 1.20 or greater."

METHODOLOGY

Based on the preceding sections, the objectives of this report can be subdivided into the following questions regarding the geotechnical analysis in the DEIS:

1) Are the calculated factors of safety reliable?
2) Was the choice of 1.2 for the minimum factor of safety appropriate for the operational period?
3) Was the choice of 1.2 for the minimum factor of safety appropriate for the post-closure period?
4) Was the Zone of Instability for open pits as specified in Western Australian guidelines properly taken into account?
5) Was the assumption that slope materials will remain unsaturated justified?
6) Is the proposed Adaptive Management plan adequate?

Before addressing the methodology for answering the preceding questions, it is appropriate to return to the issues raised in the "Overview" section that some information in the DEIS is inconsistent with information in other sources and that some information in the DEIS has already been acknowledged by the Bureau of Land Management to be out-of-date. The maps of the Tiehm's buckwheat populations prepared by Ioneer for the DEIS and in use by the Center for Biological Diversity are compared in Figs. 16a-b. On the northern side of the quarry, the Ioneer version of the population is shifted toward the east and the south, although not in a consistent manner (see Fig. 16a). On the western side of the quarry, the Ioneer version of the population appears more generalized and may show additional subpopulations or clusters to the northeast of subpopulation 5, to the west of subpopulation 4, and to the southwest of subpopulation 6A (see Fig. 16b).

The correct location of the quarry is of critical importance, since that is the basis for the slope stability analyses. Without a correct location for the quarry, due to the very complex geology of faulted and folded geologic units, there is no way of knowing which geologic units will be intersected by the quarry walls, at what depths the units will be intersected, and what will be the inclinations (dips) of the units at those depths. Shapefiles for both the quarry perimeter and the haul roads were provided to the Center for Biological Diversity by the Bureau of Land Management. The quarry perimeter shows an indentation that would exactly accommodate the planned haul road (compare Figs. 17a-b). With regard to the haul road shapefile that was provided, the Bureau of Land Management (2024c) wrote, "The haul road location is currently being adjusted by Ioneer based on the consultation process between the BLM and the U.S. Fish & Wildlife Service. As such, the current shapefiles for the haul road location would provide no valuable information." Thus, if the haul road map (see Fig. 17b) does not show the haul road that would actually be constructed, then the quarry map (see Fig. 17a) is not the quarry that would actually be constructed, although the quarry map was the basis for the stability analyses in Geo-Logic Associates (2022, 2023). In the absence of any other workable procedure, the stability analyses contained in Geo-Logic Associates (2022, 2023) were evaluated in this report, even though it is clear that they must already be out-of-date. No attempt was made in this report to document all inconsistencies or outdated information in the DEIS.

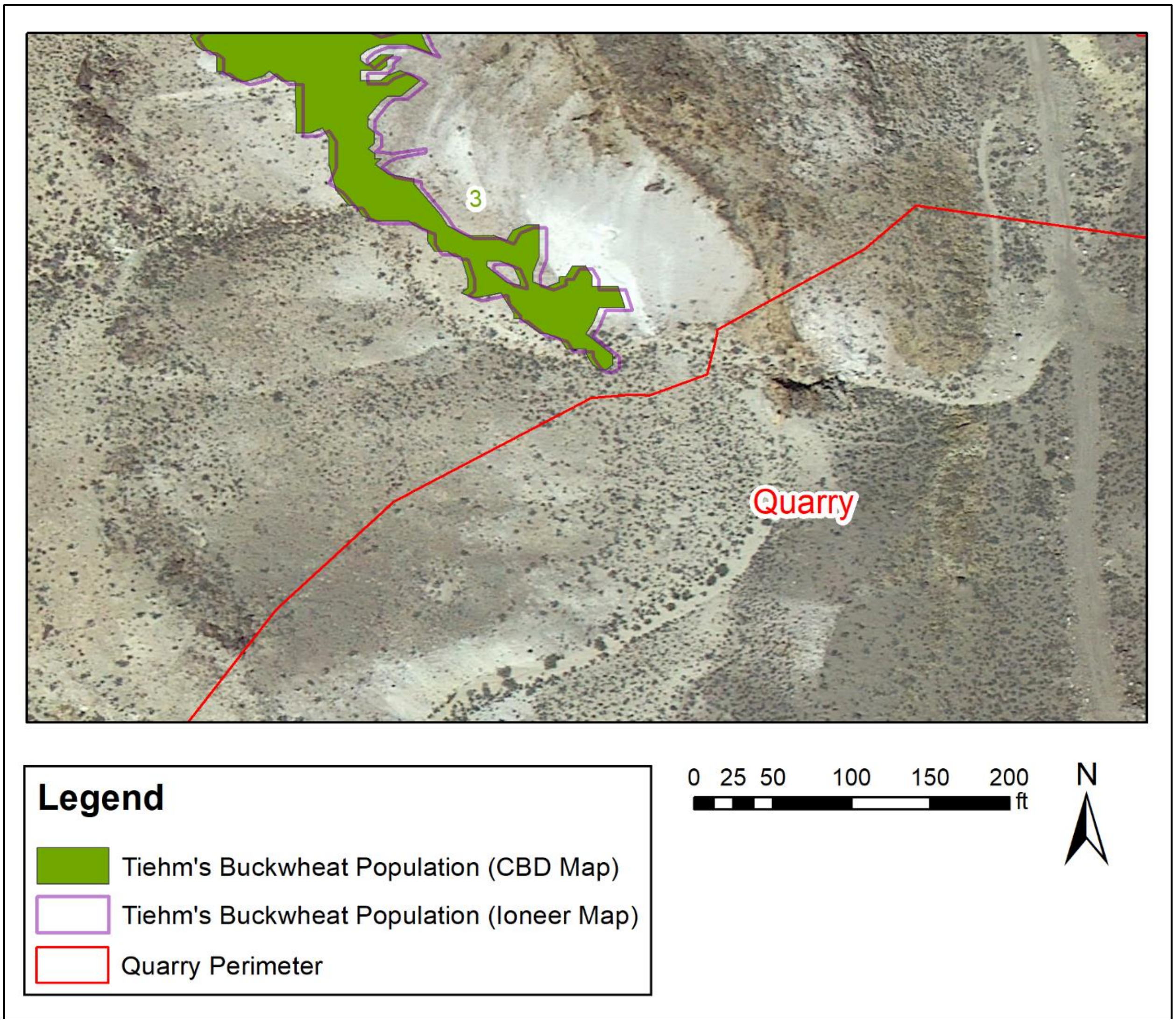

Figure 16a. The Tiehm's buckwheat population maps that are used by the Center for Biological Diversity (CBD) and Ioneer are not identical. According to the CBD map, the edge of the quarry would be 17 feet from the Tiehm's buckwheat population (see Fig. 3a), while the separation distance would be 15 feet according to the Ioneer map (see Fig. 3b). The Ioneer map was provided to the Center for Biological Diversity by the Bureau of Land Management and is the map that was used in preparation of the Draft Environmental Impact Statement. The quarry map was also provided to the Center for Biological Diversity by the Bureau of Land Management. The green number refers to the subpopulation. Background is Google Earth imagery from August 9, 2013. The map is projected onto the WGS84 coordinate system.

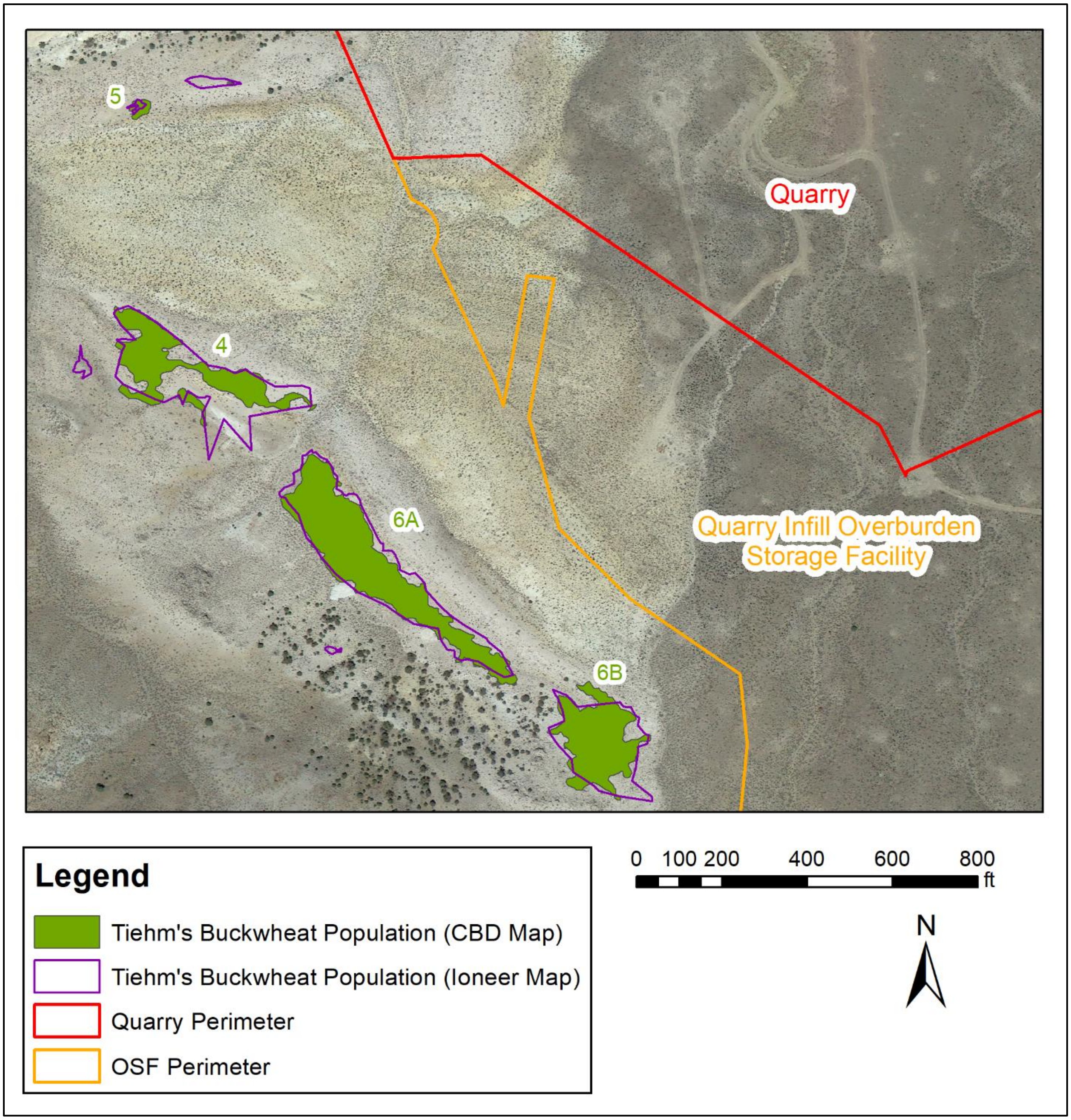

Figure 16b. The Tiehm's buckwheat population maps that are used by the Center for Biological Diversity (CBD) and Ioneer are not identical. According to the CBD map, subpopulations 5, 4, 6A, and 6B would be 380 feet, 332 feet, 283 feet, and 177 feet, respectively from the edge of the quarry (see Fig. 4a). According to the Ioneer map, subpopulations 5, 4, 6A, and 6B would be 208 feet, 329 feet, 281 feet, and 165 feet, respectively from the edge of the quarry (see Fig. 4b). On the west side of the quarry, in comparison with the CBD map, the Ioneer map appears more generalized and may show additional subpopulations or clusters to the northeast of subpopulation 5, to the west of subpopulation 4, and to the southwest of subpopulation 6A. The Ioneer map was provided to the Center for Biological Diversity by the Bureau of Land Management and is the map that was used in preparation of the Draft Environmental Impact Statement. The quarry map was also provided to the Center for Biological Diversity by the Bureau of Land Management. The green number refers to the subpopulation. Background is Google Earth imagery from August 9, 2013. The map is projected onto the WGS84 coordinate system.

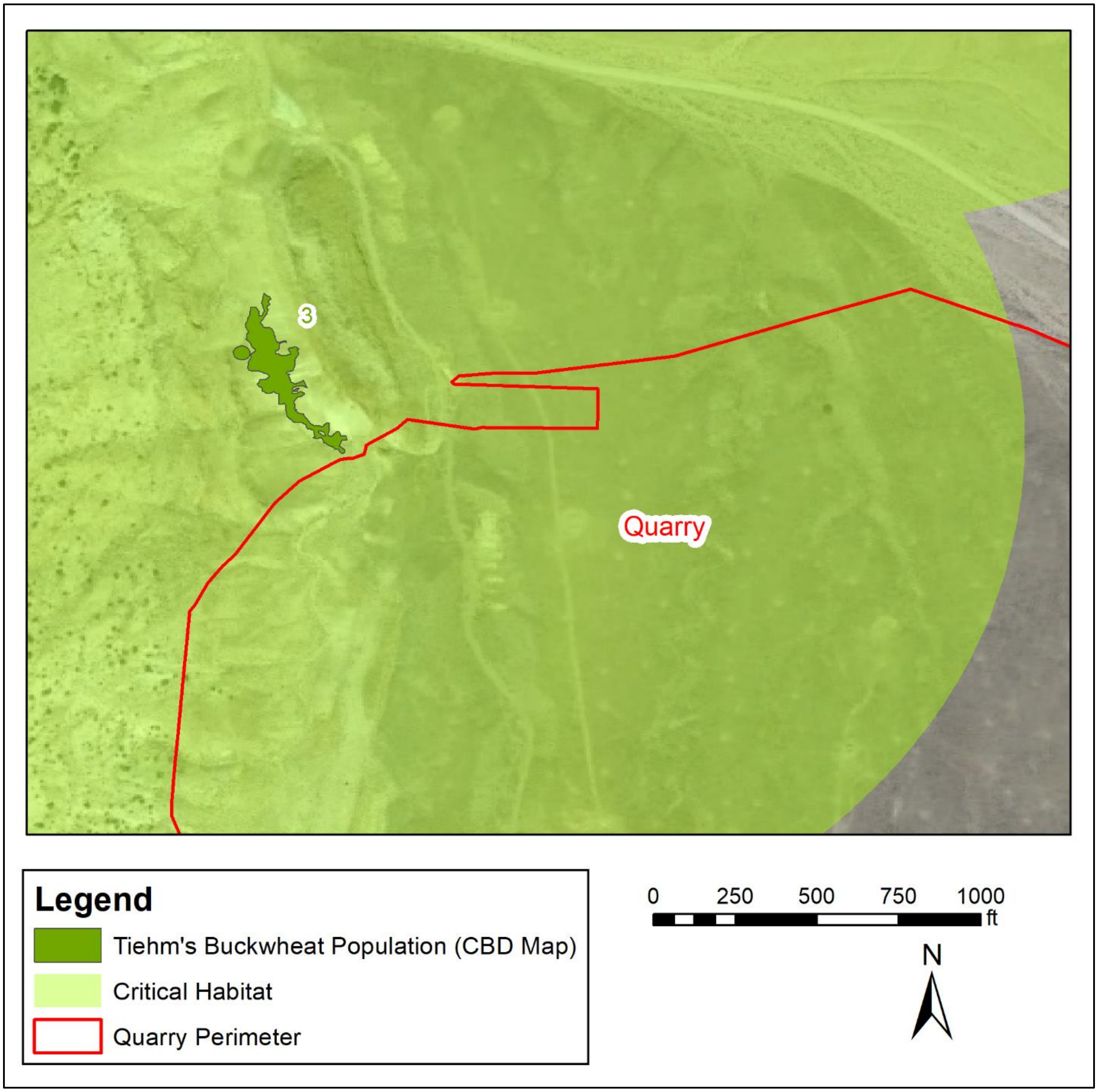

Figure 17a. The quarry perimeter shows an indentation that would exactly accommodate the planned haul road (compare with Fig. 17b). The quarry and haul road maps were provided to the Center for Biological Diversity by the Bureau of Land Management. With regard to the map that was provided, the Bureau of Land Management (2024c) wrote, "The haul road location is currently being adjusted by Ioneer based on the consultation process between the BLM and the U.S. Fish & Wildlife Service. As such, the current shapefiles for the haul road location would provide no valuable information." Thus, if the haul road map (see Fig. 17b) does not show the haul road that would actually be constructed, then the quarry map shown above is not the quarry that would actually be constructed, although the quarry map was the basis for the stability analyses in Geo-Logic Associates (2022, 2023). The green number refers to the Tiehm's buckwheat subpopulation. Background is Google Earth imagery from August 9, 2013. The map is projected onto the WGS84 coordinate system.

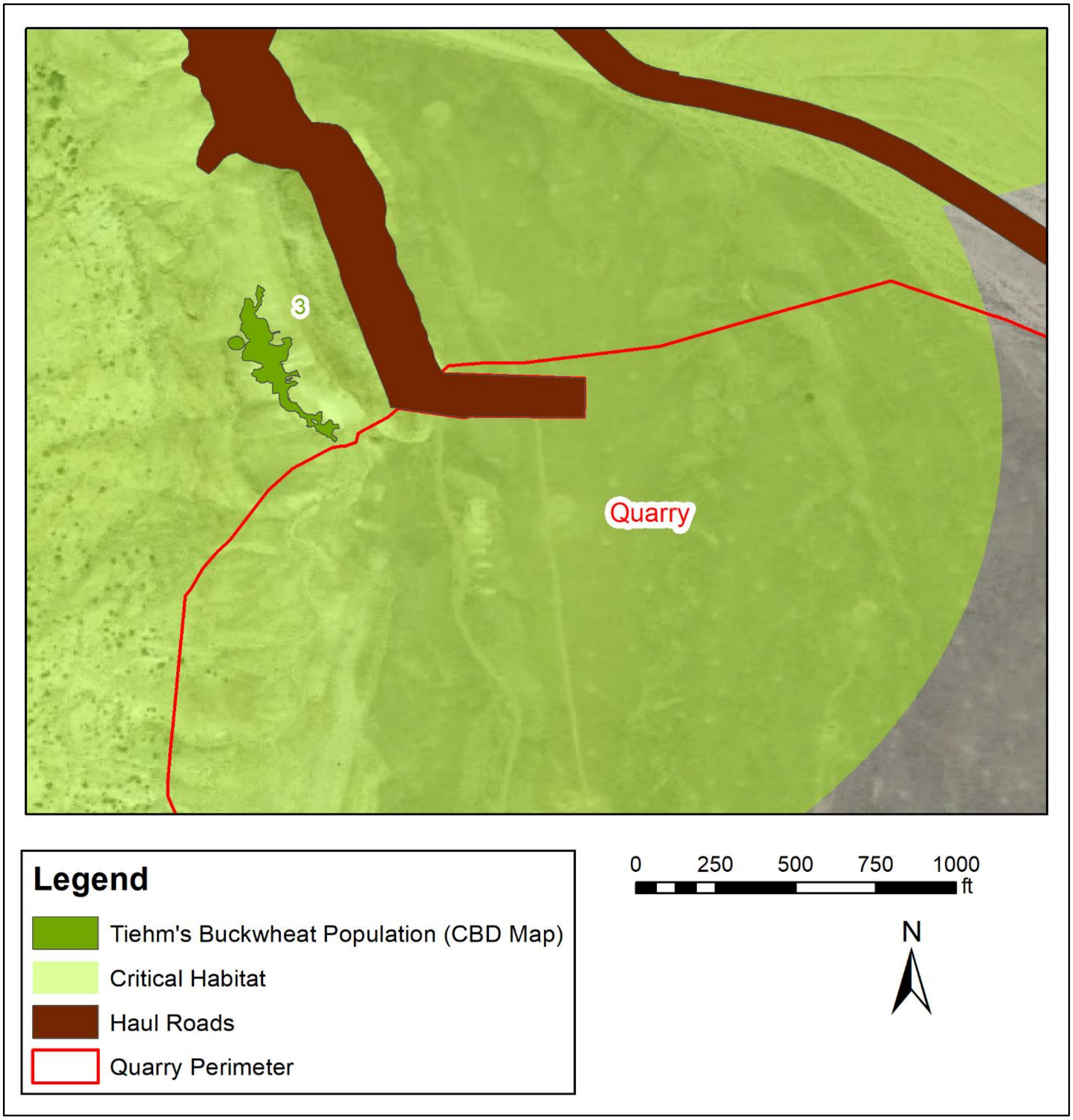

Figure 17b. The quarry perimeter shows an indentation that would exactly accommodate the planned haul road (compare with Fig. 17a). The quarry and haul road maps were provided to the Center for Biological Diversity by the Bureau of Land Management. With regard to the map that was provided, the Bureau of Land Management (2024c) wrote, "The haul road location is currently being adjusted by Ioneer based on the consultation process between the BLM and the U.S. Fish & Wildlife Service. As such, the current shapefiles for the haul road location would provide no valuable information." Thus, if the haul road map does not show the haul road that would actually be constructed, then the quarry map (see Fig. 17a) is not the quarry that would actually be constructed, although the quarry map was the basis for the stability analyses in Geo-Logic Associates (2022, 2023). The green number refers to the Tiehm's buckwheat subpopulation. Background is Google Earth imagery from August 9, 2013. The map is projected onto the WGS84 coordinate system.

