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October 15, 2022

Eric Scott
Colorado Division of Reclamation, Mining, and Safety
1313 Sherman St, Rm 215
Denver, CO 80203

Delivered Via Email

RE: Black Obsidian Pit M-1987-026

Mr. Scott:

On behalf of Colorado Quarries – the operators of the Black Obsidian Pit ("Black Obsidian") – please allow this letter and associated attachments to serve as response to your July 27, 2022 email addressed to Bob Oswald. This response also serves to address geotechnical issues are identified in the Division's Adequacy letter dated April 3, 2022.

The obsidian deposit with the pit is a generally competent, though highly fractured, rock mass. Obsidian is a strong (uniaxial compressive strength >4500 psf) but brittle material that is best analyzed for stability in the same manner as igneous rocks found in many quarries. Typical slope stability analysis of soils such as Bishop's Method of Slices is inapplicable. As such, the Factor of Safety at the Black Obsidian Pit is not directly calculatable via traditional methods as a relationship between slope material strength and stresses. Such a calculation would yield safety factors of an unreasonably high value due to the internal material strength of obsidian alone. For this reason, the stability of the slopes at Black Obsidian are based on the following factors:

1. Bench orientation with respect to kinematic analysis
2. Sufficient bench width to accommodate nodules
3. Nodule stability

1. Bench Orientation

Bench orientation, i.e. the strike of the vertical portion of a bench, is determined by conducting a kinematic analysis of the rock face itself. Cesare, Inc. conducted this analysis in their June 2022 report and determined that a bench orientation within 20° of the current bench face would be stable and not intersect the identified joint sets in a manner that would risk a large wedge failure of the bench face.

Three main joint sets were identified by Cesare and can be seen below (Table 1) along with the strike and dip of the bench face for the roughly east-west highwall and the roughly north-south highwall. Only one joint set, the tertiary, is within 20° of any highwall bench face strike and dips less than the bench face dip. This angle orientation relative to the mining bench configuration shows that toppling failure risk is very low.

Wedge failure is determined by the presence of intersecting joint or fracture sets. Cesare evaluated the identified structures within the Black Obsidian bench faces and determined that no large-scale wedge failure could be identified. Many small wedges may form (~2 ft. long) due to the intersection of small fracture sets, but such small wedges are anticipated in any hard rock highwall. Such small local break off of highwall material is managed by maintaining sufficient bench with. This is addressed under section two.

Table 1. Joint Sets and Bench Orientations

Joint Set	Strike	Dip
Primary	240	77 to 82
Secondary	150	83 to 87
Tertiary	70 to 74	44 to 49

Highwalls	Strike	Dip
East-West Highwall	95 to 110	70 to 85
North-South Highwall	200	60 to 65

2. Bench Width and Nodules

The Modified Ritchie Criteria is a useful initial guide based on empirical data for bench width versus bench height. It is considered conservative in the mining profession.

$$Bench\ width\ (ft) = 0.2 \times Bench\ Height + 15\ ft$$

The Modified Ritchie Criteria sets a minimum bench width of 15 feet, given the varied highwall heights (30-120 ft) the bench width can also vary (21 to 39 ft). At Black Obsidian there are additional driving features the dictate the minimum bench width: the small obsidian pieces that can break off the highwall (~2 ft) and the rhyolitic nodules found with the obsidian. The small obsidian pieces created by local fractures are easily accommodated by the 15-foot bench. The nodules can vary in size dramatically and have been observed to be as large as 8-feet in diameter. Benches should be large enough to handle a nodule that falls as well as the backbreak caused by nodule removal. For this reason, at least 20-foot-wide benches should be maintained onsite, thus capable of accommodating bench spill in the form of a nodule itself as well as the backbreak caused by a nodule fall.

3. Backbreak Extents

Hard rock highwalls typically see localized weathering and break-off as portions of the bench face as part of mining that will lead to the actual bench face being different from the design bench face. The horizontal distance between the original design bench crest and the final bench crest is known as backbreak. Using drone topography of the existing quarry, several examples of backbreak were identified along Black Obsidian's highwalls. Backbreak is important as it must be accommodated in the total design bench width: i.e., a bench must be wide enough to accommodate backbreak without ending up to narrow.

