24-001

A Case Study: Successfully Managing Excessive and Rapid Slope Deformation in an Open Pit Mine Utilizing Slope Monitoring Radar Systems

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ABSTRACT

Maintaining stable high walls can be a challenging task. Complex geological and structural features, alteration zones, rock mass properties, and hydrogeological conditions must be well understood to design a safe mining environment. Economic considerations must also be taken into account as the mine operator must provide ore deliveries and protect reserves. However, even when good engineering practices are followed, and proper blasting and mining techniques are implemented, slope movements may still occur.

When these slope instabilities are minor, the mine is often able to continue operations with minimal impacts on safety or production. When these occurrences are excessive and coupled with high rates of movement, a robust monitoring system is crucial to continuing mining activities while protecting personnel.

This paper summarizes the approach an open pit mine in Nevada took as excessive and rapid high-wall movement was experienced in an integral area. Creative mining approaches, combined with slope monitoring radar technology, were utilized to maintain safe and successful mining activities despite active movement that exceeded an average velocity of 30 inches per day.

INTRODUCTION

The mine is located in eastern Nevada, and is a complex copper porphyry deposit. The location has been intermittently mined since the late 1800s, with the current company operating the site since the mid-2000s. The property comprises several open pits, at various stages of operation and closure that are mined by the conventional method of blasting and truck haulage to a processing plant (Yang, 2016).

One of the open pits on the property experienced significant and constant high-wall instabilities on the North, East, and South highwalls from 2013 to 2020. During this six-and-a-half-year period, observational methods, terrestrial radar monitoring, and responsive creative mining approaches allowed the mine to successfully extract approximately 80 million additional contained pounds of copper from the pit beyond what was planned.

GEOLOGICAL AND GROUNDWATER BACKGROUND

The mine is developed in a structurally complex porphyry copper deposit. Following the main stages of copper mineralization, the quartz monzonite porphyry crystallized and was affected by meteoric water resulting in pervasive argillization. The rock mass was fragmented by normal faulting

Figure 1. Visual comparison of the different alteration grades on core samples (Yong, et al, 2022).

followed by uplift, oxidation, erosion, and mineral enrichment (Yong, et al 2022).

Faulting is significant at the mine and generally delineates the geological and geomechanical domains of the pit. The fault zones are characterized by extremely fractured and/or altered rock that is often clay-rich with RQD values near zero. Three main joint sets can be identified from investigations and generally include a sub-horizontal set and two dipping (25-degree and 55-degree) towards the east (Yong, et al, 2022).

The rock mass domains of the pit are comprised of six main lithologies and two alteration grades. The six units include porphyry (intrusive), limestone, sandstone, shale, rhyolite (volcanic), and fault zones. Significant degradation of the rock mass quality and strength are attributed to phyllic, argillic, potassic, propylitic, and gossan alteration or Grade (i), with examples shown in Figure 1. The second alteration Grade (ii) has little adverse impact on the rock mass quality or strength and represents unaltered rock. Figure 2 illustrates the alteration grades and known faults in the 2016 open pit (Yong, et al 2022).

Numerous slope instabilities at various locations in the open pits have occurred because the pit walls were comprised of highly altered and fragmented weak rock mass of the Monzonite Porphyry, Rib Hill Sandstone, and Chainman Shale units.

The pit has high pore water pressures located in the northern, eastern, and southern high walls, although the highest pore water pressures are seen in the lower walls of the pit.

The northern wall is comprised of low permeability material, including faults, shales, and bedding planes. Seeps have been observed but were generally located on the lower benches of the pit. It was observed that pore water pressures lagged significantly behind the pit dewatering activities.