The first question regarding the reliability of the calculated factor of safety was addressed based on basic scientific principles. The second question regarding the appropriate minimum factor of safety for the operational period was addressed based on the Guidelines for Open Pit Slope Design, as well as both earlier and later industry publications, and taking into account the consequences of slope failure, as discussed in the previous section. The third question regarding the appropriate minimum factor of safety for the post-closure period was addressed based on the soon to be released Guidelines for Mining Closure, as outlined in recent summaries by the principal authors. For the post-closure period, the consequences of slope failure were developed with comparison to the Global Industry Standard for Tailings Management, in addition to other industry guidance documents that relate to consequences of failure.

The fourth question regarding the Zone of Instability as specified in Western Australian guidelines was addressed by reference to Safety Bund Walls around Abandoned Open Pit Mines—Guideline (Department of Industry and Resources, 1997). Although the Western Australian governmental agency is now called the Department of Energy, Mines, Industry Regulation and Safety, recent publications on mine closure in Australia clarify that the guidelines are still in active use (Wright, 2016; de Bruyn et al, 2019; de Graaf et al., 2019). To the knowledge of the author, the only other governmental guideline or regulation regarding the unstable zone or the safe zone around a closed mining pit is Ontario Regulation 240/00—Mine Development and Closure (Government of Ontario, 2000). According to the Ontario regulations, "If boulder fencing [to indicate the boundary between the unstable zone and the safe zone] is used, the boulders … where no geotechnical study exists, shall be set back from the toe of the pit at least a distance equivalent to the pit depth so as to locate the boulder fence beyond any area of potential pit instability" (Government of Ontario, 2020). The same regulation is re-stated for the conditions "If berming is used" and "If fencing is used" (Government of Ontario, 2000). The Ontario regulation is equivalent to defining the unstable zone as the zone within a line drawn from the toe of the pit to the ground surface at a 45° angle.

According to the Western Australian guidelines, the Zone of Instability for the exterior of open pits is calculated by constructing a line from the toe of the pit to the surface. For unweathered (unoxidized) rock, the slope of the line is 45°, while the slope is 25° with respect to the horizontal for weathered (oxidized) rock. The slope of the connecting line (also called the breakback angle) changes as it passes from weathered to unweathered rock (see Fig. 18a). In pits with more complex geometry, the connecting line might intersect an interior surface before reaching the upper ground surface. In those cases, the line re-begins at the next toe (inter-ramp section) in the upward direction (see Fig. 18b). The guidelines require the construction of a safety bund wall (with a width of 5 meters) at a minimum distance of 10 meters upslope from the Zone of Instability (as measured in the horizontal direction away from the pit) (see Fig. 18a). Thus, the safe zone is regarded as 15 meters (roughly 50 feet) upslope from the Zone of Instability in the horizontal direction (see Fig. 18a). Even when there is no Zone of Instability, for example, when an open pit is constructed in unweathered rock in which the pit walls have angles shallower than 45°, the safe region still begins no closer than 50 feet from the edge of the pit. Thus, a population of Tiehm's buckwheat at a distance of 15 feet from the quarry could not be regarded as living in a safe or stable zone according to the Western Australian guidelines.

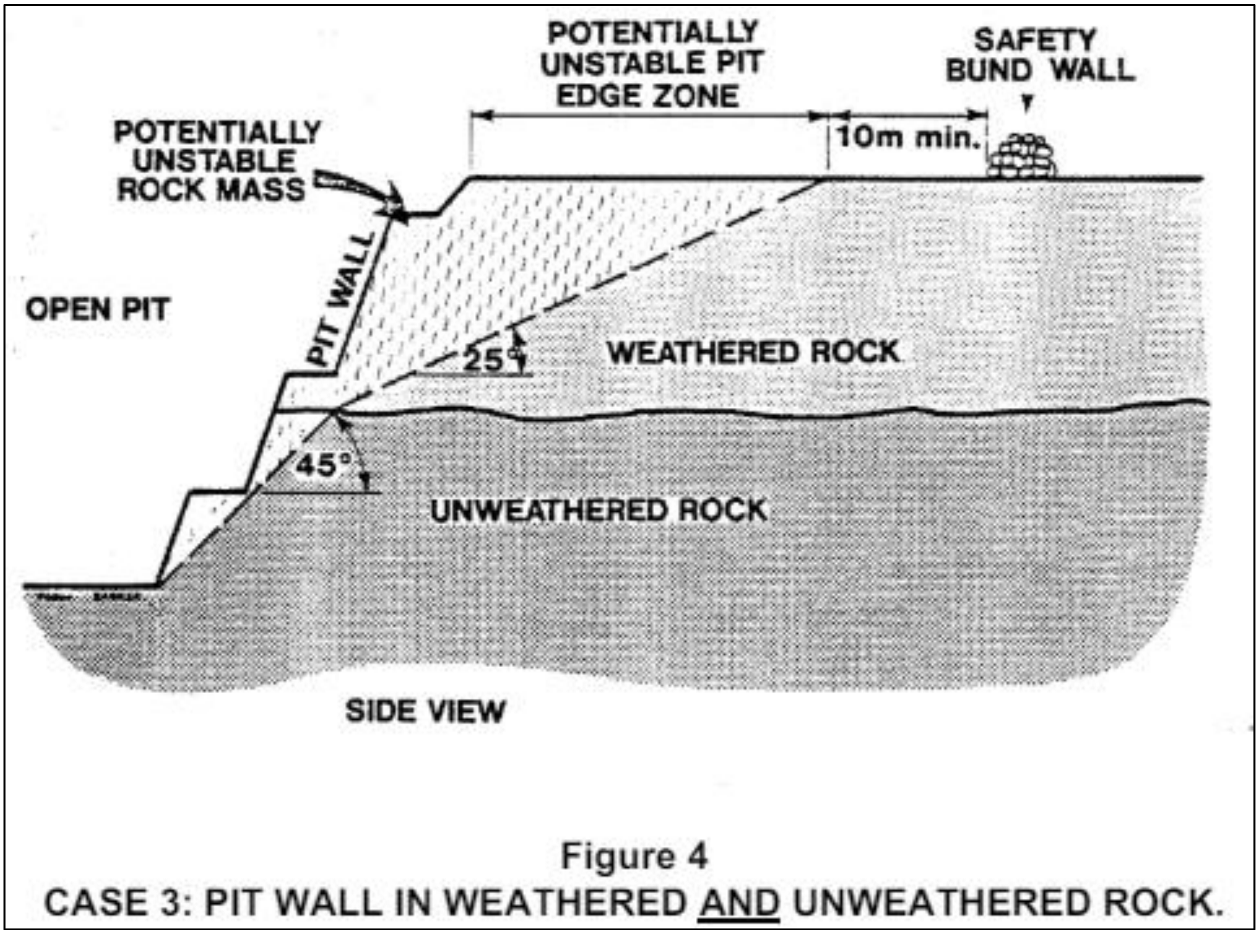

Figure 18a. According to the guidelines of Department of Industry and Resources (Western Australia), the Zone of Instability for the exterior of open pits is calculated by constructing a line from the toe of the pit to the surface. For unweathered (strong) rock, the slope of the line is 45°, while the slope is 25° with respect to the horizontal for weathered (soft) rock. The slope of the connecting line changes as it passes from weathered to unweathered rock. The guidelines require the construction of a safety bund wall (with a width of 5 meters) at a minimum distance of 10 meters upslope from the Zone of Instability (as measured in the horizontal direction away from the pit). Thus, the safe zone is regarded as 15 meters (roughly 50 feet) upslope from the Zone of Instability in the horizontal direction. Fig. 18b shows the guidelines for a more complex pit geometry. Figure from Department of Industry and Resources (Western Australia) (1997).

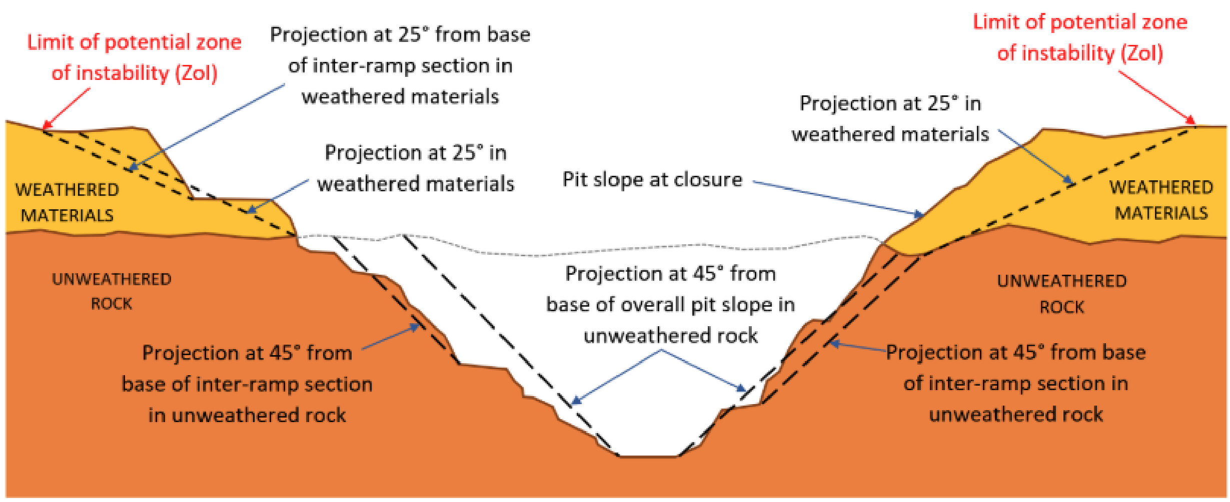

Figure 2 Sectional view through the final pit showing the projected position of the potentially unstable edge zone (zone of instability – ZoI) surrounding the pit at surface

Figure 18b. According to the guidelines of Department of Industry and Resources (Western Australia), the Zone of Instability for the exterior of open pits is calculated by constructing a line from the toe of the pit to the surface. For unweathered (strong) rock, the slope of the line is 45°, while the slope is 25° with respect to the horizontal for weathered (soft) rock. The slope of the connecting line changes as it passes from weathered to unweathered rock (see Fig. 18a). In pits with more complex geometry, the connecting line might intersect an interior surface before reaching the upper ground surface. In those cases, the line re-begins at the next toe (inter-ramp section) in the upward direction. Figure from de Bruyn et al. (2019).

The Western Australian guidelines have been applied in other countries and, in some cases, have been more conservative. For example, prior to the closure of the pit at the Voorspoed diamond mine in South Africa, four slope failures had already occurred with breakback angles ranging from 13° to 20° with respect to the horizontal (de Graaf et al., 2019). Therefore, for the purpose of defining the Zone of Instability, the connecting lines were drawn at angles of 13° with respect to the horizontal. In fact, the Western Australian guidelines allow for the use of shallower angles for the connecting lines if such shallow breakback angles or zones of weakness are observed in the pit walls or in local or regional rock exposures. According to the guidelines, "The use of these design criteria is based on the assumption that no major unfavourably oriented geological features are present within the pit walls, which could induce failure at flatter slope angles" (Department of Industry and Resources, 1997).

The Zone of Instability was not taken into account by Geo-Logic Associates (2022, 2023), so that this report represents the first attempt to calculate the Zone of Instability and the safe region for the quarry at the proposed Rhyolite Ridge mine. Since the DEIS does not explicitly describe any of the geologic units as weathered or unweathered, this report follows de Graaf et al. (2019) in setting the breakback angle at 25° for weak rock units and 45° for strong rock units, since the difference in shear strength is the reason for the difference in breakback angles (see Figs. 18a-b). The B5 Unit of the Cave Spring Formation (see Table 1 and Fig. 13) is the host of the ore body and has been described as very weak. The overlying units have also been described as very weak, especially the M5 Unit of the Cave Spring Formation, which immediately overlies the B5 Unit (see Table 1 and Fig. 13). According to Geo-Logic Associates (2022), "The proposed Rhyolite Ridge Lithium-Boron Project quarry encounters problematic adversely oriented bedding conditions where very low strength materials (i.e. layers M5a, M5, and B5) daylight on the proposed slope faces … The most important stratigraphic unit for the purposes of slope stability is the Cave Spring Formation M5 unit. The top 5-10 feet of the M5 unit [called M5a] contains swelling clays that are the weakest material within the deposit." According to Bureau of Land Management (2024b), "Within the Cave Springs Formation, the various geologic units have varying degrees of rock competence or strength (the ability for the rock to withstand pressure put upon it). The M5 unit has the lowest rock strength and tends to move or flow under pressure. The ore zone (Unit B5), which is in one of the more competent units, is in outcrop on the western part of the deposit, and dips easterly to depths greater than 700 feet below ground surface (bgs)." Thus, despite the low strength of the B5 Unit, it is still one of the more competent rock units. Geo-Logic Associates (2023) even pointed out that blasting would not be required for some of the geologic units overlying the ore body. According to Geo-Logic Associates (2023), "Some of the materials to be mined within the quarry are expected to be excavated without the need for blasting. This is particularly true of the greater than 100-foot thickness of the surficial alluvium [see Unit Q1 in Table 1 and Fig. 13] and portions of the M5 lithology."

Based on the preceding discussion, for the purpose of determining the breakback angle for application of the Western Australian guidelines (see Figs. 18a-b), all geologic units at the stratigraphic level of B5 or higher (see Table 1 and Fig. 13) were regarded as weak (weathered), while geologic units stratigraphically lower than B5 were regarded as strong (unweathered). After calculating the Zone of Instability, the beginning of the safe zone was set as 50 feet farther away from the edge of the quarry in accordance with the Western Australian guidelines (see Fig. 18a). For the calculation of the Zone of Instability for the post-closure period, a critical rock body is the buttress. The DEIS does not identify any source of material for the buttress, so that its shear strength is entirely unknown. In the absence of any other information, for the purpose of choosing the breakback angle, the buttress material was regarded as weathered (oxidized).

The fifth question regarding the assumption that the water table will not recover after dewatering and de-pressurization was addressed based on basic scientific principles, as was the first question. The sixth question regarding the adequacy of the Adaptive Management plan was addressed by reference to industry guidance documents and failure investigation reports. In this report, all maps were created and measurements were made using ESRI ArcMap v. 10.8.2. All maps are projected onto the WGS84 coordinate system.

RESPONSES

The Calculation of the Factor of Safety is Unreliable

There are multiple grounds for concluding that the calculations of the factor of safety by Geo-Logic Associates (2022, 2023; see Fig. 15) are unreliable. Whether the minimum factor of safety of 1.2 was the correct choice is a different matter, which is discussed in the following two subsections. The geotechnical parameters for each geologic unit that were the input data for the calculation of the factor of safety are stated with ultra-precision, sometimes with as many as five significant digits (see Fig. 13). Geo-Logic Associates (2022, 2023) does not provide any information on the uncertainty in the input data that would justify such a high degree of precision. As mentioned earlier, the DEIS does not identify any source of construction material for the buttress, so the material properties of the buttress must be regarded as purely hypothetical (see Fig. 13).

Geo-Logic Associates (2022) states that some of the material properties were obtained from a consulting report by EnviroMine (2019) that is not available for public review. In the report by EnviroMine (2019), some of the geotechnical parameters were developed from laboratory data, but the final values were based partly on the "judgment" of EnviroMine (2019). Other parameters were selected by Geo-Logic Associates (2022) without basis in documented measurements of the geologic units at the site of the proposed Rhyolite Ridge mine, so that they were presumably also based on "judgment." According to Geo-Logic Associates (2022), "Shear strength characteristics and material properties were taken from EnviroMine (2019) and used for GLA's analyses documented herein. Laboratory test results from EnviroMine (2019) … The final strength values utilized for each lithology within the limit equilibrium analyses was derived from the lab testing data and selected based on analyses and engineering judgment by EnviroMine. Some materials noted on the cross sections provided by NewFields do not have material parameters developed by EnviroMine. For these cases, GLA utilized conservative material parameters consistent with the described properties of other materials." Geo-Logic Associates (2022) does not clarify which parameters were obtained from EnviroMine (2019) and which were chosen by Geo-Logic Associates, nor does Geo-Logic Associates (2022) explain the procedures by which material properties were derived from laboratory data by EnviroMine (2019). There is also no explanation as to the bases for the "engineering judgments" by EnviroMine (2019) nor the choices of "conservative material parameters consistent with the described properties of other materials" by Geo-Logic Associates (2022).

Geo-Logic Associates (2022) does present a portion of the raw geotechnical data that were used by EnviroMine (2019) to develop the material properties (see Fig. 13). These raw data do not provide confidence in the lack of uncertainty and ultra-precision that is shown in the list of material properties (see Fig. 13). Many of the raw data involve only three or four measurements on a single rock sample. For example, Fig. 19 shows four measurements of the failure stress as a function of the confining stress on a sample from Unit B5. The four measurements are widely scattered and do not in any way appear to fall along a straight line (see Fig. 19). Of course, it is always possible to construct a best-fit straight line to any four points and to state the slope and intercept of the line to five significant digits, as was done in Fig. 19. However, for this rock sample, the correct procedure would have been to observe that the failure stress was independent of the confining stress, to compute the intercept by averaging the four values of failure stress, and to set the slope of the line at zero. Such a procedure would have been more consistent with the "engineering judgment" that was claimed by Geo-Logic Associates (2022) to have been used by EnviroMine (2019).

In the same way that the geotechnical parameters are stated with no uncertainty (see Fig. 13), the calculated values for the factor of safety are also stated as single values with no uncertainty (see Fig. 15). There is no discussion of the standard deviations of the factors of safety and no presentations of the distributions of possible values of the factor of safety (compare Fig. 15 with Fig. 10) that would make it possible to calculate the probability of failure. In this respect, the danger of excessive reliance on the mean value of the factor of safety without consideration of the width of the distribution of values (such as the standard deviation) should be recalled (see Fig. 11). It is most important that there is no sensitivity analysis that would show the range of possible factors of safety that could result from reasonably possible alternative values for the geotechnical parameters. If a calculated factor of safety would fall below the selected minimum factor of safety for some reasonable choice of geotechnical parameters, then results such are shown in Fig. 15 should be used with great caution. The possibility that the material properties are actually known to five significant digits and that there are no reasonable alternative values is simply absurd, especially in light of the large scatter in the raw geotechnical data (see Fig. 19).

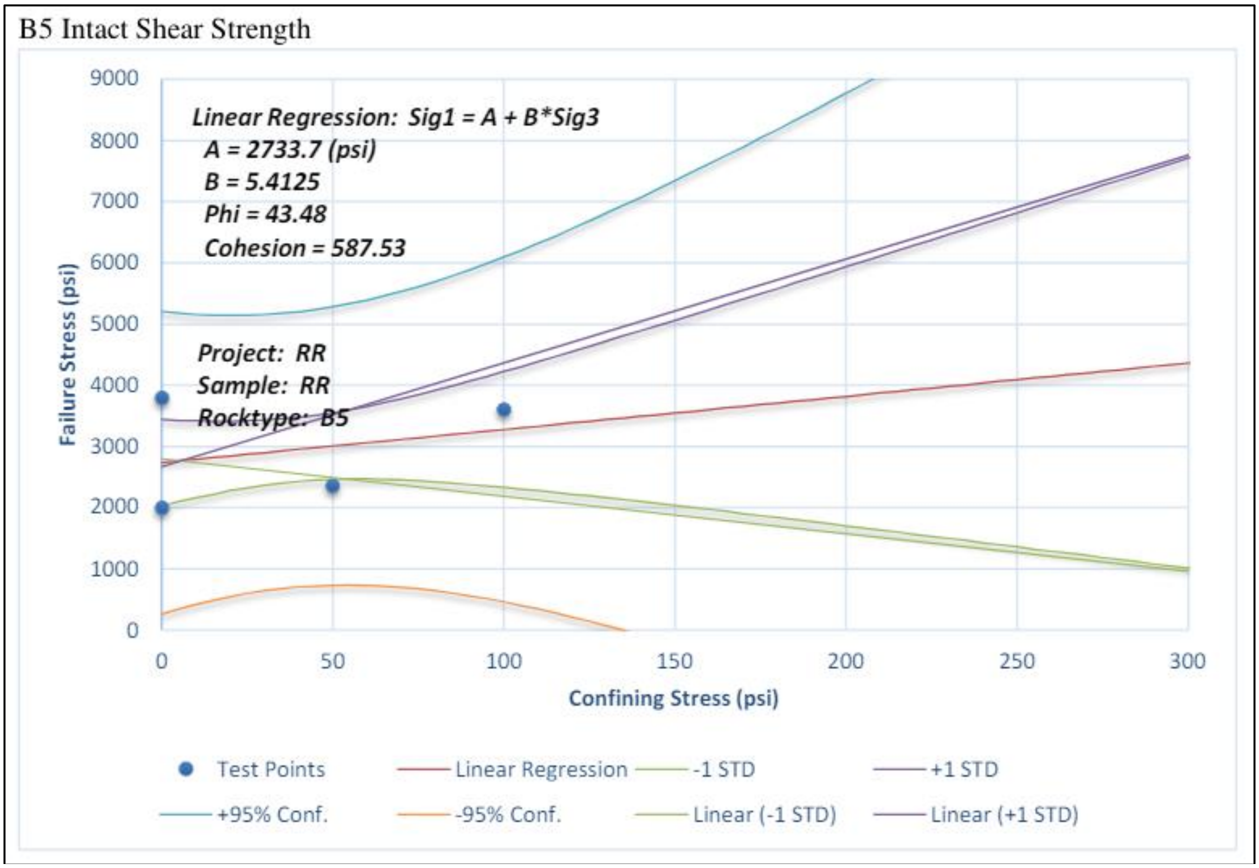

Figure 19. Geo-Logic Associates (2022) presented some of the raw laboratory data that was used to derive the material properties of the geologic units (see Fig. 13). The raw data show a small number of measurements (3 or 4) for each rock sample with a high degree of scatter. Although a straight line can be fit to the four scattered points in the above graph, the slope and intercept of the line should be regarded as highly uncertain. The high degree of uncertainty in the raw data does not justify the ultraprecision with which the slope and intercept are written on the graph nor the ultraprecision and lack of any uncertainty in the material properties (see Fig. 13). The high degree of data uncertainty should be taken into account in the determination of the minimum factor of safety and the maximum probability of failure for both the operating (see Figs. 22 and 23a) and post-closure (see Figs. 26a-c) periods. Figure from Geo-Logic Associates (2022).