Using the October 2022 acquired topographic data, profiles through the highwall were run and evaluated for backbreak; the attached Profile Map shows these profiles. Backbreak is highly varied on this site as it is almost completely a factor of nodule removal from the highwall. The bench width minimum of 20-ft is selected to accommodate nodules on the bench and also allows for a large nodule to be removed from the bench top and still retain sufficient bench width to catch another nodule.

The bench face angle onsite has been roughly 70°. The Cesare report does not identify any wedge or planar failure that would make that bench face angle unsuitable going forward. Therefore, the Black Obsidian Pit will continue to use a roughly 70° bench face angle without incurring additional risk.

4. Nodule Stability

Given that the nodules vary in size but are consistently round, a maximum percent of nodule that can project from the highwall safely needs to be determined. Figure 1 shows a simplified example of a safe projection (a) and an unsafe projection (b). The analysis of moments is used to determine maximum allowable projection.

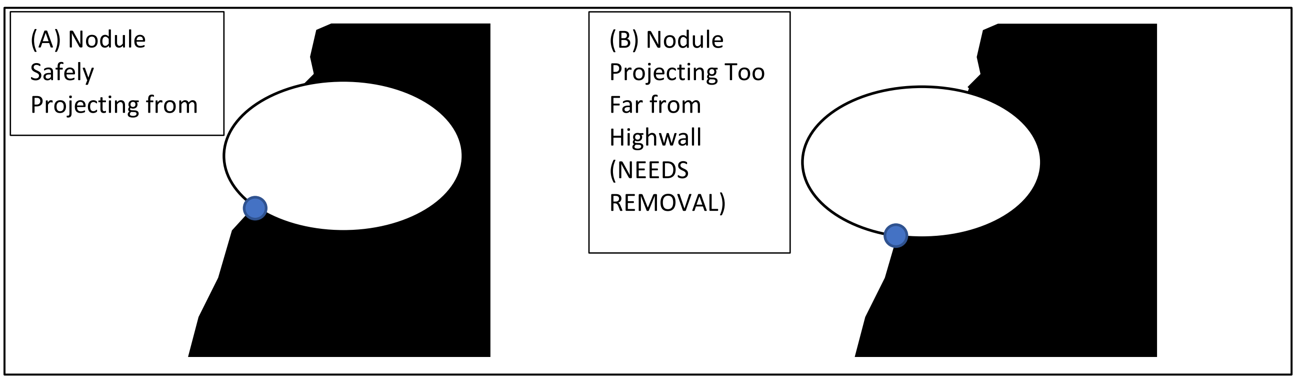

Figure 1. Nodule Projection Example

The rhyolitic nodules that occur within the deposit at Black Obsidian are at risk of falling from the highwall when the amount of nodule that is projecting from the highwall creates a net moment of overturning on the nodule greater than the nodules resisting moment. To further ensure safety, a safety factor is applied to the analysis of moments:

$$M_r \geq SF_o M_o$$

M_r is the resisting moment, SF is safety factor, and M_o is the moment of overturning the nodule. The weight of the nodule drives both the resisting moment and the overturning moment; cementation within the obsidian is ignored for simplicity and to make the analysis more conservative. The safety factor is assumed to be 1.3[1]. The question is, at what portion of nodule projecting from the highwall is the overturning moment created that would overcome the resisting moment, including the factor of safety? Conversely, how much nodule must be within the highwall to prevent the nodule from falling out? The two opposing moments are analyzed at the minimum safety factor of 1.3 (Figure 2.