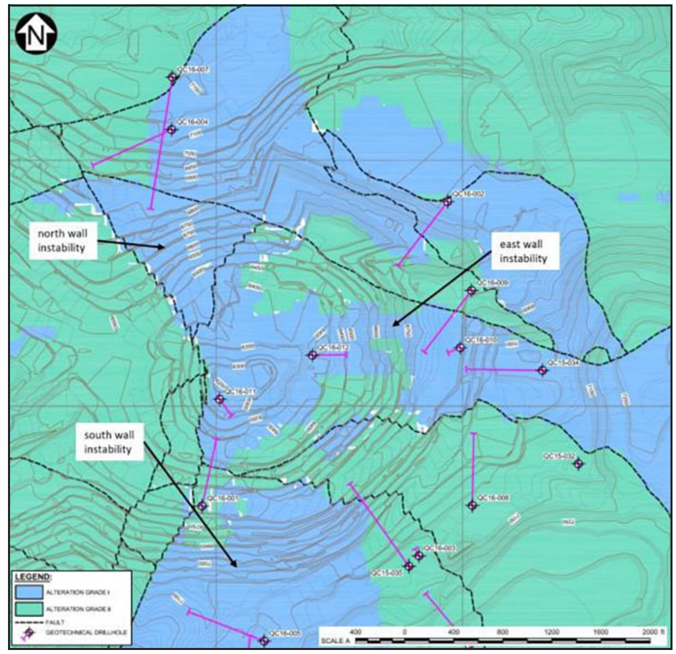

Figure 2. Map of the entire pit indicating the two different alteration grades (Yong, et al, 2022).

The southern and eastern walls were also comprised of low permeability materials, although to a lesser degree than the northern wall. This is likely due to less faulting, and fewer adverse bedding planes located in the high-wall. Additionally, a historic canyon existed behind the southern and eastern wall but had been backfilled with dump material. However, this geological feature is likely still funneling meteoric and groundwater towards the pit.

Aggressive pumping of the standing water in the pit, horizontal drains, and diverting surface water run-off were utilized to manage and reduce the impact of water in the pit.

MINING SEQUENCE AND SLOPE PERFORMANCE

The mining company started developing the pit in early 2012. The northern wall was originally developed with an inter-ramp angle of approximately 37 degrees. The Factor of Safety (FOS) for the high wall was considered marginally stable at about 1.1–1.2. This was expected to drop if the wall could not be successfully depressurized from groundwater.

By late 2012, tension cracks were observed in a haul road located directly above the north wall. A dewatering well also had to be abandoned in the area due to the ongoing slope deformation. Slope monitoring radar registered that the northern wall had an average velocity of about 2 inches per day.

Mining continued in this pit throughout 2013 and 2014. The northern wall continued to degrade, with the

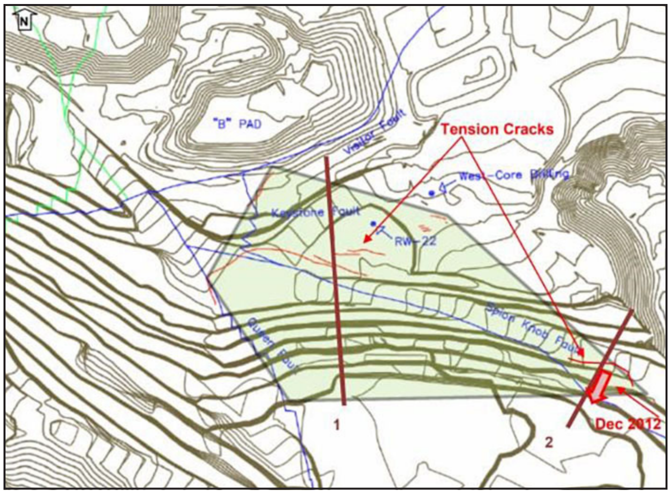

Figure 3. Topographic map of the 2012 northern wall, with indications where tension cracks were observed (Yang, 2013).

aggressive 37-degree interramp angle, rapid removal of material at the toe, and continued high pore water pressures.

By July 2014, the northern wall had an average velocity of about 0.5 inches per day, with higher velocities being observed near a western bounding fault. A third-party consulting group estimated the average FOS for the area to be about 1.08.

Due to the development of tension cracks at the base of a historic leach pad, the mine made the ultimate decision to relocate the contents to avoid any environmental hazard a slope deformation may cause. This was completed in 2014.