At the present time, a sensitivity analysis is a standard feature of evaluations of slope stability. According to the textbook Geotechnical Engineering of Dams, "In any slope stability analysis it is good practice to check the calculated factor of safety for a range of strengths, e.g. lower quartile and lower bound, to determine the sensitivity of the factor of safety to the assumed strength" (Fell et al., 2015). According to a guidance document by the Australian National Committee on Large Dams, "It is good practice that analyses are carried out to assess the sensitivity of the factor of safety to assumptions on shear strength, pore pressures and geometry of sliding, and that the embankment is designed to be stable within a range of assumptions" (ANCOLD, 2012, 2019). It is noteworthy that the DEIS carries out sensitivity analyses for dust generation and for the chemical risk to wildlife from the quarry lake, but not for stability of the quarry slopes. According to the DEIS, "The North OSF, Quarry Infill OSF, and West OSF were modeled for PM_{10} [particulate matter smaller than 10 microns] under the Proposed Action. The first and sixth highest concentrations were determined (7.03 and 8.20 μg/m^3). For the sensitivity analysis, the stockpiles were shifted to reflect the new geographic locations for the North and South OSF Alternative. Based on a sensitivity analysis that assessed the alternative's proposed locations of the OSFs, the highest impact areas were increased by 2.0 to 3.5 μg/m^3 (8.98 and 11.91 μg/m^3) … The purpose of the ERA [Ecological Risk Assessment] was to evaluate the potential for chemical risk to wildlife from exposure or ingestion of the water in the quarry lake. The ERA evaluated two scenarios: a base case scenario (Proposed Action) and twelve sensitivity analyses in which climatic input, groundwater inflow rate, and quarry wall runoff was manipulated within the model" (Bureau of Land Management, 2024a).

The Choice of the Minimum Operating Factor of Safety is too Low

The choice of a minimum factor of safety of 1.2 for the operating period is now compared with mining industry standards. Wesseloo and Read (2009) reviewed the history of minimum factors of safety for mine pit slopes prior to stating the recommendations that were made in Guidelines for Open Pit Slope Design (Read and Stacey, 2009). For consequences of failure in the Very Serious category, Priest and Brown (1983) recommended a minimum factor of safety of 2.0 with a maximum probability of failure of 0.30% and a maximum probability of 5% that the true factor of safety is less than 1.5 (see Fig. 20a). Even for the Moderately Serious category, Priest and Brown (1983) recommended a minimum factor of safety of 1.6 with a maximum probability of failure of 1% and a maximum probability of 10% that the true factor of safety is less than 1.5 (see Fig. 20a). Wesseloo and Read (2009) clarified that the intention of Priest and Brown (1983) was that a stable slope was a slope that satisfied all three of the design acceptance criteria (factor of safety, probability that the true factor of safety is less than 1.0, probability that the true factor of safety is less than 1.5) (see Figs. 20a-b). Since Geo-Logic Associates (2023) has stated that the cessation of mining activity would be an appropriate response to slope instability that affected Tiehm's buckwheat habitat, the consequences of slope failure should certainly fall into the Very Serious category. According to Swan and Sepulveda (2000), for the final (outer) wall of an open pit, the minimum factor of safety against slope failure should be 1.30-1.60 with maximum probabilities of failure of 8-12%, depending upon the volume of material that would be involved in the landslide (see Fig. 21).

The recommendation of the Guidelines for Open Pit Slope Design was that, for High consequences of failure, the minimum factor of safety should be in the range 1.3-1.5 with maximum probability of failure of 5% (see Fig. 22). The recommendations state explicitly that the minimum factor of safety plus the maximum probability of failure must both be satisfied (in addition to a minimum factor of safety of 1.1 during seismic loading) (see Fig. 22). Thus, the recommendation of the Guidelines for Open Pit Slope Design cannot be fulfilled without a consideration of the standard deviation and the distribution of possible values of the factor of safety (see Fig. 10). As mentioned above, the cessation of mining activity in response to slope instability would certainly constitute a High consequence of failure. The range of 1.3-1.5 depends upon the uncertainty in the factor of safety, which reflects the uncertainty in the input data, with the upper end of the range corresponding to high uncertainty. Based on the preceding subsection, the uncertainty is high, so that the appropriate minimum factor of safety against slope failure during pit operation should be 1.5 plus a maximum probability of failure of 5%. Therefore, the minimum factor of safety of 1.2 that was chosen by Geo-Logic Associates (2022, 2023) for the operational period is far too low.

Table 9.3: FoS and PoF guidelines

Consequence of failure	Examples	Acceptable values: Mean FoS	Minimum P[FoS < 1.0]	Maximum P[FoS < 1.5]
Not serious	Individual benches; small (< 50 m), temporary slopes, not adjacent to haulage roads	1.3	10%	20%
Moderately serious	Any slope of a permanent or semi-permanent nature	1.6	1%	10%
Very serious	Medium-sized (50–100 m) and high slopes (<150 m) carrying major haulage roads or underlying permanent mine installations	2.0	0.30%	5%

Source: Priest & Brown (1983)

Figure 20a. According to Priest and Brown (1983), the factor of safety against failure for mine pit slopes should be 1.3, 1.6, and 2.0 during mine operation for consequences of failure that are Not Serious, Moderately Serious, and Very Serious, respectively. Moreover, the maximum probability of failure (probability that the true factor of safety is less than 1.0) should be 10%, 1% and 0.3% for consequences of failure that are Not Serious, Moderately Serious, and Very Serious, respectively. Compared with the guidelines by Priest and Brown (1983), the minimum factor of safety of 1.2 during mine operation that was assumed by Geo-Logic Associates (2022, 2023) is completely inadequate. Since Geo-Logic Associates (2023) has identified the suspension or cessation of mining activity as an appropriate response if there is slope instability near sensitive habitat, the consequences of slope failure at the proposed Rhyolite Ridge mine should be regarded as Very Serious. The significance of specifying both a minimum factor of safety and maximum probabilities of failure is clarified in Fig. 20b. The heading "Mean FoS" in the above table should be understood as the mean of the distribution of all possible values of the factor of safety (see Fig. 10). Table from Wesseloo and Read (2009).

Table 9.4: Interpretation of Priest & Brown (1983) FoS and PoF guidelines

Performance of slope with respect to Table 9.3	Interpretation
Satisfies all three criteria	Stable slope
Exceeds minimum mean FoS but violates one or both probabilistic criteria	Operation of slope presents risk that may or may not be acceptable; level of risk can be reduced by comprehensive monitoring program
Falls below minimum mean FoS but satisfies both probabilistic criteria	Marginal slope: minor modifications of slope geometry required to raise mean FoS to satisfactory level
Falls below minimum mean FoS and violates one or both probabilistic criteria	Unstable slope: major modifications of slope geometry required; rock improvement and slope monitoring may be necessary

Figure 20b. The above table clarifies the significance of the guidelines for mine pit slopes in Priest and Brown (1983) that require a minimum factor of safety, a maximum probability of failure (probability that the true factor of safety is less than 1.0) and a maximum probability that the true factor safety is less than 1.5. In particular, a stable slope should satisfy all three criteria. Table from Wesseloo and Read (2009).

Table 9.7: Acceptance criteria, FoS, PoF and category of slope instability

Slope type	Case	Characteristics of instability		Acceptability Criterion		Comments
		Loss of ramp berm (%)	Material affected (ktons/m)	FoS	PoF (%)	
Bench	Expansion, not adjacent to a ramp	<25	<0.5/<1.0			Berms should have a nominal width to contain unravelling wedges whose probability of occurrence is >30%; controlled blasting will be used to minimise induced damage and presplitting on the final wall slopes
		25–50	<1.0/<2.0		<45	
		>50	>1.0/>2.0		<35	
	Expansion, adjacent to a ramp	<25	<0.5/<1.0			
		25–50	<1.0/<2.0		<40	
		>50	>1.0/>2.0		<30	
	Final wall, not adjacent to a ramp	<25	<0.5/<1.0			
		25–50	<1.0/<2.0		<35	
		>50	>1.0/>2.0		<25	
	Final wall, adjacent to a ramp	<25	<0.5/<1.0			
		25–50	<1.0/<2.0		<30	
		>50	>1.0/>2.0		<20	
Inter-ramp	Expansion	<25	<5	>1.20	<30	Stability analysis must include explicit effect of rock mass structures; two independent access ramps will be made to the pit bottom; measures will be implemented for slope drainage
			>5	>1.25	<25	
		25–50	<5	>1.25	<25	
			5–10	>1.30	<22	
			>10	>1.35	<20	
		>50	<10	>1.30	<22	
			10–20	>1.35	<20	
			>20	>1.45	<18	
	Final wall	<25	<5	>1.20	<25	
			>5	>1.25	<20	
		25–50	<5	>1.30	<22	
			5–10	>1.35	<20	
			>10	>1.45	<18	
		>50	<10	>1.35	<20	
			10–20	>1.40	<18	
			>20	>1.50	<15	
Global	Expansion		<25	>1.30	<15	Stability analysis must include mass structures; all mine infrastructure lie outside pit perimeter limits
			25–50	>1.40	<12	
			>50	>1.50	<10	
	Final wall		<25	>1.30	<12	
			25–50	>1.45	<10	
			>50	>1.60	<8	

Source: Swan & Sepulveda (2000)

Figure 21. According to Swan and Sepulveda (2000), for the final wall of an open pit, the minimum factor of safety against slope failure should be 1.30-1.60 with maximum probabilities of failure of 8-12%, depending upon the volume of material that would be involved in the landslide. Compared with the guidelines by Swan and Sepulveda (2000), the minimum factor of safety of 1.2 during mine operation that was assumed by Geo-Logic Associates (2022, 2023) is completely inadequate. Table from Wesseloo and Read (2009).

Table 9.9: Typical FoS and PoF acceptance criteria values

Slope scale	Consequences of failure[b]	Acceptance criteria[a] FoS (min) (static)	FoS (min) (dynamic)	PoF (max) P[FoS ≤ 1]
Bench	Low–high	1.1	NA	25–50%
Inter-ramp	Low	1.15–1.2	1.0	25%
	Medium	1.2	1.0	20%
	High	1.2–1.3	1.1	10%
Overall	Low	1.2–1.3	1.0	15–20%
	Medium	1.3	1.05	5–10%
	High	1.3–1.5	1.1	≤5%

a: Needs to meet all acceptance criteria
b: Semi-quantitatively evaluated (see Figure 13.9)

Figure 22. The above table shows the recommendations of the industry guidance book Guidelines for Open Pit Slope Design (Read and Stacey, 2009), which have been confirmed by the SME Surface Mining Handbook (Mohanty et al., 2023) (see Table 2). For High consequences of failure, the minimum overall factor of safety against slope failure should be 1.3-1.5 during static (non-seismic) loading and 1.1 during dynamic (seismic) loading, with a maximum probability of failure of 5%. The table clarifies that all three criteria must be satisfied. Since Geo-Logic Associates (2023) has identified the suspension or cessation of mining activity as an appropriate response if there is instability near sensitive habitat, the consequences of slope failure at the proposed Rhyolite Ridge mine should be regarded as High. The range of 1.3-1.5 depends upon the uncertainty in the input data, with high certainty corresponding to the upper end of the range. Thus, based on the high uncertainty in the geotechnical data for the Rhyolite Ridge mine (see, for example, Fig. 19), a minimum static factor of safety of 1.5 and maximum probability of failure of 5% would be appropriate during mine operation. Compared with the recommendations of the Guidelines for Open Pit Slope Design and the SME Surface Mining Handbook, the minimum factor of safety of 1.2 during mine operation that was assumed by Geo-Logic Associates (2022, 2023) is completely inadequate. Table from Wesseloo and Read (2009).

Mohanty et al. (2023) repeat the recommendations of the Guidelines for Open Pit Slope Design (Read and Stacey, 2009) in the SME Surface Mining Handbook (Darling, 2023) (see Table 2), thus, constituting confirmation of the guidelines by the US-based Society for Mining, Metallurgy and Exploration. Additional industry publications have clarified and, in some ways, strengthened the recommendations of the Guidelines for Open Pit Slope Design. According to Adams (2015), for a permanent pit slope with a design life longer than ten years, and with Major to Catastrophic consequences of failure, the minimum factor of safety should be 1.5 and the maximum probability of failure should be 5% if the Level of Design Confidence (data certainty) is Medium (see Fig. 23a), which is the same as the recommendations of the Guidelines for Open Pit Slope Design. However, if the Level of Design Confidence drops to Low, then the minimum factor of safety should be 1.6 and the maximum probability of failure should be 2%. Based upon the discussion in the preceding subsection, at the present time, the Level of Design Confidence for the quarry at the proposed Rhyolite Ridge mine should be regarded as Low.

Table 2. Acceptance criteria for factor of safety and probability of failure for open pits: Recommendations of Society for Mining, Metallurgy and Exploration (SME)[1]

Consequence of Failure	Factor of Safety	Probability of Failure (%)
Low (operating highwall)	1.2-1.3	15-20
Moderate (operating highwall)	1.3	10
High (ultimate highwall)	1.3-1.5	5

[1]Redrawn from Mohanty et al. (2023)

Consequence Level[1]		Insignificant to Minor			Moderate			Major to Catastrophic		
Level of Design Confidence[2]		High	Med	Low	High	Med	Low	High	Med	Low
Permanent cut, fill or natural slope (Design Life > 10 years)	Min FOS	1.3	1.3	1.3	1.3	1.4	1.5	1.4	1.5	1.6
	Max POF	20%	20%	20%	20%	10%	5%	10%	5%	2%
	Level of Risk Management	No monitoring or access restrictions			No monitoring or access restrictions			Minimal monitoring for defined timeframe, and/or access restrictions		
Interim cut or fill slope (Design Life 0.5-10 years)	Min FOS	1.2	1.25	1.3	1.2	1.3	1.4	1.3	1.4	1.5
	Max POF	30%	25%	20%	30%	20%	10%	20%	10%	5%
	Level of Risk Management	Basic GCMP including periodic slope monitoring. Access dependant of safety risks			Comprehensive GCMP including slope monitoring and TARPS. Access dependant of safety risks			Comprehensive GCMP including slope monitoring and TARPS. Access dependant of safety risks		
Temporary cut or fill slope (Design Life < 6 months)	Min FOS	1.2	1.25	1.3	1.25	1.3	1.35	1.25	1.35	1.4
	Max POF	30%	25%	20%	25%	20%	15%	25%	15%	10%
	Level of Risk Management	Basic GCMP including periodic slope monitoring. Access dependant of safety risks			Comprehensive GCMP including slope monitoring and TARPs. Access dependant of safety risks			Comprehensive GCMP including slope monitoring and TARPs. No access to slope.		
Excavation for immediate backfill (Design Life < several days)	Min FOS	1.05	1.1	1.15	1.1	1.15	1.2	1.15	1.2	1.25
	Max POF	45%	40%	35%	40%	35%	30%	35%	30%	25%
	Level of Risk Management	Detailed risk assessment and robust operational controls, including continuous monitoring and TARPs. No access to slope			Detailed risk assessment and robust operational controls, including continuous monitoring and TARPs. No access to slope			Detailed risk assessment and robust operational controls, including continuous monitoring and TARPs. No access to slope		

Figure 15 Example Factor of Safety (FoS)-Probability of Failure (PoF) selection matrix (Adams 2015). [1] Consequence level from business risk assessment, see Figure 14. [2] Design confidence subjective rating. [3] PoF calculated for the slope sector analyses, not the global PoF

Figure 23a. According to Adams (2015), for permanent slopes in open pits, during mine operation, for Major to Catastrophic consequences of failure, the minimum factor of safety against slope failure should be 1.4-1.6 and the maximum probabilities of failure should be 2-10%. The ranges depend upon the uncertainty in the input data (or “Level of Design Confidence”), with high certainty corresponding to the upper end of the range for minimum factor of safety and the lower end of the range for maximum probability of failure. Since Geo-Logic Associates (2023) has identified the suspension or cessation of mining activity as an appropriate response if there is instability near sensitive habitat, the consequences of slope failure at the proposed Rhyolite Ridge mine should be regarded as Major to Catastrophic (see further information in Fig. 23b). Thus, based on the recommendations of Adams (2015) and the high uncertainty in the geotechnical data for the Rhyolite Ridge mine (see, for example, Fig. 19), a minimum static factor of safety of 1.6 and maximum probability of failure of 2% would be appropriate for slope failure at the Rhyolite Ridge mine. Compared with the guidelines by Adams (2015), the minimum factor of safety of 1.2 during mine operation that was assumed by Geo-Logic Associates (2022, 2023) is completely inadequate. Table from de Graaf et al. (2019).

Adams (2015) provides further information regarding the meaning of consequences of failure. Adams (2015) clarifies that the Consequence Level that is used to set the design acceptance criteria is a “business risk assessment” (as opposed to an environmental or a health and safety assessment) (see Fig. 23a). Adams (2015) then states that an example of a Major consequence level would be “production pit closed for significant period” and an example of a Catastrophic consequence level would be “failure large enough to close mine” (see Fig. 23b). On that basis, the proposed responses by Geo-Logic Associates (2023) to indications of slope instability of “suspending mining activity” or “stopping mining activity” would certainly place the consequences of quarry slope failure at the Rhyolite Ridge mine into the categories of Major or Catastrophic.

Impact Category	Consequence Level				
	Insignificant	Minor	Moderate	Major	Catastrophic
Health & Safety	First aid injury (e.g. very slow landslide with minimal safety risk)	Medical aid injury (e.g. slow to moderate pit-slope movement where people may be exposed to secondary rockfall or tension crack hazards)	Lost Time Injury (LTI)	Permanent impairment	Fatality (e.g. any rapid failure with people exposed)
Environment	Contained (e.g. wedge failure contained on bench, minimal sediment to water)	Localised impact (e.g. sediment slug from failure contained by site water controls)	Impact within mine only (e.g. highwall failure contained within pit)	Off-site impact can be remediated (e.g. waste-rock slide runout)	Severe off-site impact (e.g. toxic tailings release to external waterway)
Business	No delay, cost < $10K (e.g. small failure outside of work area)	Minor delay, $10 - $100K (e.g. inter ramp slope failure requires stabilisation)	Total loss $100K - $5M (e.g. main access ramp destroyed causing delay and re-planning)	Total loss $5M - $100M (e.g. production pit closed for significant period, ore sterilised)	Total financial loss > $100M (e.g. failure large enough to close mine)

Figure 14 Example consequence table (Adams 2015)

Figure 23b. According to Adams (2015), examples of Major consequences of failure include "production pit closed for significant period", while examples of Catastrophic consequences of failure include "failure large enough to close mine." Since Geo-Logic Associates (2023) has identified the suspension or cessation of mining activity as an appropriate response if there is instability near sensitive habitat, the consequences of slope failure at the proposed Rhyolite Ridge mine should be regarded as Major to Catastrophic (see application of this conclusion in Fig. 23a). Table from de Graaf et al. (2019).

The Choice of the Minimum Post-Closure Factor of Safety is too Low

There are two main reasons as to why the minimum factor of safety must increase in the transition from the operational to the post-closure period. First, any data uncertainty during the operational period is amplified into the post-closure period. Even if there is excellent knowledge of the geotechnical properties during pit operation, there is much less certainty about the rate and extent of the degradation over time of the strength of the rock masses adjacent to the pit walls (de Bruyn et al., 2019; Carter et al., 2022; de Graaf et al., 2024). In addition, it has already been mentioned that there are still gaps in theoretical knowledge regarding the processes that drive rock strength degradation (de Graaf et al., 2024; see Fig. 8). Therefore, keeping the factor of safety fixed even as the data uncertainty increases has the potential to greatly increase the probability of failure during the post-closure period (see Fig. 24). The second reason as to why the minimum factor of safety must increase is that the post-closure period will see a reduction in or complete cessation of monitoring, as well as a reduction in or the complete absence of an on-site trained workforce. Thus, the reduced ability to detect instability or to respond to instability in a timely manner means that the probability of failure must be greatly reduced.

Carter et al. (2022) has proposed a minimum factor of safety even greater than 2.0 during the post-closure period (see Fig. 25a). Carter et al. (2022) has also emphasized that the calculation of factor of safety for the post-closure period must be based upon the strength of the rock masses and the groundwater levels that will exist in the post-closure period, not the greater strength and lower water table of the operational period (see Fig. 25a). There are case studies and recommendations for estimating post-closure shear strengths (de Bruyn et al., 2019). These estimates of post-closure strength degradation involve a great deal of uncertainty, which leads precisely to the point that there must be an increase in the minimum factor of safety.