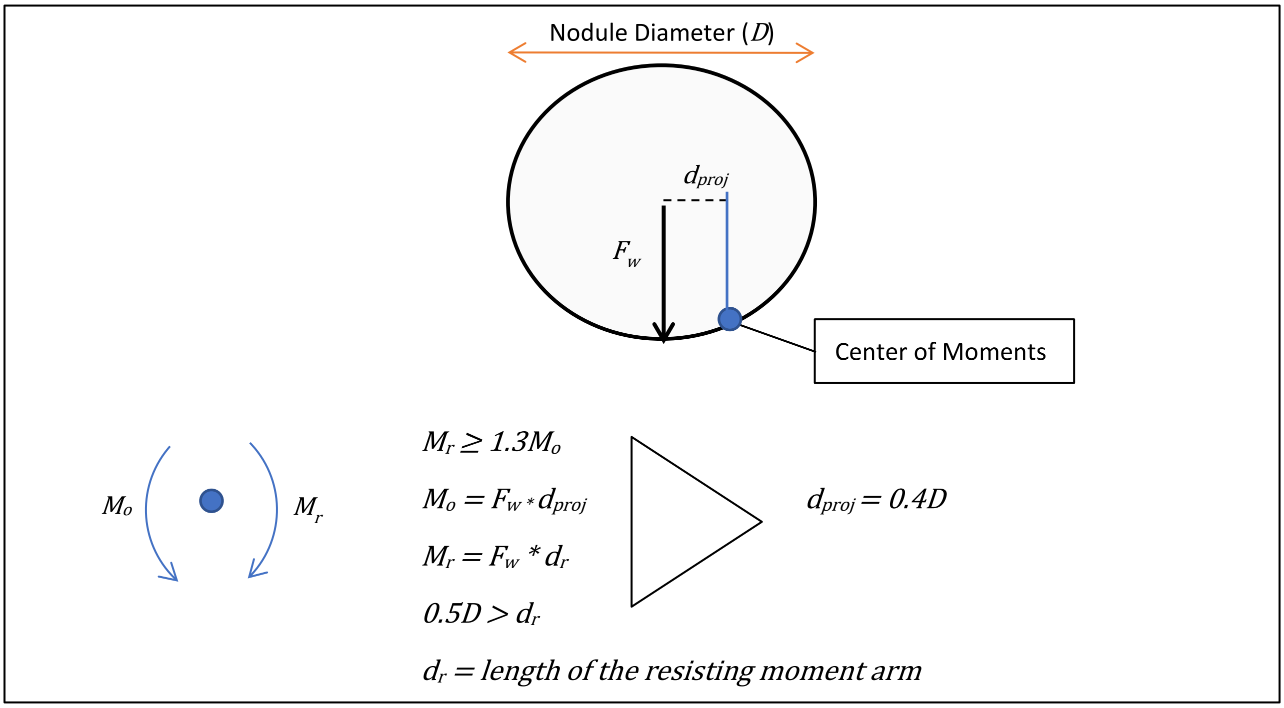

Figure 2. Sum of Moments on Nodule

The analysis gives us a projection limit of 0.4 times the diameter, or roughly 40%. Any nodule that projects more than 40% from the highwall should be removed mechanically to prevent rock fall from said nodule. This can be determined by operators with a simple visual check of nodules in the highwall, given that most nodules are 8 feet in diameter or less, more than 3 feet of nodule projecting from the highwall most likely means the nodule is ready for removal.

[1] 1.3 is a standard engineering factor of safety.

5. Conclusion

There are two slope stability scenarios that were evaluated in this report: first, the mining high wall condition and second, is the permanent highwall left in reclamation. The mining highwall scenario needs to maintain sufficient stability to ensure safety and prevent major slope failures during operations. Permanent stable slope must provide long term slope stability and facilitate other components of reclamation like revegetation. Based on the analysis in this report and the Cesare report, the following slope conditions should be maintained in each condition based on these criteria.

Table 2. Stable Slope Criteria

	Mining Conditions	Reclamation Conditions
Bench Orientation	95 to 110 for East-West highwalls; 190 to 210 for North-South highwalls	95 to 110 for East-West highwalls; 190 to 210 for North-South highwalls
Minimum Bench Width	20-ft	20-ft
Overall Slope Angle Limit	0.8H1V	2H:1V
Bench Face Angle	~70°	~70°
Nodule Projection Limit	40% of diameter	N/A

The lower overall slope angle limit in the permanent condition is to facilitate successful revegetation by supporting any backfilling and topsoiling conducted onsite. All nodules that need removal will be removed during mining. Using the current highwall toe at the quarry bottom, the final highwall extent is shown on the Profile Map.

Please do not hesitate to contact me with questions and we look forward to receiving the Division's review of this submittal.

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Attached:

Profile Map