In February 2015, a slope movement occurred on the eastern wall of the pit due to high pore water pressures, saturated toe, and very weak rock masses. The mine initially mitigated the area by dozing down the loose material, but the mass had eventually shifted again by April of the same year.

In 2016, the mining sequence resulted in the necessary placement of a haul road across the northern wall instability, with mining activities also being held at the toe of the same wall. During this year, the northern wall displaced approximately 300 feet, created a scarp of about 150 feet in height, and had ongoing average velocities that ranged from 4 to 33 inches per day. This amount of movement became too much for safe access, and mining activities were temporarily halted in the pit by the end of 2016.

Mining did not resume in this pit until 2018 when the haul road was re-established across the north wall instability. At this time, the typical movement rate for the failing mass was about an average velocity of 2 inches per day.

This increased to above 10 inches per day as mining resumed against the toe of the north wall.

The mining company was able to successfully continue operations in this pit through 2019 despite the continuous

Figure 4. Photograph showing the high-wall movement on the eastern side of the pit (Yang, 2015).

Figure 5. Photograph of the northern wall taken in 2020. Backfilling operations were started to buttress against further movement.

slope deformations by implementing slower mining rates and allowing the deforming slopes longer times to settle between events.

The pit was successfully completed in early 2020. A total of 80 million additional contained pounds of copper were safely extracted from this pit. No personnel were injured, and no equipment was damaged during the mining operations of this pit.

SLOPE MONITORING

Mining activities with such active high walls would not be possible without critical slope monitoring devices and methods in place. This section will outline the three key approaches that the mine operator used to successfully complete the pit.

Prism Array

From 2011 to mid-2012, the mine utilized a total station and prism array to monitor the high walls in the pit. These prisms were installed on all the walls at regular distances to provide continuous displacement monitoring. Additional prisms were installed along the north haul road as well.

The prisms were monitored via two robotic total stations (RTS) that were controlled remotely. The RTS units were housed in a climate-controlled shack and all data was able to be remotely viewed and assessed. The software used with this setup also provided the ability to create alarms should movement thresholds be reached.

However, the prisms did not perform well in an environment with rapid and constant slope deformations. Prisms were routinely lost due to rock fall strikes or failing benches. Replacement of lost prisms was not usually possible due to no safe access points for personnel.

In 2012, it was decided that a more robust monitoring device was needed that would not require personnel to enter failing areas.

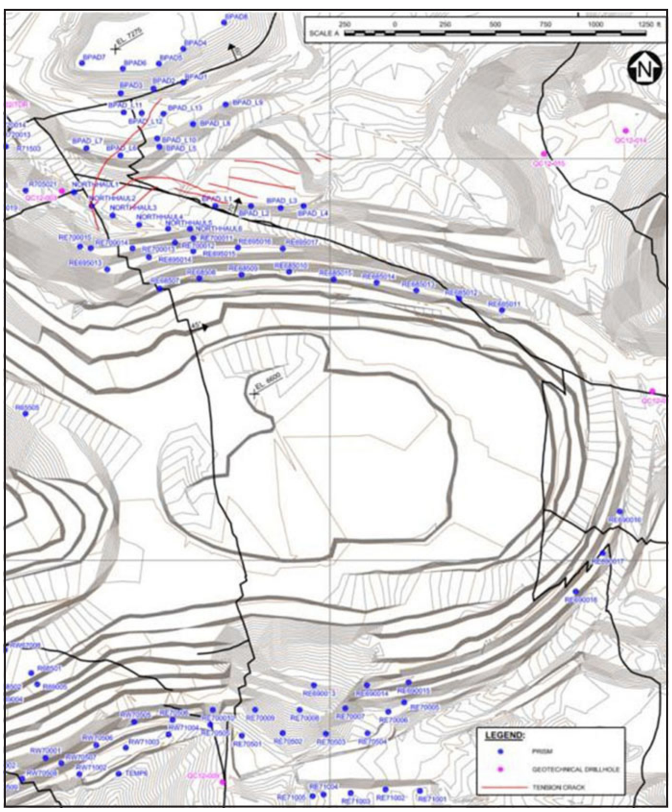

Figure 6. Topographic map indicating prism locations throughout the pit (Yang, 2013). ***Slope Monitoring Radar***