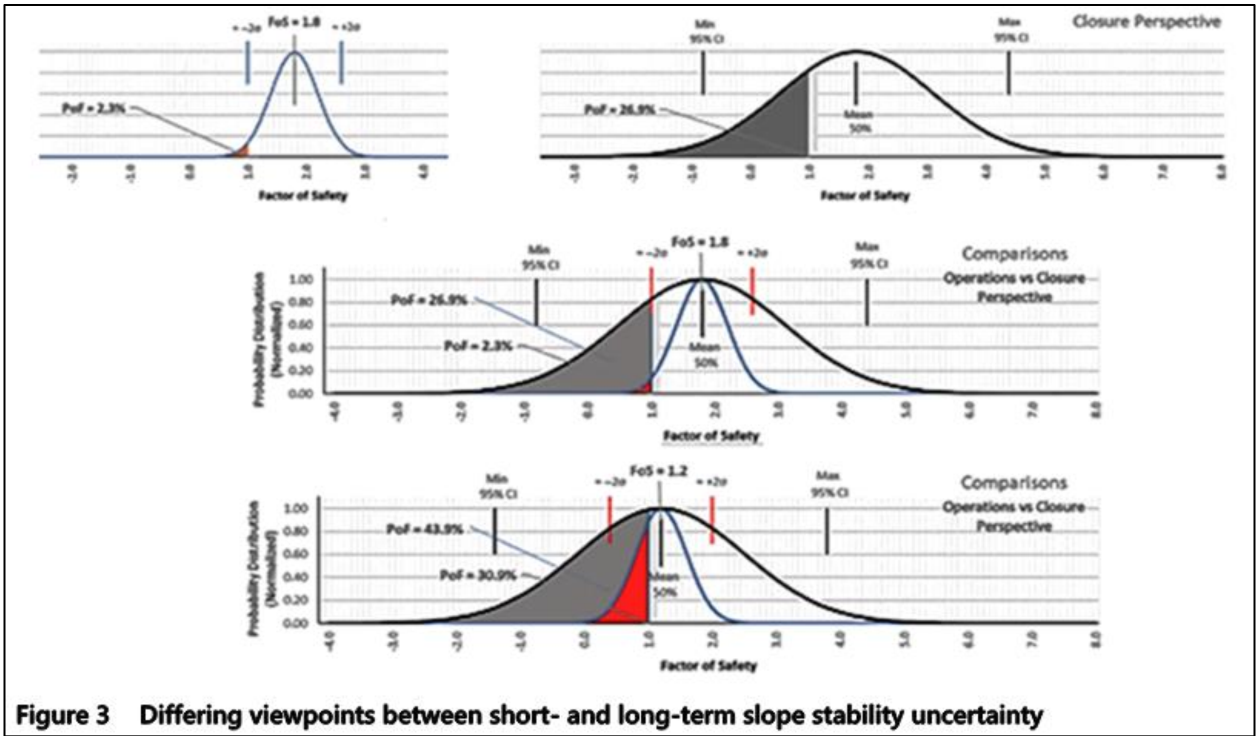

Figure 24. If the factor of safety against slope failure remains unchanged as the mine transitions from operating (short-term) to post-closure (long-term), then the probability of failure increases. As a result, the post-closure factor of safety should be greater than the operating factor of safety. For a given factor of safety, the probability of failure increases after closure because of the greater uncertainty in the input data that are used to calculate the factor of safety. The uncertainty in input data for the post-closure condition include uncertainty in the long-term degradation of the rock mass due to the time-delayed impacts of blasting and changes in topography and stress levels (see Figs. 6-7) and the lack of current theoretical knowledge regarding the long-term interactions among erosional processes, slope instability, and climatic change (see Fig. 8). The upper row compares typical probabilities of failure (shaded areas) for the operating condition (left-hand side) and the post-closure condition (right-hand side) for a given factor of safety of 1.8. The middle row superimposes the two distributions of factor of safety for the operating and post-closure conditions for a mean factor of safety of 1.8. The bottom row superimposes the two distributions of factor of safety for the operating and post-closure conditions for a mean factor of safety of 1.2. Figure from Carter et al. (2022).

Macciotta et al. (2020) has recommended that mine closure plans should “aim for the highest credible FoS [Factor of Safety]”, especially at the point of relinquishment of the open pit (see Fig. 25b). At the same time, the probability of failure should be lowered to the ALARP (As Low as Reasonably Practicable) level (see Fig. 25b). The word “credible” and the expression “ALARP” require clarification. “Credible” should be understood in the sense of “believable” or “reliable.” A non-credible claim that the post-closure factor of safety will be 3.0 does not benefit anyone. The issue is that, for very large factors of safety, the probability of failure is controlled not by the bulk properties of materials, but the presence of thin discontinuities or zones of weakness, which would not be revealed without extensive geotechnical field testing. According to Silva et al. (2008), “Increasing the safety factor well beyond the typical values used for earth structures provides little benefit with respect to the corresponding probability of failure. Discontinuities, weak zones, wet zones, high or low permeability zones, and other features that can elude a geotechnical investigation control the level of safety for grossly overdesigned facilities.” According to the Global Industry Standard for Tailings Management, “ALARP requires that all reasonable measures be taken with respect to ‘tolerable’ or acceptable risks to reduce them even further until the cost and other impacts of additional risk reduction are grossly disproportionate to the benefit" (ICMM-UNEP-PRI, 2020). By this point, it should be clear that the selection of the minimum factor of safety of 1.2 for the post-closure period at the proposed Rhyolite Ridge mine is grossly out-of-line with contemporary guidance.

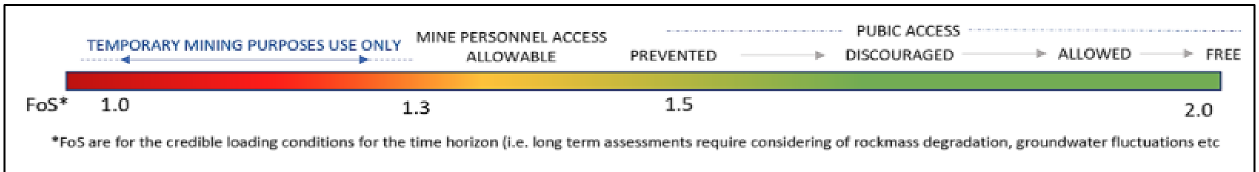

Figure 7 Comparative scale of Factor of Safety in operations versus closure

Figure 25a. The above color scale shows how the appropriate minimum factor of safety against slope failure might increase from less than 1.3 during mine operation to even greater than 2.0 during post-closure. There are two reasons for the increase in the appropriate minimum factor of safety in the transition from the operating state to the post-closure state. First, there is greater uncertainty in the input data that are used to calculate the factor of safety (see Fig. 24). The uncertainty in input data for the post-closure condition include uncertainty in the long-term degradation of the rock mass due to the time-delayed impacts of blasting and changes in topography and stress levels (see Figs. 6-7) and the lack of current theoretical knowledge regarding the long-term interactions among erosional processes, slope instability, and climatic change (see Fig. 8). Second, there will be a decrease in or a complete lack of monitoring and on-site trained personnel during the post-closure period and, thus, a decreased inability to respond to any indication of slope instability. The figure clarifies that, for the post-closure state, the factor of safety should be calculated based on the degraded rock mass strength that will evolve in the post-closure state, not for the greater rock mass strength that would have prevailed prior to and during open pit operation. Figure from Carter et al. (2022).

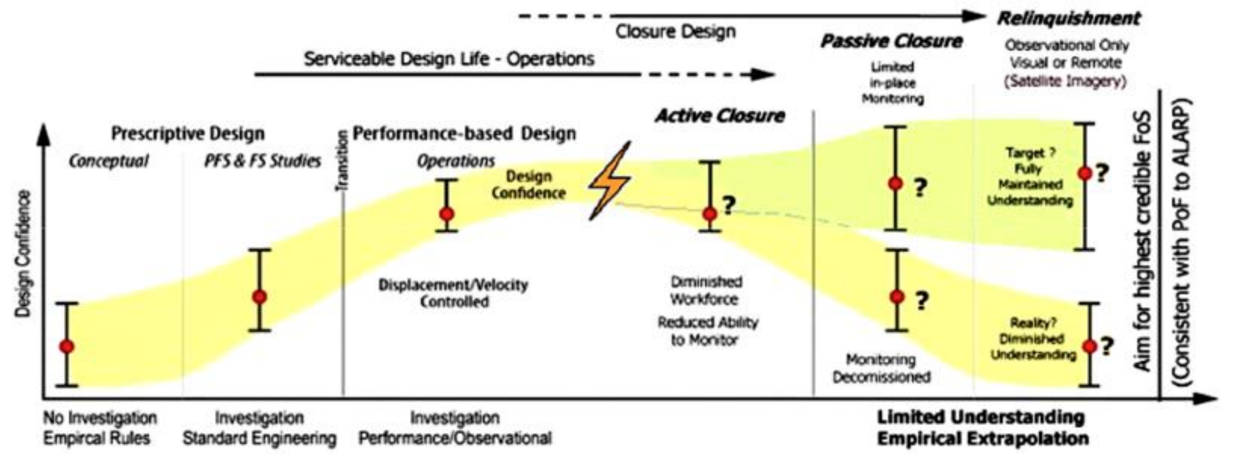

Figure 2 Conceptual level of mine life geotechnical understanding with indications for possible range of understanding at relinquishment, based on slope behaviour in post-operations close-down and decommissioning, as well as long timeline forecasting into passive closure (adapted from Macciotta et al. 2020); Lightning bolt symbolises change in focus: operations to closure)

Figure 25b. According to the above diagram, the minimum factor of safety against slope failure during the post-closure period (or certainly by the time of the relinquishment of the open pit) should aim for the highest credible value, while the maximum probability of failure should be reduced to the ALARP (As Low as Reasonably Practicable) level. There are two reasons for the increase in the appropriate minimum factor of safety in the transition from the operating state to the post-closure state. First, there is greater uncertainty in the input data that are used to calculate the factor of safety (see Fig. 24). The uncertainty in input data for the post-closure condition include uncertainty in the long-term degradation of the rock mass due to the time-delayed impacts of blasting and changes in topography and stress levels (see Figs. 6-7) and the lack of current theoretical knowledge regarding the long-term interactions among erosional processes, slope instability, and climatic change (see Fig. 8). Second, there will be a decrease in or a complete lack of monitoring and on-site trained personnel during the post-closure period and, thus, a decreased inability to respond to any indication of slope instability. Figure from Carter et al. (2022).

Carter et al. (2022) includes an excellent step-by-step summary of the procedures for recommending an appropriate minimum factor of safety for the post-closure period that will be found in the upcoming Guidelines for Mine Closure (LOP, 2024). The minimum factor of safety against slope failure during the post-closure period should be determined based upon the Relative Stability Guideline (RSG) for each slope. The RSG is the product of the score for the Pit Wall Condition Class (on a scale of 1 to 7 with lower scores indicating more competent slopes), the Adjacent Impact Consequence (on a scale of 1 to 5 with higher scores indicating more severe consequences), and the Existing Design Confidence (on a scale of 1 to 5 with higher scores indicating less confidence or greater data uncertainty). Fig. 26a shows an example for a particular open pit. For Domain F in the pit, the product of a score of 6 for Pit Wall Condition Class B, a score of 5 for Very High consequences, and a score of 4 for Low Existing Design Confidence yields an RSG of 120. This would be a very dangerous situation and the recommendation is for "avoidance of any slopes with RSGs > 100" (Carter et al., 2022). By contrast, the goal is "targeting slope geometries to achieve RSG scores of less than 20" (Carter et al., 2022). Note that the design confidence could be increased (reducing the score) by the acquisition of more high-quality data, while the failure consequences could be reduced (also reducing the score) by changing the location of the pit wall with respect to populated areas, civil infrastructure, or cultural and biological resources. The Wall Condition Class is more difficult to change and really just reflects the geotechnical materials of the pit walls, although it can be affected by changing the geometry of the pit walls or by constructing buttresses.

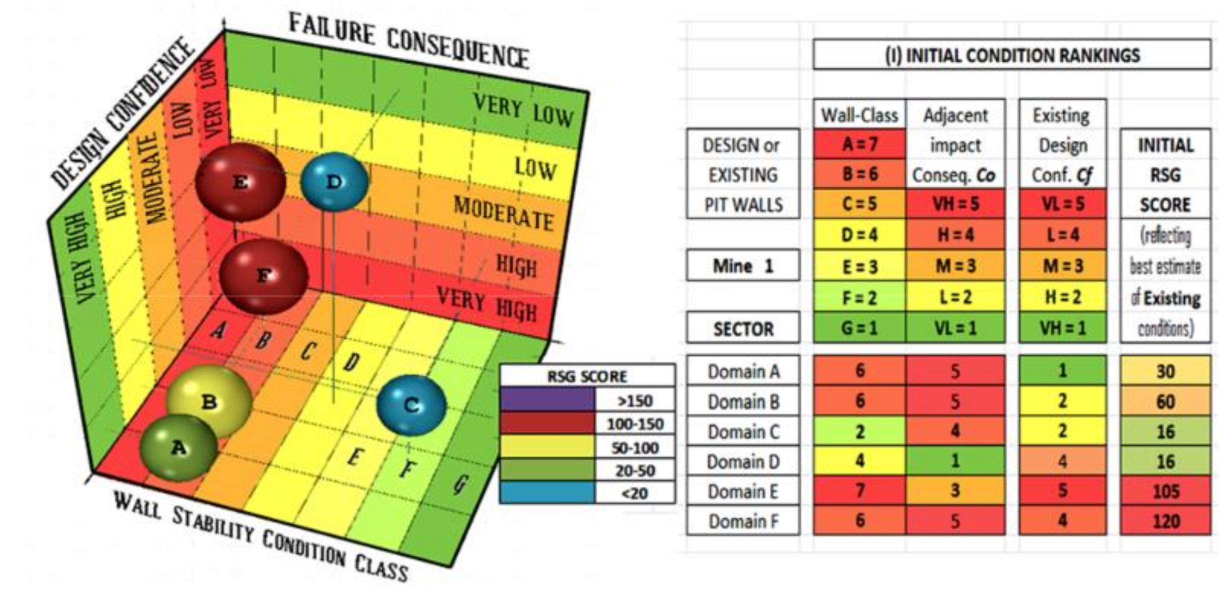

Figure 9 Conceptual results of relative stability guideline assessments for hypothetical example open pit configuration and sector geometry shown in Figure 8

Figure 26a. According to the mining industry guidance book Guidelines for Mine Closure (de Graaf et al., 2021, 2024; LOP, 2024), the minimum factor of safety against slope failure during the post-closure period should be determined based upon the Relative Stability Guideline (RSG) for each slope. The RSG is the product of the score for the Pit Wall Condition Class (on a scale of 1 to 7 with lower scores indicating more competent slopes), the Adjacent Impact Consequence (on a scale of 1 to 5 with higher scores indicating more severe consequences), and the Existing Design Confidence (on a scale of 1 to 5 with higher scores indicating less confidence or greater data uncertainty). The figure shows an example for a particular open pit. For Domain F in the pit, the product of a score of 6 for Pit Wall Condition Class B, a score of 5 for Very High consequences, and a score of 4 for Low Existing Design Confidence yields an RSG of 120. Note that the design confidence could be increased (reducing the score) by the acquisition of more high-quality data, while the failure consequences could be reduced (also reducing the score) by changing the location of the pit wall with respect to populated areas, civil infrastructure, or cultural and biological resources. See further information regarding Guidelines for Mine Closure in Figs. 26b-c. Figure from Carter et al. (2022).

The procedures in Guidelines for Mine Closure can now be applied to the quarry at the proposed Rhyolite Ridge mine. Fig. 26b shows a rough equivalence (at the screening level) between the Pit Wall Condition Class and the calculated factor of safety. The only relevant Pit Wall Condition Classes would be C (corresponding to a factor of safety of 1.2) and D (corresponding to a factor of safety of 1.5 (see Fig. 26b). Although the lack of reliability of the calculated factors of safety has already been discussed, the post-closure factors of safety (after buttress construction) are closer to 1.2 for Sections TR02E-6, TR02E-9, and TR02E-11 and closer to 1.5 for Sections TR02E-5, TR02E-7, and TR02E-8 (see Fig. 15). Pit Wall Condition C is described as "unvegetated slopes with uncontrolled rockfall risk and undesirable risk of failure" and with "high level of concern," while Pit Wall Condition D is described as "standard design reliability, slopes with rockfall control" and with "moderate level of concern" (Carter et al., 2022; see Fig. 26b). Pit Wall Condition is assigned a score of 5, while Pit Wall Condition D is assigned a score of 4 (see Fig. 26a).

Table 3 Suggested screening classification table for benchmarking open pit slope wall conditions and probable significance for slope failure risk (modified from Carter & Miller 1995; McCracken & Jones 1986; Kirsten & Moss 1985; Priest & Brown 1983; Pine 1992; Cole 1993)

Existing pit wall condition class	Existing pit wall likely Probability of Failure %	Existing pit wall likely Factor of Safety*	Assessed existing wall reliability index*, ß)	Existing pit wall likely long-term reliability*	Indicative stakeholder position on closure strategy	Suggested Controls	
						Public Access	Operating Surveillance
A	50 – 100	<1	<0.1	Effectively zero	Totally Unacceptable	Forbidden	Ineffective
B	20 – 50	1.0	0.5	Quasi-stable Slopes	Not acceptable	Forcibly Prevented	Continuous sophisticated monitoring
C	10 – 20	1.2	1.0	Unvegetated slopes with uncontrolled rockfall risk and undesirable risk of failure	High level of concern	Actively prevented	Continuous monitoring with instruments
D	5 – 10	1.5	1.2	Standard design reliability, slopes w/rockfall control	Moderate level of concern	Prevented	Continuous simple monitoring
E	1.5 – 5	1.8	1.5	Good design reliability, unvegetated slopes, but w/rockfall protection	Low to moderate level of concern	Discouraged	Conscious superficial monitoring
F	0.5 – 1.5	2.0	2.5	Design reliability to routine civil design standards, incl. rockfall protection & berm drainage	Of limited concern	Allowed	Incidental superficial monitoring
G	<0.5	>>2	>3	Extremely high reliability, controls far exceed credible hazards (vegetated slope to full highway design standards)	Of no concern	Free	No monitoring required

*For closure loading conditions considering material degradation & longevity events.

Note $ß \approx log_{10}(PoF)$, where $PoF = p(FoS<1.0) = p(SM<0) \approx 10^{-ß}$ (after Pine 1992).

Figure 26b. According to the mining industry guidance book Guidelines for Mine Closure (de Graaf et al., 2021, 2024; LOP, 2024), the assumption of a minimum factor of safety against slope failure of 1.2 by Geo-Logic Associates (2022, 2023) would put the pit slopes at the Rhyolite Ridge mine into Pit Wall Condition Class C, corresponding to a score of 5 (see Fig. 26a). Note that Pit Wall Condition Class D (more competent slopes) would require a calculated factor of safety of 1.5. The above table describes Pit Wall Condition Class C as "unvegetated slopes with uncontrolled rockfall risk and undesirable risk of failure," together with "high level of concern" and the need for "continuous monitoring with instruments." Figure from Carter et al. (2022).

In the post-closure period, the slope failure consequence of the cessation of mining activity is no longer relevant, since mining activity will already have ceased. Carter et al. (2022) do not discuss the loss of irreplaceable biological resources in terms of a failure consequence category, so recourse must be sought in other types of mining industry guidance documents. The Global Industry Standard on Tailings Management has a five-level consequence scale (Low, Significant, High, Very High, Extreme) for failure of tailings facilities. Extreme failure consequences include "catastrophic loss of critical habitat or rare and endangered species" (ICMM-UNEP-PRI, 2020), which would be analogous to the irreplaceable loss of Tiehm's buckwheat habitat. The International Commission on Large Dams (ICOLD) also has a five-level scale for consequences of failure for tailings dams. For this scale, Extreme consequences include “catastrophic loss of critical environmental values including rare and endangered species of high significance” (ICOLD, 2022). Finally, the Canadian Dam Association has a five-level scale for consequences of failure of both water-retention and tailings dams. In this case, Extreme consequences include “major loss of critical fish or wildlife habitat” (Canadian Dam Association, 2013). By comparison with the three preceding industry guidance documents, in the terms of the five-level scale of Guidelines for Mine Closure, the loss of Tiehm’s buckwheat habitat should have an Adjacent Impact Consequence of Very High, corresponding to a score of 5 (see Fig. 26a).

At this point, the discussion will be temporarily restricted to Sections TR02E-6, TR02E-9, and TR02E-11 (see Figs. 14-15), which have been assigned to Pit Wall Condition Class C with a score of 5 (see Figs. 26a-b). All three sections intersect Tiehm’s buckwheat population (see Fig. 14). In this regard, Section TR02E-11 is the most critical since it intersects the Tiehm’s buckwheat population that occurs only 15 feet from the proposed quarry (compare Fig. 14 with Figs. 2 and 3a-b). The multiplication of a Wall-Class Condition score of 5 and an Adjacent Impact Consequence score of 5 yields 25, which still needs to be multiplied by the score for Existing Design Confidence to obtain the RSG. The RSG score would need to be less than 20 for a minimum post-closure factor of safety in the range 1.2-1.5 (see Fig. 26c). Note that, according to Fig. 26c, a minimum post-closure factor of safety of 1.2 would not be acceptable under any circumstances, no matter how low the RSG score was. In the case of Sections TR02E-6, TR02E-9, and TR02E-11, an RSG score of 25 would result from an Existing Design Confidence of Very High with a score of 1 (see Fig. 26a). At the present time, the Existing Design Confidence must be quite low, but it could be imagined that it might eventually be brought up to Medium with a score of 3 (see Fig. 26a). Scores for the Wall-Class Condition, Adjacent Impact Consequence, and Existing Design Confidence of 5, 5, and 3, respectively, would yield an RSG score of 75, which would imply a minimum post-closure factor of safety greater than 2.0 (see Fig. 2c). Note that, even an Existing Design Confidence of High (score of 2) would yield an RSG score of 50, which would still imply a minimum post-closure factor of safety greater than 2.0 (see Fig. 26c).

The less critical Sections TR02E-5, TR02E-7, and TR02E-8 with Pit Wall Condition D (score of 4) can now be considered. The Adjacent Impact Consequence should still be Very High with a score of 5 (see Fig. 26a). If the Existing Design Confidence could be raised to Medium (score of 3), then the RSG score would be 60, which would again imply a minimum post-closure factor of safety greater than 2.0 (see Fig. 26c). However, if the Existing Design Confidence could be raised to High (score of 2), then the RSG score would be reduced to 40, which would imply a minimum post-closure factor of safety in the range 1.5-2.0 (see Fig. 26c). In summary, a minimum post-closure factor of safety of 2.0 seems to be reasonable, which is far greater than the minimum post-closure factor of safety of 1.2 that was selected by Geo-Logic Associates (2022, 2023).

Table 4	Suggested actions, dependent on RSG score	
RSG score	**RSG level**	**Appropriate action**
RSG>100	Extreme	Comprehensive and extremely rigorous analysis required, based likely on additional data acquisition so that deep understanding of failure mechanisms and behaviour can be gained to allow extremely robust controls to be implemented. Very high design reliability required. **FoS >> 2 needed unless quantitative risk analysis (QRA) undertaken**
50≤RSG≤100	High	Rigorous analysis necessary, so that thorough understanding of mechanisms is gained, so robust controls can be implemented High design reliability required. **FoS > 2**
20≤RSG≤50	Moderate	Standard analysis sufficient, good understanding needed of scenario so that appropriate controls can be implemented Good design reliability required. **FoS > 1.5**
RSG<20	Low	Apply good practice, guidance and hierarchy of controls Fair design reliability required **FoS > 1.2**

Figure 26c. The RSG score for the pit slopes at the Rhyolite Ridge mine can be calculated by multiplying the score of 5 for Pit Wall Condition Class C (see Fig. 26b) by the scores for Existing Design Confidence and Adjacent Impact Consequence (see Fig. 26b). The Guidelines for Mine Closure do not address the irreplaceable loss of biological resources, but other five-level consequence classifications, such as the Global Industry Standard for Tailings Management place accidents with "catastrophic loss of critical habitat or rare and endangered species" (ICMM-UNEP-PRI, 2020) into the most severe category of Extreme consequences. Thus, a score of 5 for Adjacent Impact Consequences, corresponding to Very High consequences (see Fig. 26a), would yield an RSG score of 25 multiplied by the score for Existing Design Confidence. On that basis, the minimum post-closure factor of safety of 1.2, which was assumed by Geo-Logic Associates (2022, 2023) would not be appropriate even if the Existing Design Confidence could be raised to the level of Very High (corresponding to a score of 1) (see Fig. 26a). The Existing Design Confidence is certainly not at the level of Very High, based on the low-quality geotechnical data that are currently available (see, for example, Fig. 19). If the Existing Design Confidence could be raised to a level of Medium with a score of 3 (see Fig. 26a), then the RSG score would be 75, which would demand a post-closure factor of safety greater than 2.0. The best that could be hoped for would be to raise the Existing Design Confidence to High (score of 2) or Very High (score of 1), yielding RSG scores of 50 and 25, respectively, both of which would demand minimum post-closure factors of safety greater than 1.5.

The Post-Closure Zone of Instability has not been Taken into Account

From a superficial standpoint, Geo-Logic Associates (2022, 2023) appears to have calculated some version of a "Zone of Instability" through using the limit equilibrium method to calculate the location of the critical failure surfaces, which are the curved lines labeled with a boxed number indicating the factor of safety in Figs. 27, 28a-b, 29a-b, 30a-b, 31a-b, and 32a-b (compare with list of calculated factors of safety in Fig. 15). For example, the shifting of the critical failure surface inward toward the quarry after construction of a buttress would seem to reduce or eliminate any unstable zone outside of the quarry after closure. The standpoint is superficial for three reasons. First, just as there has been no sensitivity analysis as to how the factor of safety would change in response to reasonably possible alternative values of the geotechnical parameters, there has been no analysis as to how the location of the critical failure surface might change. If the location of the critical failure surface could change significantly, especially if it did not shift in an inward direction after construction of a buttress, then any predictions regarding the elimination of an unstable zone should be viewed with great caution.

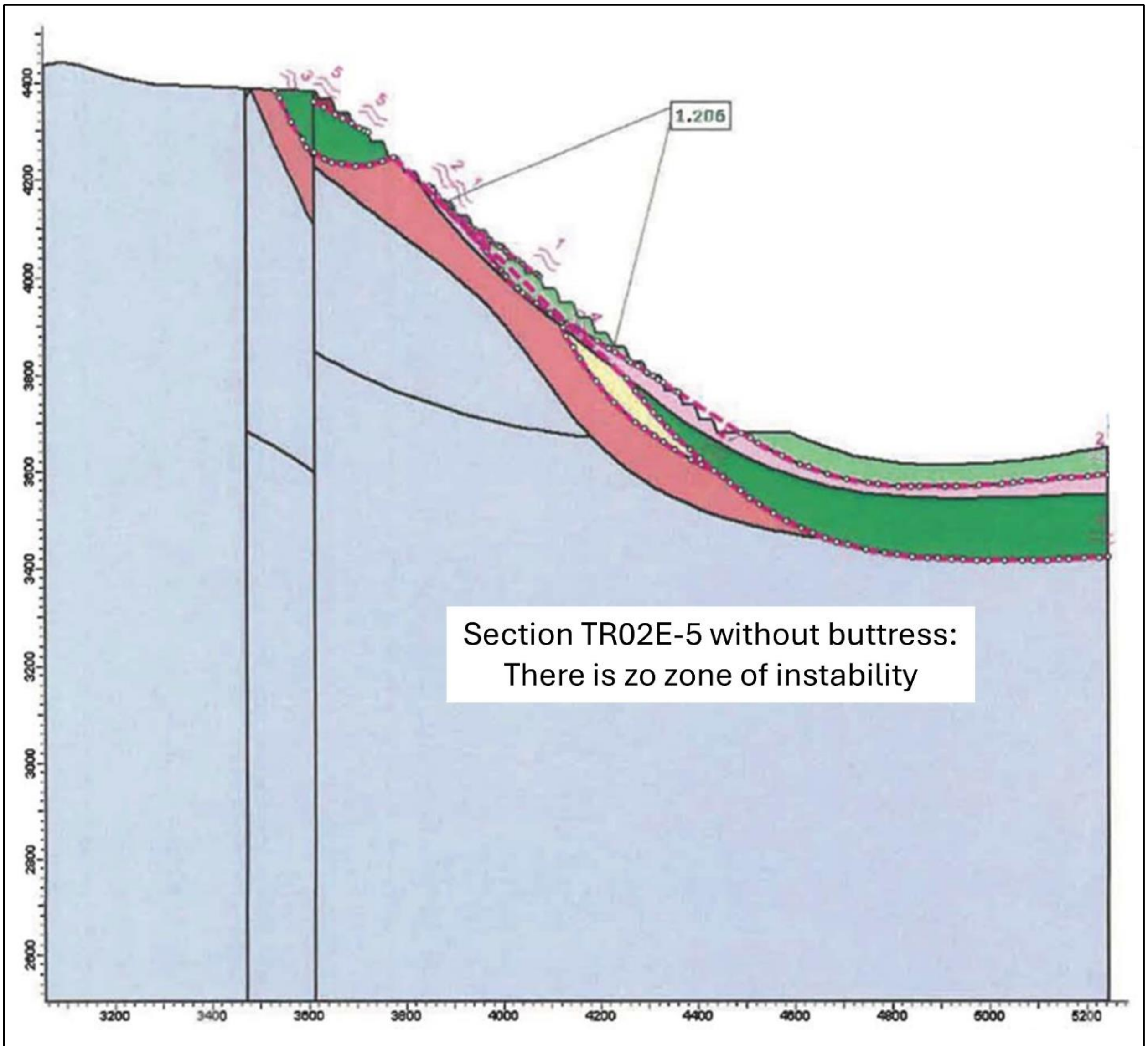

Figure 27. Based on the guidelines of Department of Industry and Resources (Western Australia) (1997), Section TR02E-5 (see Fig. 14) has no Zone of Instability, so that the region more than 50 feet upslope (in the horizontal direction) from the edge of the quarry could be regarded as a safe zone (see Fig. 18a and Table 3). Since the entire section consists of rock units stratigraphically lower than B5 (see Fig. 13 and Table 1), all of the rocks were assumed to be unweathered (strong), so the line connecting the toe of the pit with the surface should have a 45° angle (see Fig. 18a). The lack of a Zone of Instability results from the slope of the pit being shallower than 45°. Figure is portion of figure from Geo-Logic Associates (2023) with addition of a label.

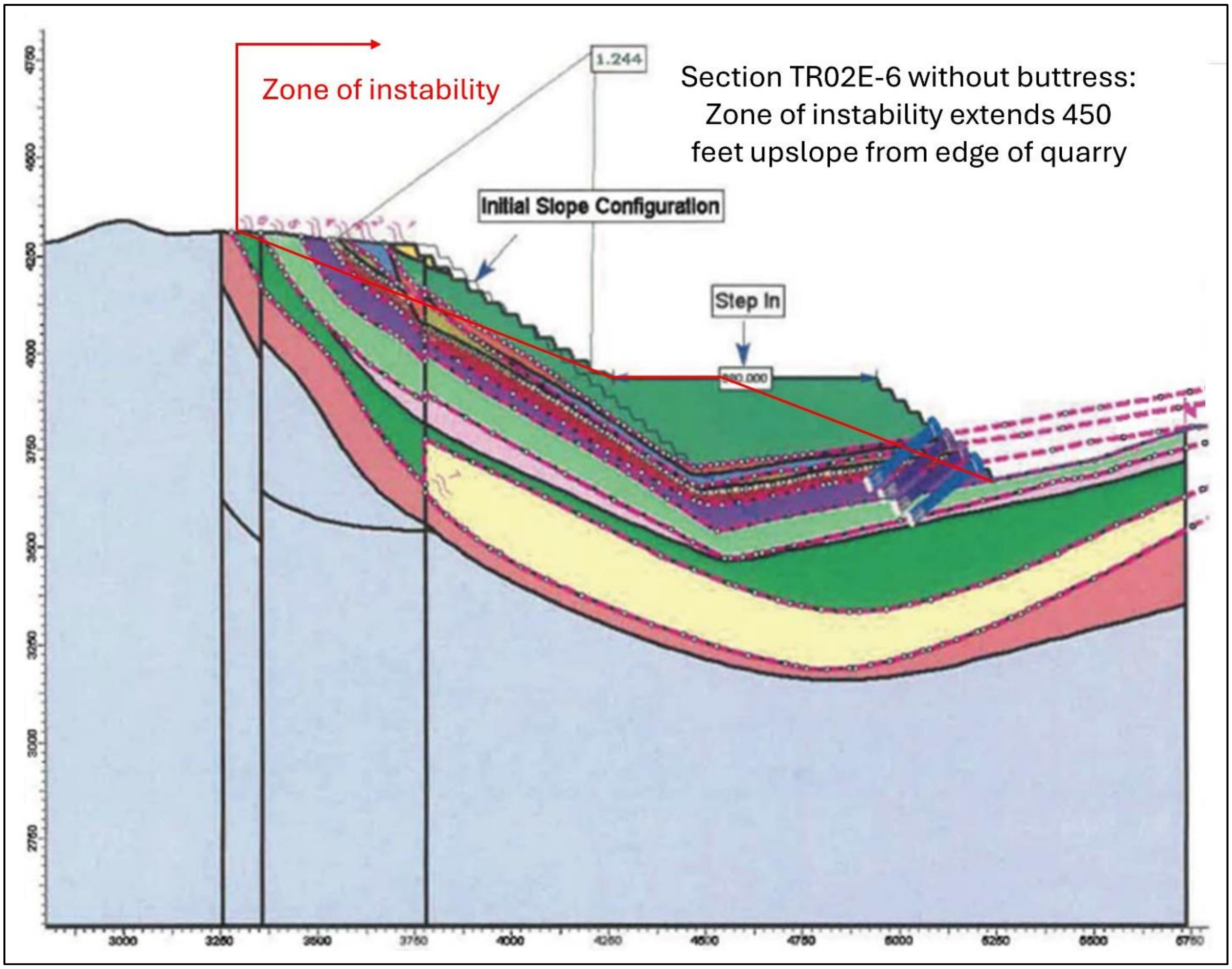

Figure 28a. Based on the guidelines of Department of Industry and Resources (Western Australia) (1997), the Zone of Instability for Section TR02E-6 (see Fig. 14), without a buttress, extends 450 feet upslope from the edge of the quarry, so that the region more than 500 feet upslope (in the horizontal direction) from the edge of the quarry could be regarded as a safe zone (see Fig. 18a and Table 3). Since all of the rocks above the toe of the pit are at the stratigraphic level of Unit B5 or higher (see Fig. 13 and Table 1), all rocks are regarded as weathered (weak) and the red connecting lines are drawn with slopes of 25° with respect to the horizontal. The above diagram follows the guidelines for complex pit geometries in which the connecting line intersects an interior surface of the pit (see Fig. 18b). Figure is portion of figure from Geo-Logic Associates (2023) with overlay of additional labels and red connecting lines.

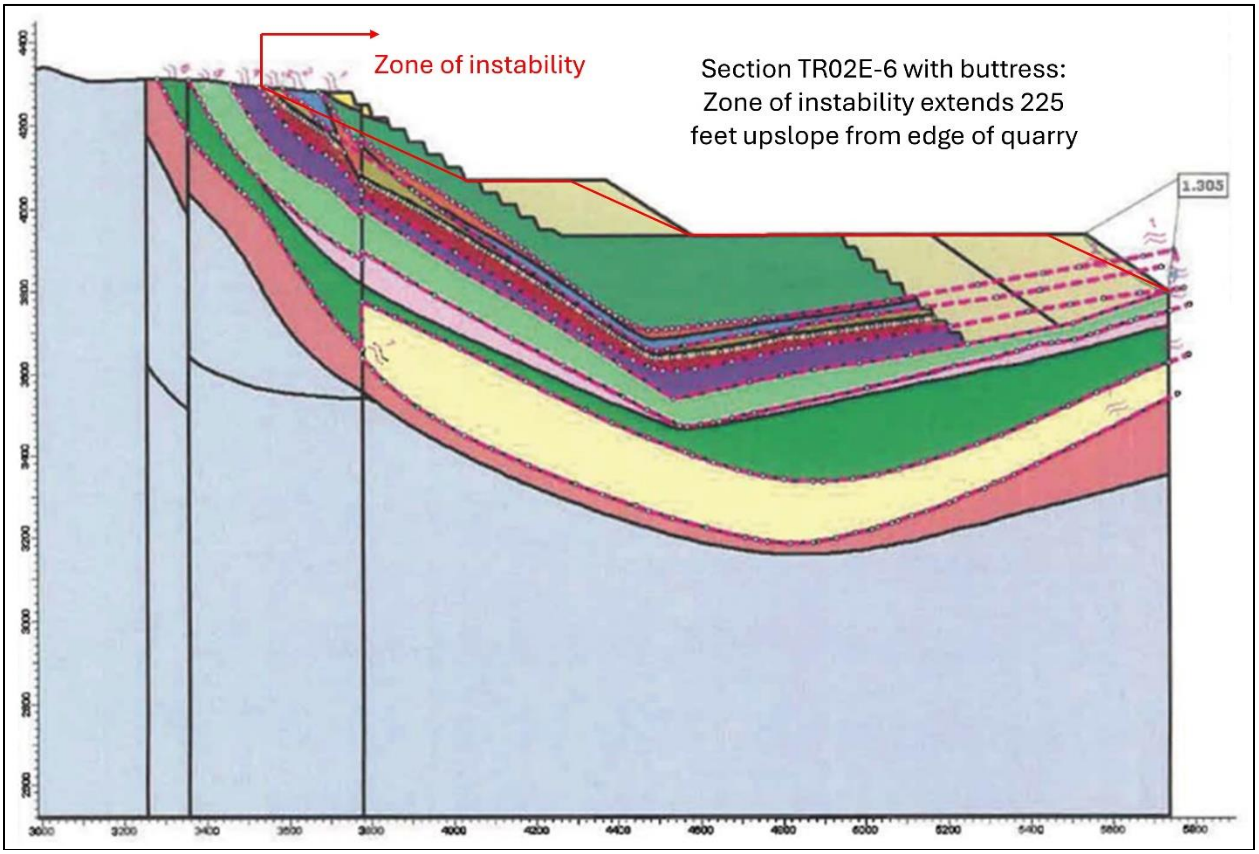

Figure 28b. Based on the guidelines of Department of Industry and Resources (Western Australia) (1997), the Zone of Instability for Section TR02E-6 (see Fig. 14), with a buttress, extends 225 feet upslope from the edge of the quarry, so that the region more than 275 feet upslope (in the horizontal direction) from the edge of the quarry could be regarded as a safe zone (see Fig. 18a and Table 3). Thus, the addition of a buttress reduced the width of the Zone of Instability from 450 feet (compare with Fig. 28a and Table 3), but did not eliminate the Zone of Instability. Since all of the rocks above the toe of the pit are at the stratigraphic level of Unit B5 or higher (see Fig. 13 and Table 1), all rocks are regarded as weathered (weak) and the red connecting lines are drawn with slopes of 25° with respect to the horizontal. In the absence of any further information, it is assumed that the buttress will be constructed out of weathered or oxidized material. The above diagram follows the guidelines for complex pit geometries in which the connecting line intersects an interior surface of the pit (see Fig. 18b). Figure is portion of figure from Geo-Logic Associates (2023) with overlay of additional labels and red connecting lines.

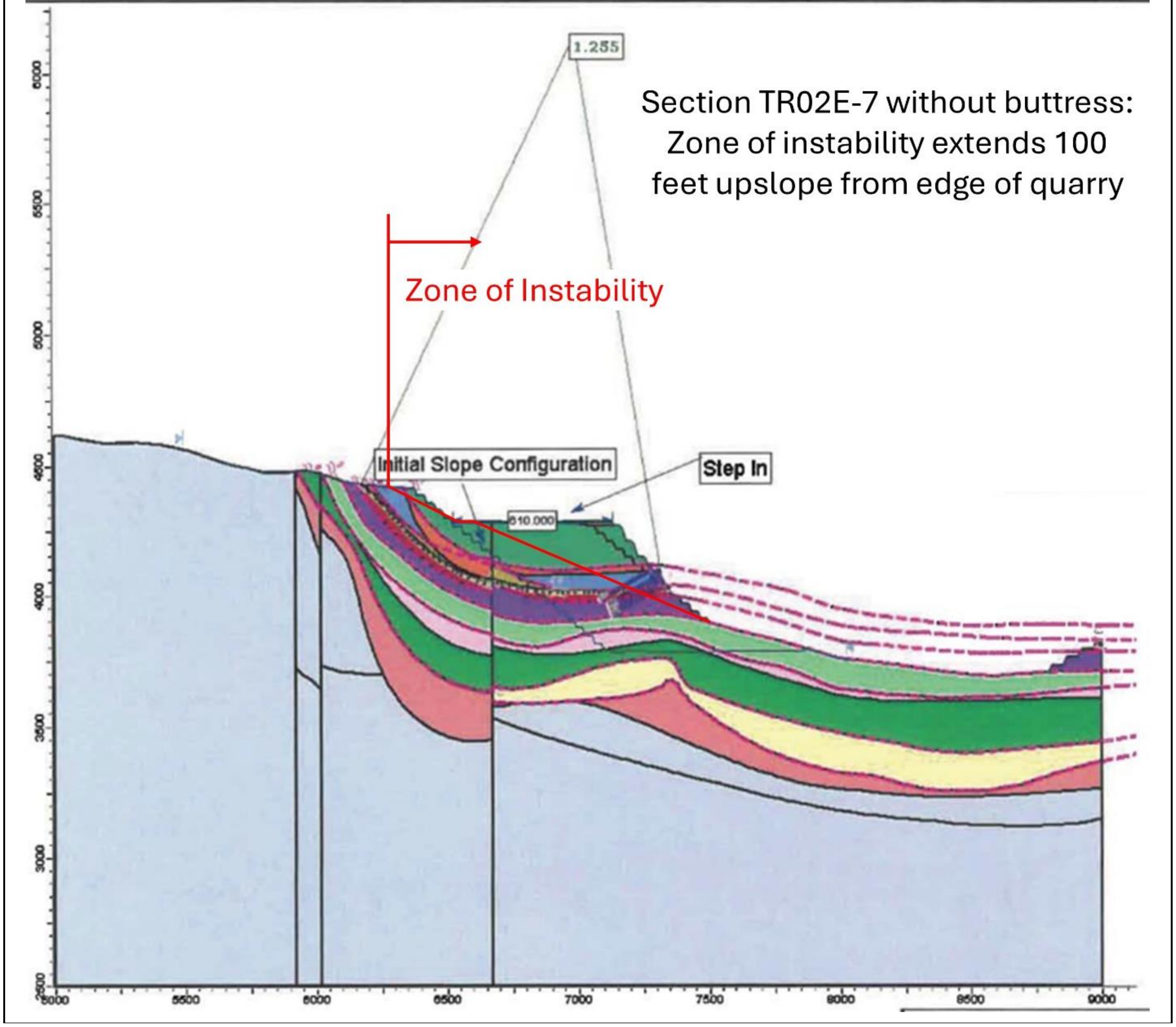

Figure 29a. Based on the guidelines of Department of Industry and Resources (Western Australia) (1997), the Zone of Instability for Section TR02E-7 (see Fig. 14), without a buttress, extends 100 feet upslope from the edge of the quarry, so that the region more than 150 feet upslope (in the horizontal direction) from the edge of the quarry could be regarded as a safe zone (see Fig. 18a and Table 3). Since all of the rocks above the toe of the pit are at the stratigraphic level of Unit B5 or higher (see Fig. 13 and Table 1), all rocks are regarded as weathered (weak) and the red connecting lines are drawn with slopes of 25° with respect to the horizontal. The above diagram follows the guidelines for complex pit geometries in which the connecting line intersects an interior surface of the pit (see Fig. 18b). Figure is portion of figure from Geo-Logic Associates (2023) with overlay of additional labels and red connecting lines.