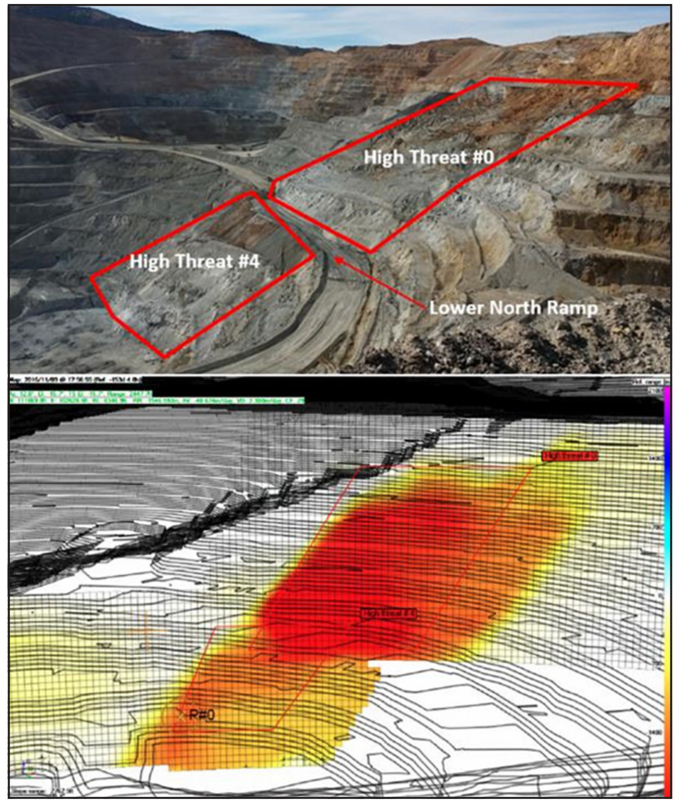

Figure 7. Screenshot of heat map created by the slope monitoring radar unit (Yong, et al, 2022).

In 2012, the mine purchased a slope monitoring radar unit. The unit was mobile, had the ability to run via an onboard generator or be tied into an existing electrical power supply, and did not need targets or prisms installed on the high wall.

One advantage of the radar unit was that it would display exactly what sections of the high wall showed movement. This was key in both determining where mining activities could or could not be performed, but also aided the Geotechnical Department in determining which, if any, faults, or structures could be involved in the movement.

A second advantage of the radar unit was the speed at which it could scan the high walls and provide the latest information. On average, the radar unit would scan about half of the pit in about five minutes. This was a huge improvement over the prism array, which would only be able to scan every 30 to 40 minutes.

The software associated with the radar unit allowed the Geotechnical Engineers to set up tighter alarms for areas showing movement. The software was also flexible, enabling the use of multiple alarm areas within the same scan region. This tailored approach meant that appropriate alarms could be added to each individual area, without the need to apply a single, overly conservative value to the entire pit.

One of the key features that the radar unit offered was the ability to see small, but potentially important changes or shifts in the high-wall movement. Utilizing the charts in the software, the Geotechnical Department could see in real-time increases in average velocity, and velocity delta, and monitor any changes to the relative range (distance from the slope to the radar unit). Due to the extreme sensitivity of the high walls to any increased precipitation and mining activities within the pit, the Geotechnical Department quickly adopted a protocol that relied heavily on interpreting the small changes seen in the radar data.

With near-constant movement, the velocity delta chart proved to be the most reliable way to predict when the moving mass was changing into a progressive failure. Tight alarm thresholds were placed around the velocity delta, and strict protocols for those working in the area were developed. This included cessation of mining activities, removal of equipment and personnel from the area, or the closure of the haul road into the pit should alarms be received.

Observational Methods

The ongoing and dynamic nature of the slope movements experienced in this pit meant that a more hands-on approach to slope monitoring was required throughout the pit mining operations. In-field assessments were crucial to understanding the wall performance and keeping personnel safe.

The Geotechnical Department of the mine routinely performed visual inspections of all areas of movement within the pit, as well as the condition of the haul road. Any changes found were noted and shared with the rest of the engineering team as well as Mine Operations. New tension cracks were painted bright orange, and GPS coordinates were taken to mark their location. Pieces of lathe were often used as makeshift extensometers to help gauge tension crack growth.

The Pit Supervisors were also encouraged to report any changes they observed in the high-walls or haul road during their shift to the Geotechnical Department. When a report or concern was received, the area involved was visually inspected by a Geotechnical Engineer. If the area was not able to be inspected due to weather, or darkness, the area was bermed off and the inspection occurred as soon as it was daylight or the weather cleared. Mining activities could be halted even without an active radar alarm.

Effective communication and building trust with the Mine Operations department was key in successfully using the observational method. The Geotechnical Group benefited from the additional 'eyes on the wall' that the Pit Supervisors provided. In turn, the Pit Supervisors understood that the Geotechnical Department would take their concerns seriously to keep their personnel safe.

CREATIVE MINING

Traditional mine planning and removal techniques were not effective in an open pit that had such active and changing high walls. This forced the mine to adopt creative mining methods to both manage the high walls and provide a safe and productive working environment.

Both the mine planners and pit operators had to be open and flexible to frequent mine design changes and had to be comfortable making 'on the fly' and 'field fit' decisions to avoid equipment idling and to keep the progression of the pit on track to forecast.

North Haul Ramp Maintenance

Due to pit geometry and ore body restrictions, the only viable access into the pit had to cross the northern wall instability. This meant that safe access had to be maintained despite the road being subjected to average daily velocities that ranged from 2 to 33 inches per day.

Initially, maintenance of the haul road only required tension cracks or soft spots to be repaired weekly, or bi-weekly. Repairing the cracks involved a dozer or grader ripping the ground as deep as possible, and then blading over the area. This not only provided a smoother running surface but also sealed the cracks from channeling any surface water into the failure mass.

As mining progressed in the pit, the average velocity increased on the haul road. This caused the road to slump and become steeper than originally designed. When the road became too steep for haul traffic, additional material was dumped in, and the road was rebuilt back to a 10 percent ramp.

Eventually, this method became ineffective as well. During the life of the pit, the entire haul road was dozed down to an angle of repose that matched the high-wall, and additional material was brought in to completely rebuild the section of road that crossed the failing mass several times. Each time this mitigation was performed, the haul road would have a limited time before it was necessary to repeat. Towards the end of the pit, major dozing activities were occurring on the road every day to maintain safe access.

Before each mitigation was performed on the haul road, data from the radar unit was analyzed to determine if the high wall was indicating a progressive failure mode. The radar data was also closely watched during each mitigation to ensure that the activities were not further damaging the wall or causing the failing mass to accelerate.

North Toe Removal

Removal of material against the base of the northern wall proved to be challenging as the north wall instability became quite sensitive to any removal of material. The mine used several different tactics to overcome this obstacle.

In 2016, the mine implemented a fast-paced mining method against the toe of the north wall. This essentially meant that Mine Operations would remove as much as possible, and as quickly as possible, and then retreat to allow the wall to settle. While this method worked, it would negatively affect the upper slope stability. This resulted in periods where no mining occurred as the high wall had to settle, slow down, and de-accelerate. However, the average velocity would continue to increase. By the end of 2016, the mine had to repair the haul road daily, and the area had an average velocity of about 33 inches per day. This was deemed too excessive, and mining activities were halted.

When the mine resumed activities against the north toe in 2018, the mine implemented tactics that maintained a manageable average velocity rate of the highwall and haul road. Previous radar data from 2016 showed that deformation of the upper slope and haul road would be manageable if the average velocity could be maintained at equal to or less than 15 inches per day (with no acceleration). To achieve this, mining decisions were heavily based on what the radar monitoring was indicating. If the average velocity remained constant and within the accepted parameters, no changes were made to the mining activities in the pit. However, once an unacceptable change was discovered, both the engineering team and Mine Operations reacted quickly to adjust.