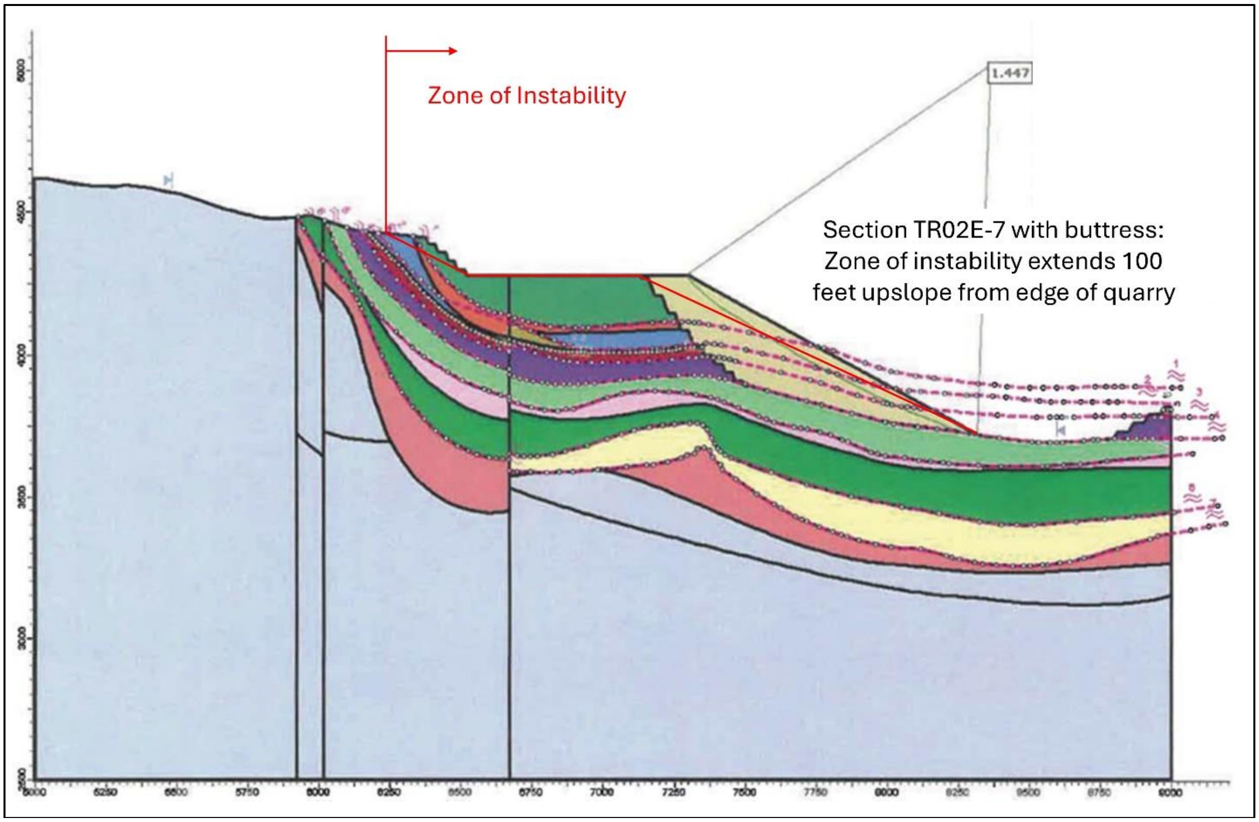

Figure 29b. Based on the guidelines of Department of Industry and Resources (Western Australia) (1997), the Zone of Instability for Section TR02E-7 (see Fig. 14), with a buttress, extends 100 feet upslope from the edge of the quarry, so that the region more than 150 feet upslope (in the horizontal direction) from the edge of the quarry could be regarded as a safe zone (see Fig. 18a and Table 3). Thus, the addition of a buttress did not change the width of the Zone of Instability (compare with Fig. 28a and Table 3). Since all of the rocks above the toe of the pit are at the stratigraphic level of Unit B5 or higher (see Fig. 13 and Table 1), all rocks are regarded as weathered (weak) and the red connecting lines are drawn with slopes of 25° with respect to the horizontal. In the absence of any further information, it is assumed that the buttress will be constructed out of weathered or oxidized material. The above diagram follows the guidelines for complex pit geometries in which the connecting line intersects an interior surface of the pit (see Fig. 18b). Figure is portion of figure from Geo-Logic Associates (2023) with overlay of additional labels and red connecting lines.

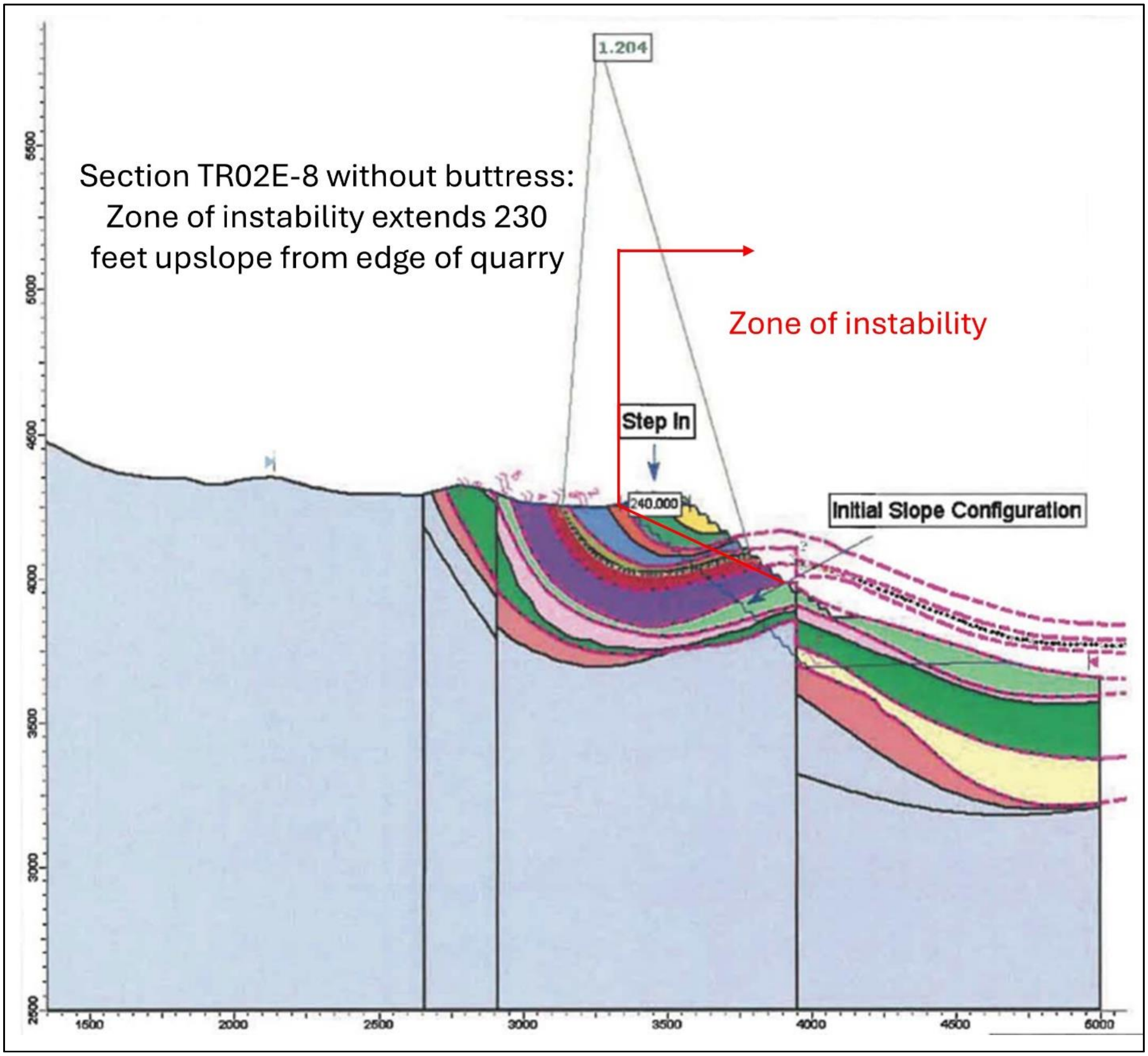

Figure 30a. Based on the guidelines of Department of Industry and Resources (Western Australia) (1997), the Zone of Instability for Section TR02E-8 (see Fig. 14), without a buttress, extends 230 feet upslope from the edge of the quarry, so that the region more than 280 feet upslope (in the horizontal direction) from the edge of the quarry could be regarded as a safe zone (see Fig. 18a and Table 3). Since all of the rocks above the toe of the pit are at the stratigraphic level of Unit B5 or higher (see Fig. 13 and Table 1), all rocks are regarded as weathered (weak) and the red connecting lines are drawn with slopes of 25° with respect to the horizontal. The above diagram follows the guidelines for complex pit geometries in which the connecting line intersects an interior surface of the pit (see Fig. 18b). Figure is portion of figure from Geo-Logic Associates (2023) with overlay of additional labels and red connecting lines.

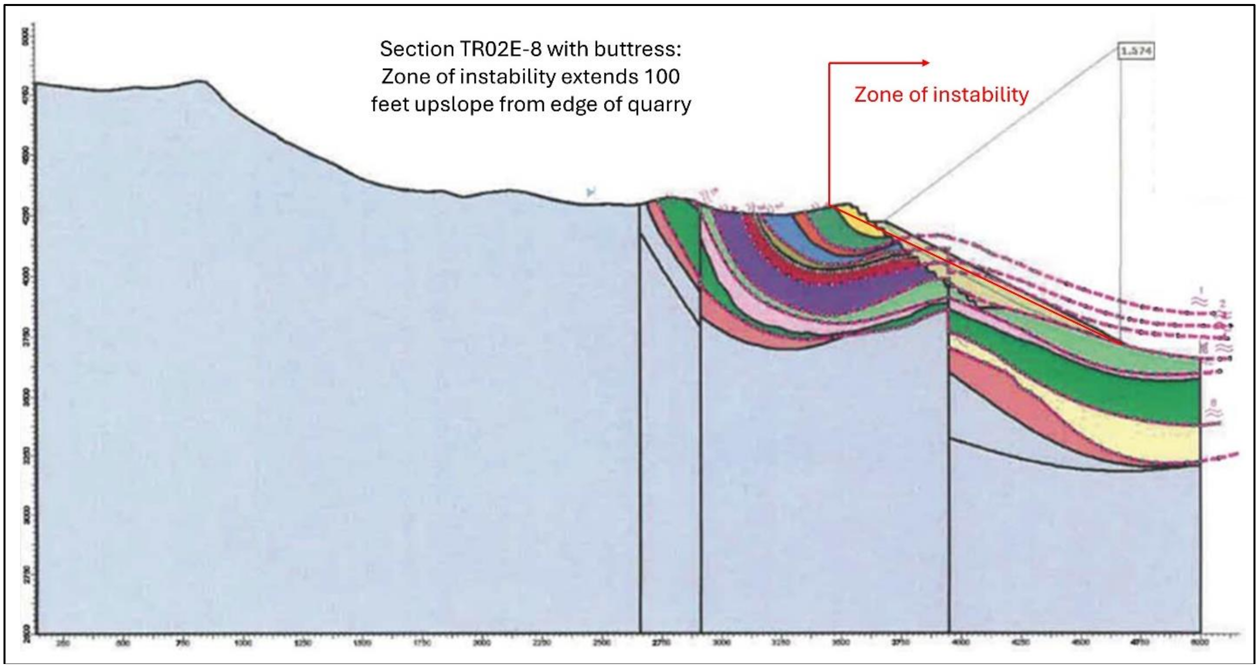

Figure 30b. Based on the guidelines of Department of Industry and Resources (Western Australia) (1997), the Zone of Instability for Section TR02E-8 (see Fig. 14), with a buttress, extends 100 feet upslope from the edge of the quarry, so that the region more than 150 feet upslope (in the horizontal direction) from the edge of the quarry could be regarded as a safe zone (see Fig. 18a and Table 3). Thus, the addition of a buttress reduced the width of the Zone of Instability from 230 feet (compare with Fig. 30a and Table 3), but did not eliminate the Zone of Instability. Since all of the rocks above the toe of the pit are at the stratigraphic level of Unit B5 or higher (see Fig. 13 and Table 1), all rocks are regarded as weathered (weak) and the red connecting lines are drawn with slopes of 25° with respect to the horizontal. In the absence of any further information, it is assumed that the buttress will be constructed out of weathered or oxidized material. The above diagram follows the guidelines for complex pit geometries in which the connecting line intersects an interior surface of the pit (see Fig. 18b). Figure is portion of figure from Geo-Logic Associates (2023) with overlay of additional labels and red connecting lines.

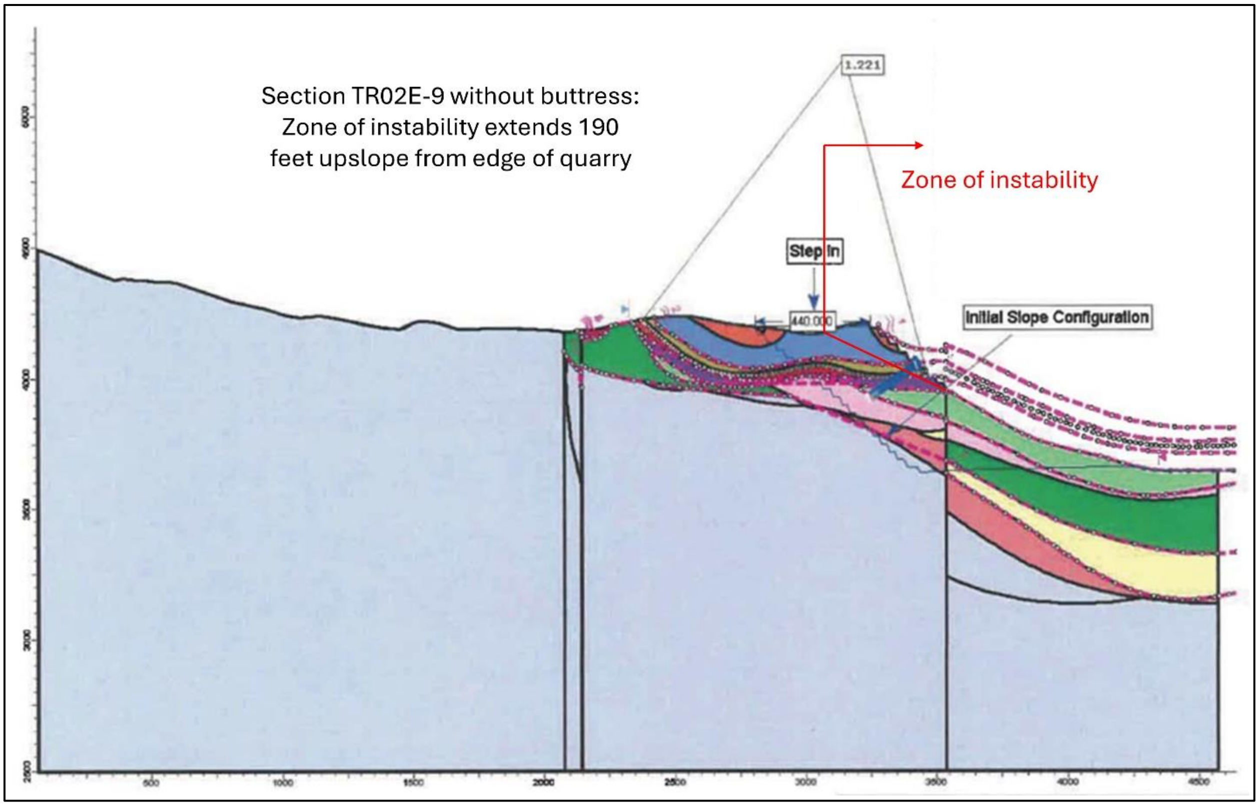

Figure 31a. Based on the guidelines of Department of Industry and Resources (Western Australia) (1997), the Zone of Instability for Section TR02E-9 (see Fig. 14), without a buttress, extends 190 feet upslope from the edge of the quarry, so that the region more than 240 feet upslope (in the horizontal direction) from the edge of the quarry could be regarded as a safe zone (see Fig. 18a and Table 3). Since all of the rocks above the toe of the pit are at the stratigraphic level of Unit B5 or higher (see Fig. 13 and Table 1), all rocks are regarded as weathered (weak) and the red connecting lines are drawn with slopes of 25° with respect to the horizontal. The above diagram follows the guidelines for complex pit geometries in which the connecting line intersects an interior surface of the pit (see Fig. 18b). Figure is portion of figure from Geo-Logic Associates (2023) with overlay of additional labels and red connecting lines.

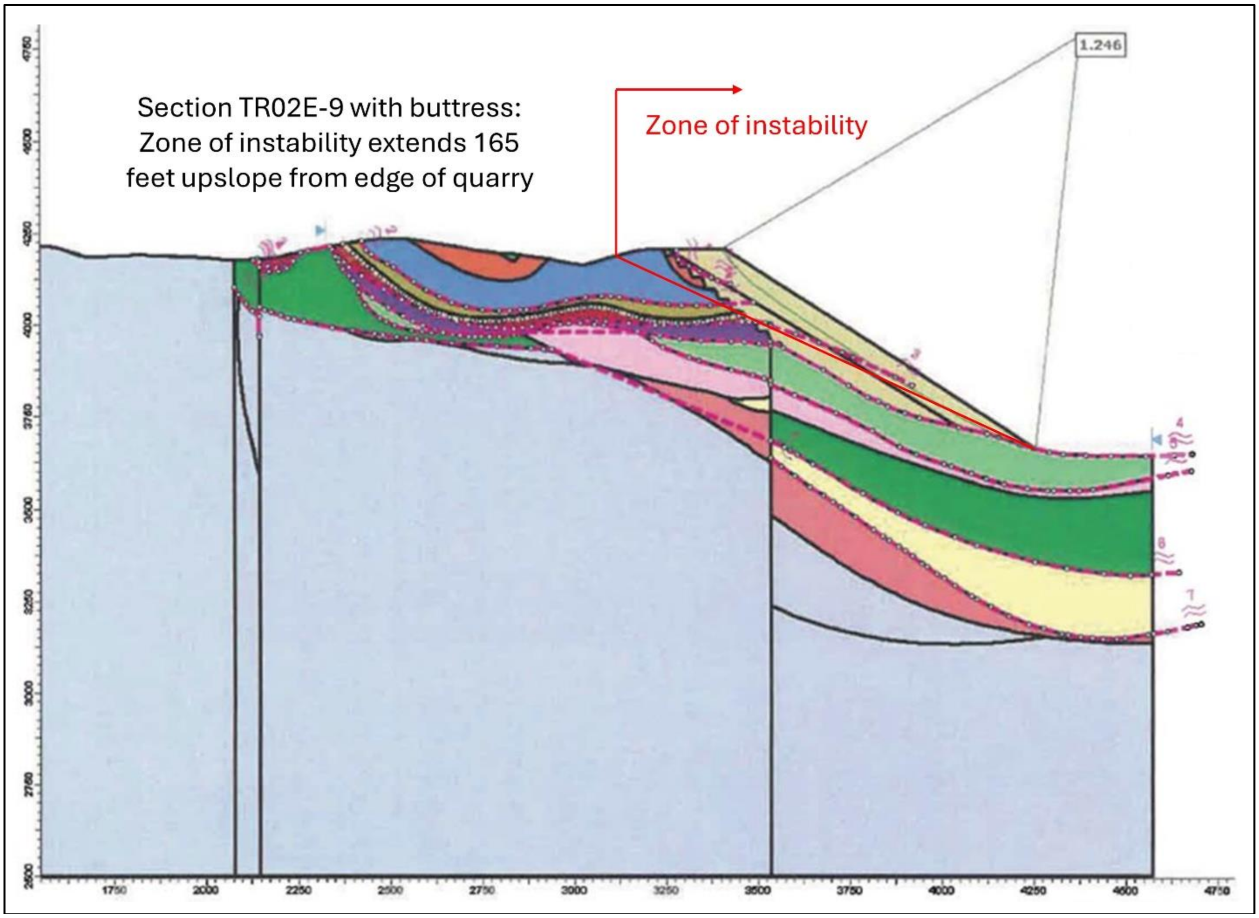

Figure 31b. Based on the guidelines of Department of Industry and Resources (Western Australia) (1997), the Zone of Instability for Section TR02E-9 (see Fig. 14), with a buttress, extends 165 feet upslope from the edge of the quarry, so that the region more than 215 feet upslope (in the horizontal direction) from the edge of the quarry could be regarded as a safe zone (see Fig. 18a and Table 3). Thus, the addition of a buttress reduced the width of the Zone of Instability from 190 feet (compare with Fig. 31a and Table 3), but did not eliminate the Zone of Instability. Since all of the rocks above the toe of the pit are at the stratigraphic level of Unit B5 or higher (see Fig. 13 and Table 1), all rocks are regarded as weathered (weak) and the red connecting lines are drawn with slopes of 25° with respect to the horizontal. In the absence of any further information, it is assumed that the buttress will be constructed out of weathered or oxidized material. The above diagram follows the guidelines for complex pit geometries in which the connecting line intersects an interior surface of the pit (see Fig. 18b). Figure is portion of figure from Geo-Logic Associates (2023) with overlay of additional labels and red connecting lines.