Adjustments made included periods of extremely slow mining, where a maximum of 25,000 tons were removed per day from the pit, periods where the tonnage rate was as fast as possible, specific placement of the shovel in the dig face, or even pulling out all operations and letting the pit 'rest'. At times, multiple types of adjustments were used within the same 24-hour period to maintain the desired average velocity. These tactics were implemented until the pit was successfully completed in 2020.

CONCLUSIONS

Successfully managing rapid and excessive slope deformations would not be possible without state-of-the-art radar slope monitoring devices and a team of engineers and operators who are willing to think outside of the box when it comes to mine design and implementation.

Creative mining methods and discussions surrounding acceptable risks should be brought to the table when a mine is facing challenging slopes and traditional approaches are not working.

This mine proved that by applying radar slope monitoring with creative mining methods in areas with extreme deformation, an actively deforming high-wall and haul road could be maintained so that personnel and equipment could have safe access. This unique approach to mining resulted in approximately 80 million additional contained pounds of copper being produced from the pit, with no injuries to personnel or equipment.

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24-002

A History of Gold Mining in Oatman & Gold Road, Az

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INTRODUCTION

Gold-bearing outcrops were discovered in 1862 by Union soldiers garrisoned at Needles, CA, near the northwest corner of the future State of Arizona. Sporadic mining began several years later, but engineered shaft sinking and mill construction were not adopted at Oatman and the neighboring camp of Goldroad until about 1900. Geological interpretations in 1915 enabled major production during the next decade. In the late-1930s, USSR&M built a new mine and mill in Gold Road and the District flourished until closure by Federal Order L-208 in October 1942. For about a decade, Oatman's mines were among the largest gold producers in the American West.

1850–1862

The following historical context was published by Donnell. The Territory of New Mexico was an incorporated territory of the United States from September 9, 1850, until New Mexico Statehood on January 6, 1912. The Territory of Arizona was a territory of the United States from February 24, 1863 until Arizona gained statehood on February 14, 1912.

Tensions between Mexico and the United States and the United States' need for a southern railroad route to California led to the Gadsden Treaty, or so-called “Gadsden Purchase.” This agreement, finalized in 1854, resulted in acquisition of the southern portions of the New Mexico Territory.

When the Civil War officially began on April 12, 1861, turmoil resulted almost immediately in the New Mexico Territory as the Confederacy moved to claim part of the region. Motivations included access to mineral resources and a secure route to California where it was believed that sympathizers could be enlisted.

In July 1861, Jefferson Davis authorized Gen. H. H. Sibley to march to Fort Bliss and take over New Mexico Territory. There were a few skirmishes: The Battle of Glorietta Pass east of Santa Fe, March 26–28, 1862, was won by the Union, but the Confederacy won the brief fight at Picacho Peak north of Tucson on April 5, 1862. The matter was settled on July 8, 1862, when the Fifth California Volunteers led by Gen. J. H. Carleton drove the Confederates from the New Mexico Territory.

1862–1896

It was during Carleton's occupation of New Mexico Territory that gold was discovered in 1862 in what was initially named the San Francisco mining district. Many of the soldiers were experienced miners from the eastern US and they relieved the monotony of garrison duty by prospecting, as reported by Ransome. At the time of Ransome's survey (1922), a “dozen or more” stone cabins reportedly built by Carleton's troops remained on Silver Creek, about 4 miles north of the future town of Oatman.

Around 1863–64, John Moss discovered free gold in an outcropping vein one mile north of Silver Creek. Moss may have recovered as much as $240,000 (about 11,600 ounces). $20.67) from a pocket near the surface, but extensive subsequent development on the vein was disappointing.

Figure 1 is a map of Arizona showing the location of the Oatman district as a blue rectangle (not to scale) near the western edge of the state on old Highway 66. The district measured roughly 7 miles wide by 10 miles long in a north-south direction. It was 20 miles from Needles,