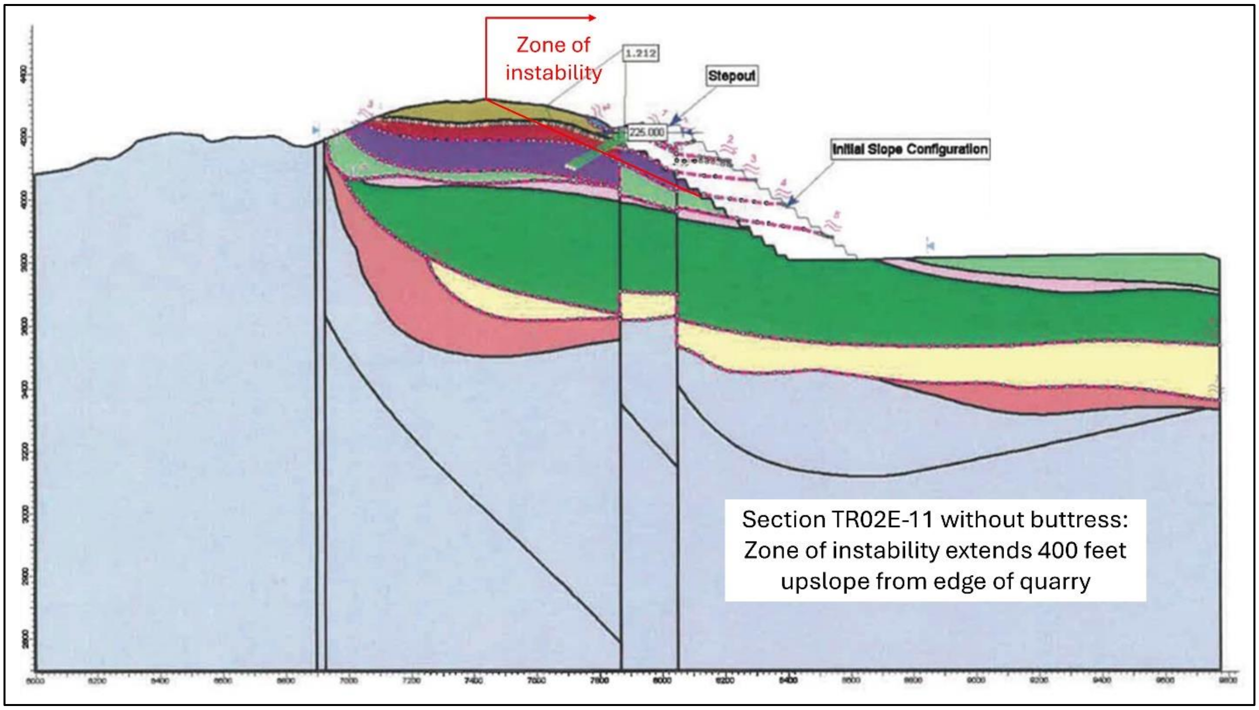

Figure 32a. Based on the guidelines of Department of Industry and Resources (Western Australia) (1997), the Zone of Instability for Section TR02E-11 (see Fig. 14), without a buttress, extends 400 feet upslope from the edge of the quarry, so that the region more than 450 feet upslope (in the horizontal direction) from the edge of the quarry could be regarded as a safe zone (see Fig. 18a and Table 3). Since all of the rocks above the toe of the pit are at the stratigraphic level of Unit B5 or higher (see Fig. 13 and Table 1), all rocks are regarded as weathered (weak) and the red connecting lines are drawn with slopes of 25° with respect to the horizontal. The above diagram follows the guidelines for complex pit geometries in which the connecting line intersects an interior surface of the pit (see Fig. 18b). Figure is portion of figure from Geo-Logic Associates (2023) with overlay of additional labels and red connecting lines.

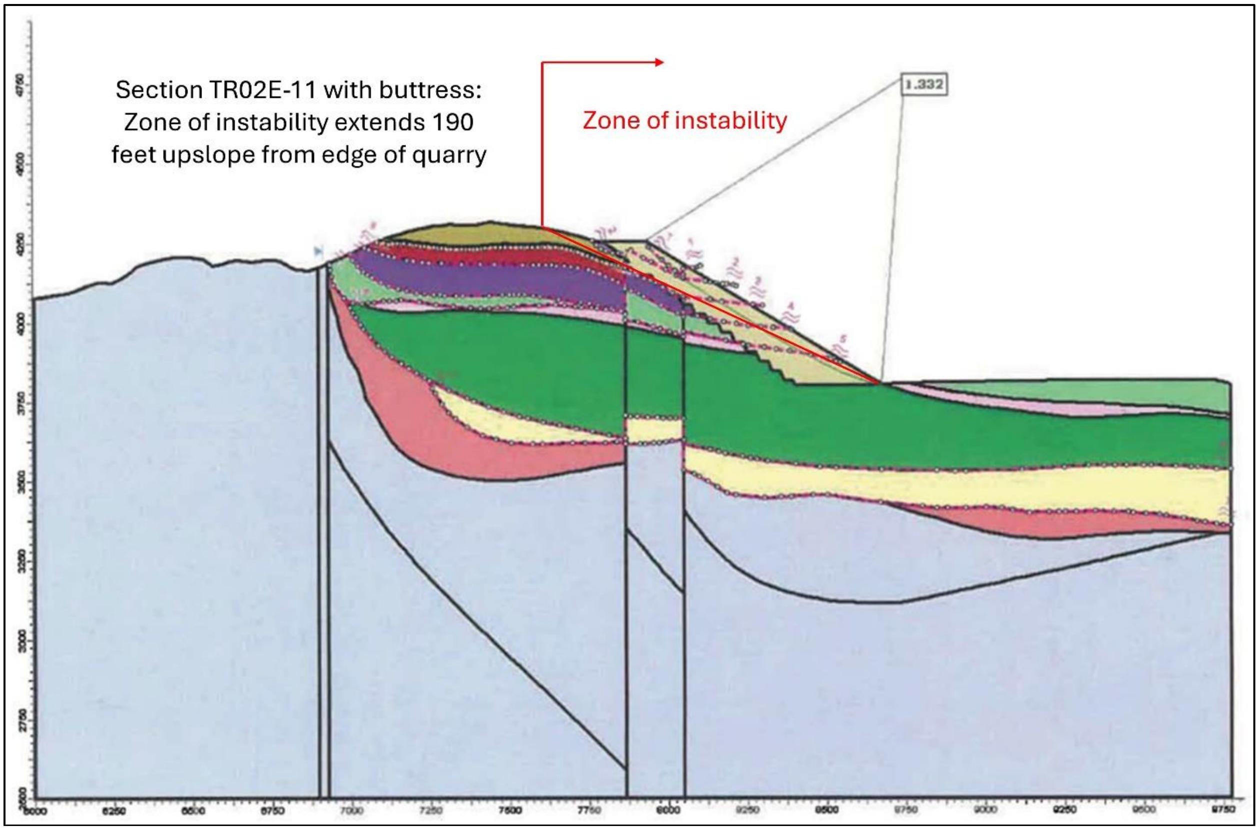

Figure 32b. Based on the guidelines of Department of Industry and Resources (Western Australia) (1997), the Zone of Instability for Section TR02E-11 (see Fig. 14), with a buttress, extends 190 feet upslope from the edge of the quarry, so that the region more than 240 feet upslope (in the horizontal direction) from the edge of the quarry could be regarded as a safe zone (see Fig. 18a and Table 3). Thus, the addition of a buttress reduced the width of the Zone of Instability from 400 feet (compare with Fig. 32a and Table 3), but did not eliminate the Zone of Instability. Since all of the rocks above the toe of the pit are at the stratigraphic level of Unit B5 or higher (see Fig. 13 and Table 1), all rocks are regarded as weathered (weak) and the red connecting lines are drawn with slopes of 25° with respect to the horizontal. In the absence of any further information, it is assumed that the buttress will be constructed out of weathered or oxidized material. The above diagram follows the guidelines for complex pit geometries in which the connecting line intersects an interior surface of the pit (see Fig. 18b). Figure is portion of figure from Geo-Logic Associates (2023) with overlay of additional labels and red connecting lines.

The second reason as to why Geo-Logic Associates (2022, 2023) has not really calculated the extent of the post-closure unstable zone is that the critical failure surface has been calculated based on the existing geotechnical parameters, and not based on the degraded rock strengths that could exist after pit closure (see Figs. 6-7). Of course, there is always a great deal of uncertainty in the future degraded rock strengths, which again underscores the importance of a complete sensitivity analysis. The third reason is that the application of the limit equilibrium method is the beginning of a stability analysis and not the end. The limit equilibrium method considers only the initiation of failure through one rigid block sliding over another. The method does not consider how failure might progress after initiation. For example, it does not consider how the sliding along one surface could initiate sliding along another surface in the backward direction (away from the center of the quarry). It is most important that the method does not consider rockfall or structurally-controlled failure along joints or faults. The latter could be especially important because of the opening and weathering of joints that occurs during the post-closure period.

The Western Australian guidelines are not foolproof and not the final word in a stability analysis, but they are the culmination of years of experience with the typical widths of unstable zones in arid climates. According to the Western Australian guidelines, "Whilst it is recognised that the controls on the stability of pit walls will be site specific, the design criteria provided represent a generalised, conservative approach for determining the location of long-term abandonment bunds in all open pits. The design information provided in this document is based on field measurements of failures and tension cracks around pit edges in operating and abandoned open pit gold mines in Western Australia … The long-term stability of the open pit edge is dependent on a number of geotechnical factors … This guideline provides generic design criteria that allow for the normal variation of all these factors" (Department of Industry and Resources, 1997). Therefore, the Western Australian guidelines ought to be followed, unless it can be convincingly argued that the guidelines are excessively conservative for a particular mining pit, which is exactly what is stated in the guidelines. According to the Western Australian guidelines, "In cases where the mine owner wishes to locate the abandonment bund closer to the edge of the open pit than specified by this guideline, it must be demonstrated that the stability of the ground mass between the pit edge and the abandonment bund can be ensured for the very long term" (Department of Industry and Resources, 1997).

Out of the six sections for which the stability analyses were updated by Geo-Logic Associates (2023), only Section TR02E-5 has no Zone of Instability outside of the quarry even without a buttress (see Fig. 27). The lack of a Zone of Instability results from all of the exposed geologic units being stratigraphically lower than Unit B5 (compare Fig. 27 with Table 1 and Fig. 13) and from the pit slope being shallower than 45°. For each of the other five sections, either all of the exposed geologic units are at the stratigraphic level of Unit B5 or higher or the Zone of Instability begins at the base of Unit B5 (see Figs. 28a-b, 29a-b, 30a-b, 31a-b, 32a-b). In the absence of a Zone of Instability for Section TR02E-5, the safe region begins 50 feet from the edge of the quarry (see Table 3). It should be noted that Section TR02E-5 is the least critical of the six sections, since it is the only one that does not intersect a population of Tiehm's buckwheat (see Fig. 14).

Table 3. Widths of post-closure zones of instability and safe regions[1]

Cross-Section[2]	Width of Zone of Instability (feet)		Safe Region (feet)[3]	
	Without Buttress	With Buttress	Without Buttress	With Buttress
TR02E-5	0	0	50	50
TR02E-6	450	225	500	275
TR02E-7	100	100	150	150
TR02E-8	230	100	280	150
TR02E-9	190	165	240	215
TR02E-11	400	190	450	240

[1]Zones of instability and safe regions were calculated using procedures described in Department of Industry and Resources (Western Australia) (1997) (see Figs. 18a-b).
[2]See Figs. 14, 27, 28a-b, 29a-b, 30a-b, 31a-b, and 32a-b.
[3]The safe region is the region more than 50 feet upslope (in the horizontal direction) from the outer edge of the Zone of Instability.

For Section TR02E-6, without a buttress, the Zone of Instability encompasses a portion of the "Step In" plus a portion of the region upslope from the "Step In" and the "Initial Slope Configuration" (see Fig. 28a). The width of the Zone of Instability is 450 feet, as measured from the edge of the quarry, so that the safe region begins 500 feet from the edge of the quarry (see Table 3). After the addition of two buttresses, the Zone of Instability encompasses a portion of the inner buttress, a portion of the outer buttress, and a portion of the region upslope from the outer buttress (see Fig. 28b). The width of the Zone of Instability is reduced to 225 feet and the distance of the beginning of the safe region from the edge of the quarry is reduced to 275 feet (see Table 3).

For Section TR02E-7, without a buttress, the Zone of Instability again encompasses a portion of the "Step In" plus a portion of the region upslope from the "Step In" and the "Initial Slope Configuration" (see Fig. 29a). The width of the Zone of Instability is 100 feet, as measured from the edge of the quarry, so that the safe region begins 150 feet from the edge of the quarry (see Table 3). After the addition of a buttress, the Zone of Instability encompasses a portion of the buttress plus a portion of the region upslope from the "Initial Slope Configuration" (see Fig. 29b and compare with Fig. 29a). Since the addition of a buttress does not change the unstable portion of the region upslope from the "Initial Slope Configuration," (see Figs. 29a-b) the width of the Zone of Instability is still 100 feet with the safe region beginning 150 feet from the edge of the quarry (see Table 3).

For Section TR02E-8, without a buttress, the Zone of Instability encompasses a portion of the "Step In" plus a very small portion of the region upslope from the "Initial Slope Configuration" (see Fig. 30a). The width of the Zone of Instability is 230 feet, as measured from the edge of the quarry, with the safe region beginning 280 feet from the edge of the quarry (see Table 3). After the addition of a buttress, the Zone of Instability encompasses a portion of the buttress plus a portion of the region upslope from the "Step In" (see Fig. 30b and compare with Fig. 30a). The width of the Zone of Instability is reduced to 100 feet and the distance of the beginning of the safe region from the edge of the quarry is reduced to 150 feet (see Table 3).

For Section TR02E-9, without a buttress, the Zone of Instability encompasses only a portion of the "Step In" (see Fig. 31a). The width of the Zone of Instability is 190 feet, as measured from the edge of the quarry, with the safe region beginning 240 feet from the edge of the quarry (see Table 3). After the addition of a buttress, the Zone of Instability encompasses most of the buttress plus a portion of the "Step In" (see Fig. 31b and compare with Fig. 31a). The width of the Zone of Instability is reduced to 165 feet and the distance of the beginning of the safe region from the edge of the quarry is reduced to 215 feet (see Table 3).

Section TR02E-11 is the most critical, since it would intersect the population of Tiehm's buckwheat that would be only 15 feet from the edge of the quarry (see Fig. 14 and compare with Figs. 2 and 3a-b). For this section, without a buttress, the Zone of Instability begins at the base of Unit B5 on the side of the quarry and extends to the crest of a hill upslope from both the "Initial Slope Configuration" and the "Stepout" (see Fig. 32a). The width of the Zone of Instability is 400 feet, as measured from the edge of the quarry, with the safe region beginning 450 feet from the edge of the quarry (see Table 3). After the addition of a buttress, the Zone of Instability encompasses about half of the buttress and does not extend all the way to the crest of the hill (see Fig. 32b). The addition of a buttress reduces the width of the Zone of Instability to 190 feet and the distance of the beginning of the safe region from the edge of the quarry to 240 feet (see Table 3). In summary, even with a buttress, the Zone of Instability would extend far into the population of Tiehm's buckwheat.

The Assumption that Slope Materials will remain Unsaturated is Unjustified

The argument by Geo-Logic Associates (2023) as to why the quarry slope materials could not become re-saturated or re-pressurized even in response to extreme snowmelt or precipitation events was quoted at length in the section "Summary of Stability Analysis for Rhyolite Ridge Open Pit." The argument expresses the opinion that any snowmelt or precipitation would either become surface runoff or would infiltrate to a shallow depth and then evaporate. It should be noted that the argument is only a qualitative opinion and is not accompanied by any empirical data, calculations, or modeling. In the absence of any quantitative reasoning, at the present time, it is impossible to determine whether extreme snowmelt or precipitation events could or could not re-saturate the slope materials and thus, affect the stability of the quarry walls.

It is important to consider not only whether the slope materials could become saturated during the operational period when, presumably, quarry dewatering could be an ongoing process, but also during the indefinitely long post-closure period when ongoing quarry dewatering is no longer possible. According to Geo-Logic Associates (2023), "As difficult as it may be to depressurize and remove water from these low permeability clays, it is even more difficult to put it back in." However, there has been no consideration of the meteorological and hydrogeological processes that resulted in the saturation and pressurization of the clay-rich units (M5 and B5) in the first place. Based on the available information, it cannot be said whether the water in Units M5 and B5 is formation water (trapped when the clay was first deposited) or meteoric water (originating in precipitation). Thus, it is not known whether the clay-rich units will recharge over decades or over geologic time, or how the recharge rate could be affected by climate change. In the absence of any of these types of quantitative studies, it should be imperative that the post-closure factors of safety be evaluated not only in light of the reduced rock strengths that develop during the post-closure period, but also for the wide range of water tables and pore pressures that might develop during the post-closure period.

An issue that has not been considered in any documents is the possible localized impact on slope stability of watering the haul roads for dust suppression. In this respect, it should be noted that, based on the design in the DEIS, the main haul road that leaves the quarry would come to within 140 feet of the Tiehm's buckwheat population (see Fig. 17b), which would be very close to Section TR02E-11 (see Fig. 14) with a calculated factor of safety of only 1.21 under the assumption that the quarry slope materials will be unsaturated (see Fig. 15). McCarthy (2024) has estimated that, at the control efficiency level of 95%, dust suppression will require the application of 50,000 gallons of water per hour on the haul roads continuously for the lifetime of the mine. Thus, there needs to be a quantitative analysis of the impact of the water application and not simply the expression of an opinion.

On the subject of haul roads, the U.S. Fish and Wildlife Service (2022) has expressed concern as to how the vehicular traffic on the roads could affect the stability of the quarry walls in the context of concern as to whether the quarry walls would be stable under any circumstances. According to U.S. Fish and Wildlife Service (2022), "Then there is a statement in here [document not available to author] that says, 'It is not feasible to reclaim the slopes of the Quarry wall due to instability and other geologic factors.' If they are stating this slope is unstable, why is there no concern for Tiehm's sliding off into a hole?" U.S. Fish and Wildlife Service (2022) continued, "The actual stability analyses should also show whether surcharge loads from the heavy trucks are being included. Since there are haul roads along this slope, it is assumed they will have included surcharge loads but that should be verified." However, the slope stability analyses by Geo-Logic Associates (2022, 2023) do not consider the additional weight of vehicular traffic on the haul roads, which could be especially important for Section TR02E-11 (compare Fig. 14 with Fig. 17b). In fact, Geo-Logic Associates emphasized the assumed irrelevance of vehicular weight on slope stability. According to Geo-Logic Associates (2022), "It is recommended that the required minimum static factor of safety of 1.2 be used for slopes with or without haul road access."

The Adaptive Management Plan is Inadequate

As discussed in the section "Summary of Stability Analysis for Rhyolite Ridge Open Pit," the set of preplanned actions ready for execution in response to adverse observations of slope stability consists of the single sentence: "Preliminary concepts for adaptive management actions include suspending mining activity, stopping mining activity and implementing mitigation measures in an area if detrimental instability near sensitive habitat is identified, based on monitoring" (Geo-Logic Associates, 2023). The first concern is the lack of detail in the preplanned actions and the lack of connecting specific actions to particular observations. The need for specific preplanned actions in an Adaptive Management plan (also called the Observational Method) cannot be overemphasized. According to the investigation report on the catastrophic failure at the Mount Polley mine in British Columbia in 2014, "The Observational Method is useless without a way to respond to the observations" (Independent Expert Engineering Investigation and Review Panel, 2015). According to Safety First: Guidelines for Responsible Mine Tailings Management, "There must be a system in place to respond to the observations" (Morrill et al., 2022). The SME (Society for Mining, Metallurgy and Exploration) Tailings Management Handbook warned, "The observational method, since its inception, has experienced definitional and applicational drift, gradually being misused and redefined in a transition from planned change management to a 'make it up as you go' process. This is the paradox. The observational method is intended to leave nothing to uncertainty" (Hatton and van Zyl, 2022). The same handbook reviewed the original formulation of the Observational Method by Peck (1969) with the critical step: "Selection in advance of a course of action or modification of design for every foreseeable significant deviation of the observational findings from those predicted on the basis of the working hypothesis" (Hatton and van Zyl, 2022).

There are implications in Geo-Logic Associates (2023) that specific actions in response to adverse observations will be developed later. Geo-Logic Associates (2023) states, "The majority of the adaptive management plan will be implemented once mining commences to allow for applicable monitoring threshold values and conditions to be established based on the understanding of the quarry stability," which seems to confuse the formulation of the Adaptive Management plan with the implementation of the plan. Geo-Logic Associates (2023) continues, "Responses at Rhyolite Ridge will be developed as experience is gained and a trigger action response plan (TARP) will be developed. This TARP will be developed by the Rhyolite Ridge Technical service group with the support of third-party geotechnical experts (EnviroMine, Dec 2019)." The problem with the later development of the Adaptive Management plan is the lack of a later opportunity for the public to review or to even have knowledge of the contents of the Adaptive Management plan.

The lack of an opportunity for public review of the Adaptive Management plan leads to the second concern, which is the apocalyptic nature of the preliminary plan. The plan as expressed above calls for the cessation of mining activity, either temporarily or permanently, if there is indication of slope instability that could affect sensitive habitat, without any consideration of intermediate steps. At this stage, it is difficult for the public to determine whether the threat or the promise to close the Rhyolite Ridge mine to save the Tiehm's buckwheat is supposed to be taken literally. This threat or promise is found only in an attachment to the DEIS that was written by consultants for Ioneer. The mining company has not stated that they will close the mine to save the Tiehm's buckwheat population. The Bureau of Land Management has not stated they will rescind the mining permit to save the Tiehm's buckwheat population. It is not even clear that Ioneer can close the mine, even temporarily, considering the commitments that have been made or will have been made to other companies. Thus, the public is left in the position of needing to evaluate the status of a claim by a consulting company that there will be a cessation of mining activity in response to an indication of slope instability, but without any corresponding commitment on the part of the mining company.

SUMMARY CONCLUSIONS

The six questions posed in the "Methodology" section are repeated below, followed by very brief responses. More complete responses can be found in the "Responses" section.

1) Are the calculated factors of safety reliable?

No, the calculated factors of safety are not reliable. Although the raw data that were used to develop the geotechnical parameters show considerable scatter, the geotechnical parameters and factors of safety are stated with no uncertainties and there is no sensitivity analysis. No source has been identified for the buttress material, so that the geotechnical parameters for the buttress are purely hypothetical.

2) Was the choice of 1.2 for the minimum factor of safety appropriate for the operational period?

No, according to the Guidelines for Open Pit Slope Design (published by the Large Open Pit Project) and the SME Surface Mining Handbook (published by the Society for Mining, Metallurgy and Exploration), based upon the data uncertainty and the consequences of slope failure, the minimum factor of safety should be 1.5 and the maximum probability of failure should be 5% during the operational period (prior to buttress construction).

3) Was the choice of 1.2 for the minimum factor of safety appropriate for the post-closure period?

No, according to the Guidelines for Mine Closure (published by the Large Open Pit Project), based upon the data uncertainty, the consequences of slope failure, and the pit wall condition, the minimum factor of safety should be 2.0 during the post-closure period (after buttress construction).

4) Was the Zone of Instability for open pits as specified in Western Australian guidelines properly taken into account?

No, the concept of the Zone of Instability was not taken into account at all. Application of the guidelines shows that the minimum separation distance between the quarry and the Tiehm's buckwheat population ought to be 450 feet before buttress construction and 240 feet after buttress construction along the profile where the proposed quarry would be only 15 feet from the Tiehm's buckwheat population

5) Was the assumption that slope materials will remain unsaturated justified?

No, the assumption is not justified. The stability analysis does not consider the hydrogeological and meteorological processes by which the current state of saturation and over-pressurization was achieved, nor does it consider the time period over which re-saturation and re-pressurization could occur.

6) Is the proposed Adaptive Management plan adequate?

No, the Adaptive Management plan lacks any specifics or details. The plan states the mine could be closed in response to an indication of slope instability, although without any apparent commitment on the part of the mining company.

RECOMMENDATIONS

The recommendation of this report is that the geotechnical sections of the Draft Environmental Impact Statement be completely rewritten with special attention to the following:

1) A specific source should be identified for the buttress material with estimation of the geotechnical parameters for that particular source.
2) All of the raw geotechnical data should be presented with a complete explanation as to how those data were used to develop the geotechnical parameters.
3) The Draft Environmental Impact Statement should specify which parameters were developed from data and which were based on judgment. Parameters that were based on judgment should be rigorously defended.
4) The discussion of the geotechnical parameters should include the uncertainty in the parameters.
5) The calculated factors of safety should include the uncertainty, such as the standard deviation.
6) A sensitivity analysis should be carried out in which the factor of safety for each section is re-calculated based on the entire range of reasonable values for the geotechnical parameters, such as the lowest reasonable values for cohesion and friction angle. If the factors of safety vary significantly for the reasonable range of input data, the results should be used with great caution.
7) A sensitivity analysis should be carried out in which the critical failure surface for each section is re-calculated based on the entire range of reasonable values for the geotechnical parameters, such as the lowest reasonable values for cohesion and friction angle. If the positions of the critical failure surfaces vary significantly for the reasonable range of input data, the results should be used with great caution.
8) It should not be assumed that all slope materials will be unsaturated. The factors of safety should be re-calculated for a range of possible pore pressures and water tables, including the

eventual possibility that pore pressures and the water table will return to pre-mining levels. If the factors of safety are strongly dependent upon the assumption that all slope materials will be unsaturated, then the results for unsaturated materials should be used with great caution.

9) The localized re-saturation of slope materials that could result from the surface application of water for dust suppression on the haul roads should be calculated and the potential impact on slope stability should be assessed.
10) The weight of vehicular traffic on the haul roads should be taken into consideration for analyses of slope stability.
11) The distribution of possible values of the factor of safety should be developed for each section, so that the probability of failure can be calculated.
12) The stability analyses should be carried out in accordance with the most up-to-date map for the intended quarry.
13) The Draft Environmental Impact Statement should adhere to the recommendations of Guidelines for Open Pit Slope Design (published by the Large Open Pit Project) and the SME Surface Mining Handbook (published by the Society for Mining, Metallurgy and Exploration) that the minimum factor of safety should be 1.5 and the maximum probability of failure should be 5% during the operational period (prior to buttress construction).
14) The Draft Environmental Impact Statement should adhere to the recommendations of the Guidelines for Mine Closure (published by the Large Open Pit Project) that the minimum factor of safety should be 2.0 during the post-closure period (after buttress construction).
15) The factors of safety and the critical failure surfaces for the post-closure period should be calculated based on reasonable expectations for the rock mass degradation that will occur during the post-closure period.
16) For each section, the Zone of Instability should be calculated according to the guidelines of the Western Australian Department of Industry and Resources. The connecting lines for the geologic units that are at the stratigraphic level of Unit B5 of the Cave Spring Formation or higher should have an angle of 25° with respect to the horizontal. Local and regional outcrops should be investigated to determine whether some geologic units show breakback angles less than 25°, in which case, the connecting lines should be assigned the lower angle for those units.
17) Unless it can be convincingly argued to the contrary, the quarry should be designed so that the Tiehm's buckwheat population is at least 50 feet beyond the Zone of Instability, as specified in Western Australian regulations.
18) The Adaptive Management plan for the response to indications of slope instability should be specific and detailed with intermediate steps that would occur prior to a cessation of mining activity. Any claims that the mine will be closed in response to evidence of slope instability should be supported by a binding commitment from the mining company.

ABOUT THE AUTHOR

Dr. Steven H. Emerman has a B.S. in Mathematics from The Ohio State University, M.A. in Geophysics from Princeton University, and Ph.D. in Geophysics from Cornell University. Dr. Emerman has 31 years of experience teaching hydrology and geophysics, including teaching as a Fulbright Professor in Ecuador and Nepal, and has over 70 peer-reviewed publications in these areas. Since 2018 Dr. Emerman has been the owner of Malach Consulting, which specializes in evaluating the environmental impacts of mining for mining companies, as well as governmental and nongovernmental organizations. Dr. Emerman has evaluated proposed and existing mining projects in North America, South America, Europe, Africa, Asia and Oceania, and has testified on issues of mining and water before the U.S. House of Representatives Subcommittee on Indigenous Peoples of the United States, the European Parliament, the United Nations Permanent Forum on Indigenous Issues, the United Nations Environment Assembly, the Permanent Commission on Human Rights of the Chamber of Deputies of the Dominican Republic, and the Minnesota Senate Environment, Climate and Legacy Committee. Dr. Emerman is the former Chair of the Body of Knowledge Subcommittee of the U.S. Society on Dams and one of the authors of Safety First: Guidelines for Responsible Mine Tailings Management.

Steven H. Emerman

REFERENCES

Adams, B.M., 2015. Slope stability acceptance criteria for opencast mine design: In Ramsey, G. (Ed.), Proceedings of the 12th Australia New Zealand Conference on Geomechanics, Wellington, New Zealand, February 22-25, 2015. 9 p. Available online at: https://www.researchgate.net/publication/279196497_Slope_Stability_Acceptance_Criteria_for_Opencast_Mine_Design

ANCOLD (Australian National Committee on Large Dams), 2012. Guidelines on tailings dams—Planning, design, construction, operation and closure, 84 p. Available online at: https://www.resolutionmineeis.us/sites/default/files/references/ancold-2012.pdf

ANCOLD (Australian National Committee on Large Dams), 2019. Guidelines on tailings dams—Planning, design, construction, operation and closure—Addendum—July 2019, 11 p. Available online at: https://www.ancold.org.au/wp-content/uploads/2019/07/Tailings-Guideline-Addendum-July-2019.pdf

Bureau of Land Management, 2024a. Rhyolite Ridge Lithium-Boron Project—Draft Environmental Impact Statement: DOI-BLM-NV-B020-2021-0020-EIS, April 2024, 230 p. Available online at: https://eplanning.blm.gov/public_projects/2012309/200540745/20108267/251008267/Rhyolite%20Ridge%20DEIS%20-%2020240415_508.pdf

Bureau of Land Management, 2024b. Geology and Minerals—Supplemental Environmental Report—Rhyolite Ridge Lithium-Boron Project, 34 p. Available online at: https://eplanning.blm.gov/public_projects/2012309/200540745/20108274/251008274/05_rr_ser_geology_minerals_20240415_508.pdf

Bureau of Land Management, 2024c. Another GIS file request for Rhyolite Ridge: Email from S. Distel to P. Donnelly (Center for Biological Diversity), May 20, 2024.

Canadian Dam Association, 2013. Dam safety guidelines 2007 (2013 edition), 88 p.

Carter, T.G., P.J.H. de Graaf, J. Dixon, A. Creighton, R. Macciotta, F. Silva-Tulla, and P. Stacey, 2022. Transitioning from mine operations to closure—The dilemma of differing geotechnical design acceptance criteria perspectives: In Tibbett, M., A.B. Fourie, and G. Boggs (Eds.), Mine Closure 2022 (pp. 237-258), Australian Centre for Geomechanics, Perth, Australia. Available online at: https://papers.acg.uwa.edu.au/p/2215_14_Carter/

Darling, P. (Ed.), 2023. SME Surface mining handbook: Society for Mining, Metallurgy and Exploration, Englewood, Colorado, 652 p.

de Bruyn, I., D. Prado, J. Mylvaganam, and D. Walker, 2019. Geotechnical considerations for the stability of open pit excavations at mine closure—Some scenarios: In Tibbett, M. and A.B. Fourie (Eds.), Mine Closure 2019 (pp. 235-248), Australian Centre for Geomechanics, Perth, Australia. Available online at: https://papers.acg.uwa.edu.au/p/1915_19_de_Bruyn/

de Graaf, P.J.H., M. Desjardins, and P. Tsheko, 2019. Geotechnical risk management for open pit mine closure—A sub-arctic and semi-arid case study: In Fourie, A.B. and M. Tibbett (Eds.), Mine Closure 2019 (pp. 211-234), Australian Centre for Geomechanics, Perth, Australia. Available online at: https://papers.acg.uwa.edu.au/p/1915_18_de_Graaf/

de Graaf, P.J.H, G.B. Piteau, T.G. Carter, J. Dixon, and P.F. Stacey, 2021. Geotechnical Guidelines for Open Pit Closure – a new publication by the Large Open Pit (LOP) project: In Fourie, A.B., M. Tibbett, and A. Sharkuu (Eds.), Mine Closure 2021, Australian Centre for Geomechanics, Perth, Australia, 16 p. Available online at: https://www.researchgate.net/profile/Phil-De-Graaf/publication/353859362_Geotechnical_Guidelines_for_Open_Pit_Closure_-_a_new_publication_by_the_Large_Open_Pit_LOP_project/links/6131a9f50360302a00765b1a/Geotechnical-Guidelines-for-Open-Pit-Closure-a-new-publication-by-the-Large-Open-Pit-LOP-project.pdf

de Graaf, P.J.H., G. Beale, and T.G. Carter, 2024. Guidelines for open pit and waste dump closure: In Slope Stability 2024, Belo Horizonte, Brazil, April 14-19, 2024, 18 p. Available online at: https://www.researchgate.net/profile/Phil-De-Graaf/publication/379954290_Guidelines_for_Open_Pit_and_Waste_Dump_Closure/links/6622fbe943f8df018d1c97a5/Guidelines-for-Open-Pit-and-Waste-Dump-Closure.pdf

Department of Industry and Resources (Western Australia), 1997. Safety bund walls around abandoned open pit mines—Guideline: Document No—ZMA048HA, MOSAHAB (Mines Occupational Safety and Health Advisory Board) Approved, December, 1997, 14 p. Available online at: https://www.dmp.wa.gov.au/Documents/Safety/MSH_G_SafetyBundWallsAroundAbandonedMines.pdf

EnviroMine (2019). Stage 1 quarry geotechnical recommendations—Rhyolite Ridge Lithium Boron Project, Esmeralda County, Nevada, Revision 0, September 2019.

Fell, R., P. MacGregor, D. Stapledon, G. Bell, and M. Foster, 2015. Geotechnical engineering of dams, 2nd ed.: CRC Press, 1348 p.

Geo-Logic Associates, 2022. Geotechnical Quarry Slope Stability Report—Quarry TR03-D—Rhyolite Ridge Lithium-Boron Project—Esmeralda County, Nevada: Report prepared at the request of Ioneer Rhyolite Ridge LLC, Project No. AS22.1013, July 2022, Rev. 3, 462 p.

Geo-Logic Associates, 2023. Supplemental Geotechnical Report—Rhyolite Ridge Lithium-Boron Project—Esmeralda County, Nevada: Report prepared at the request of Ioneer Rhyolite Ridge LLC, Project No. AS22.1013, March 2023, 54 p.

Government of Ontario, 2000. Ontario Regulation 240/00—Mine Development and Closure under Part VII of the Act: Made—April 19, 2000, Filed—April 25, 2000. Available online at: https://www.ontario.ca/laws/regulation/r00240

Hatton, C.N. and D. van Zyl, 2022. Chapter 41—Observational method: In Morrison, K. (Ed.), Tailings management handbook—A life-cycle approach (pp. 821-833), Society for Mining, Metallurgy and Exploration, Englewood, Colorado, 1004 p.

ICMM (International Council on Mining & Metals), 2021. Conformance Protocols—Global Industry Standard on Tailings Management, 110 p. Available online at: https://www.icmm.com/website/publications/pdfs/environmental-stewardship/2021/tailings_conformance-protocols.pdf?cb=21097

ICMM (International Council on Mining & Metals), 2024. Our Members. Available online at: https://www.icmm.com/en-gb/our-story/our-members

ICMM-UNEP-PRI (International Council on Mining & Metals-United Nations Environment Programme-Principles for Responsible Investment), 2020. Global industry standard on tailings management—August 2020, 40 p, Available online at: https://globaltailingsreview.org/wp-content/uploads/2020/08/global-industry-standard-on-tailings-management.pdf

ICOLD (International Commission on Large Dams), 2022. Tailings dam safety: Bulletin No. 194, 192 p.

ILA (International Lithium Association), 2024. Members. Available online at: https://lithium.org/members/

Independent Expert Engineering Investigation and Review Panel, 2015. Report on Mount Polley Tailings Storage Facility breach: Report to Ministry of Energy and Mines and Soda Creek Indian Band, 156 p. Available online at: https://www.mountpolleyreviewpanel.ca/sites/default/files/report/ReportonMountPolleyTailingsStorageFacilityBreach.pdf

LOP, 2024. Large Open Pit Project—Open Pit of the Future. Available online at: https://www.lopproject.com/

Macciotta, R., A. Creighton, and D. Martin, 2020. Design acceptance criteria for operating open-pit slopes—An update: CIM Journal, vol. 11, pp. 248-265. Available online at: https://www.researchgate.net/publication/346550905_Design_acceptance_criteria_for_operating_open-pit_slopes_An_update/link/643f7d0b2eca706c8b6b84a0/download?_tp=eyJjb250ZXh0Ijp7ImZpcnN0UGFnZSI6InB1YmxpY2F0aW9uIiwicGFnZSI6InB1YmxpY2F0aW9uIn19

MCA (Minerals Council of Australia), 2024. Our Members. Available online at: https://minerals.org.au/membership-and-benefits/our-members/

McCarthy, M., 2024. Water Rates: MS Excel spreadsheet prepared at the request of Center for Biological Diversity, 1 sheet.

Mining Technology, 2024. Rhyolite Ridge Lithium-Boron Project, Nevada, US: May 15, 2024. Available online at: https://www.mining-technology.com/projects/rhyolite-ridge-lithium-boron-project-nevada-usa/?cf-view

Mohanty, S., J. Friedman, and D. Conover, 2023. Chapter 7—Soil stability, support, and control: In Darling, P. (Ed.), SME Surface mining handbook (pp. 117-139), Society for Mining, Metallurgy and Exploration, Englewood, Colorado, 652 p.

Morrill, J., D. Chambers, S. Emerman, R. Harkinson, J. Kneen. U. Lapointe, A. Maest, B. Milanez, P. Personius, P. Sampat, and R. Turgeon, 2022. Safety first—Guidelines for responsible mine tailings management: Earthworks, MiningWatch Canada, and London Mining Network: Version 2.0, May 2022, 55 p. Available online at: https://earthworks.org/resources/safety-first/

Peck, R., 1969. Advantages and limitations of the observational method in applied soil mechanics: Géotechnique, vol. 19, pp. 171-187. Available online at: https://www.icevirtuallibrary.com/doi/epdf/10.1680/geot.1969.19.2.171

Priest, S.D. and E.T. Brown, 1983. Probabilistic stability analysis of variable rock slopes: Transactions of Institution of Mining and Metallurgy, Section A—Mining Industry, vol. 92, pp. A1–12.

Read, J. and P. Stacey (Eds.), 2009. Guidelines for open pit slope design: CSIRO Publishing, 511 p.

Sengani, F. and D. Allopi, 2022. Accuracy of two-dimensional limit equilibrium methods in predicting stability of homogenous road-cut slopes: Sustainability, vol. 14, 26 p. Available online at: https://www.mdpi.com/2071-1050/14/7/3872

Silva, F., T.W. Lambe, and W.A. Marr, 2008. Probability and risk of slope failure: Journal of Geotechnical and Geoenvironmental Engineering, vol. 134, pp. 1691-1699.

Steffen, O.K.H., P.J. Terbrugge, J. Wesseloo, and J. Venter, 2006. A risk consequence approach to open pit slope design: In Proceedings of International Symposium on Stability of Rock Slopes in Open Pit Mining and Civil Engineering, Cape Town (pp. 81-96), South African Institute of Mining and Metallurgy, Johannesburg, South Africa.

Swan, G. and R. Sepulveda, 2000. Slope stability at Collahausi: In Hustrulid, W.A., K.M. McCarter, and D.J.A. Van Zyl (Eds.), Slope stability in surface mining (pp. 163–170), Society for Mining, Metallurgy and Exploration, Englewood, Colorado, 442 p.

U.S. Fish and Wildlife Service, 2022. Rhyolite Ridge PoO: Email from S. Kulpa (Reno Fish and Wildlife Office) to B.J. Crosby (Bureau of Land Management), 4 p.

Wesseloo, J. and J. Read, 2009. Chapter 9—Acceptance criteria: In Read, J. and P. Stacey (Eds.), Guidelines for open pit slope design (pp. 221-236), CSIRO Publishing, 511 p.

Whitham, R.V., 1984. Evaluating calculated risk in geotechnical engineering: Journal of Geotechnical Engineering, vol. 110, pp. 143-188. Available online at: https://pdfcoffee.com/evaluating-calculated-risk-in-geotechnical-engineering-1984-3-pdffree.html

Wright, A., 2016. A common-sense approach to mine closure design in the remote Western Australian interior: In Fourie. A.B. and M. Tibbett (Eds.), Mine Closure 2016, Australian Centre for Geomechanics, Perth, Australia. Available online at: https://papers.acg.uwa.edu.au/p/1608_47_Wright/