Managing Pit Slope Stability at the Kemess South Mine - Changes over Time

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Abstract

The Kemess South Mine is located in north-central British Columbia. The open pit mine has operated continuously since 1996 and closed in early 2011 after approximately 14 years of operation. The mine successfully managed various pit slope stability issues by applying a range of techniques over this period.

Initial slope stability work focused on obtaining a better understanding of the pit wall geology and the geomechanical characteristics of each of the geomechanical domains. On-going structural mapping, refinements to the geological model and appropriate stability analyses allowed for timely modifications to the pit slope design.

As mining progressed, and as knowledge of the rock mass increased, potential slope instabilities were categorized by dominant failure modes, including those attributed to adverse structures, high water pressures, degradation of certain rock units over time and unfavourable wall geometries. Increased knowledge of the factors influencing slope performance allowed for more focused adjustments to the pit slope geometry and the implementation of low-damage controlled blasting and slope de-pressurization.

Near the end of mine life, the performance characteristics of each geomechanical domain were well understood and many of the instabilities were anticipated. Since major modifications to the slope geometry were no longer possible, the risk management strategy became increasingly dependent upon slope monitoring and the implementation of appropriate operational protocols. Provisions employed by the mine included: constructing rock fall protection berms, mining only during daylight hours in critical areas, using slope stability radar, increasing the number of monitoring prisms, implementing visual pit inspections and improving work force awareness.

The Kemess South Mine is a good example of how pit slope risk management strategies need to evolve as mining progresses and how the tools employed must allow for changes in mining flexibility and differing economic realities over time.

1 Introduction

The Kemess South Mine is located 250 km north of Smithers, British Columbia. The copper-gold porphyry open pit mine has operated since 1996 and closed in early 2011. At the end of mine life, the open pit had a footprint of 1.1 km by 2 km and reached a maximum depth of approximately 350 m (Fig. 1). The average production rate was 50,000 tpd throughout mine life and it produced an average of 250,000 to 300,000 ounces of gold and 65 to 75 million pounds of copper annually. Knight Piésold has provided on-going geotechnical support to the Kemess South open pit operations since 2000.

During the mine life, the Kemess mine staff successfully managed a variety of pit slope stability issues by applying a range of techniques. As the pit matured, the techniques employed evolved to be consistent with
changes in mining flexibility and in economic realities. This paper summarizes some of the slope stability issues encountered during pit operation. Case examples have been selected from each phase of the mine development (i.e., early, middle and late) to help demonstrate how the employed risk management strategies changed over time. Unless otherwise noted, the content of this paper has been taken from internal Knight Piésold reports that were produced for the use of Kemess Mines.

2 Background

Early geotechnical investigations suggested that the pit walls would be mined within four major rock units, each of which formed a separate geomechanical domain (as below and shown on Fig. 2):

- Toodoggone Tuff, which formed the South Wall and the southern portion of the West Wall.
- Quartz Monzonite Intrusives, including the Leach Cap, Supergene and Hypogene sub-units, exposed in the lower portions of the pit walls.
- Asitka Sediments, exposed along the North Wall and bounded by a southerly dipping fault to the south.
- Takla Volcanics, bounded by a flat lying basal fault at pit bottom.

The site investigation results suggested that the average rock mass quality was in the FAIR to GOOD range (i.e., RMR=50 to 65). Clay seams were found within the Asitka Sediments unit and potential planar instability was recognized in the North Wall due to adverse orientations of the bedding. During mine development an Epiclastic version of the Toodoggone rock mass in the northwest corner of the pit was also encountered, which proved to be particularly weak and sensitive to moisture.

Several large-scale structural features were recognized during mine development, including:

- An east-west trending North Boundary Fault (NBF) dipping at approximately 55 degrees to the south with an average thickness of 5 to 15 m. The fault runs the length of the pit near the toe of the North Wall.
- A north-south trending West Block Fault (WBF) dipping approximately 60 degrees to the east. This feature runs behind the West Wall.
- Two minor faults running parallel to one another and nearly perpendicular into the North Wall.

Figure 2. Updated pit wall geology based on initial pit design. The limits of the initial failure within the Epiclastic Toodoggone are shown.

Initial pit slope designs concluded that planar and wedge failures would control slope performance and that achievable inter-ramp angles would likely be between 40 and 48 degrees. Due to the economic constraints in the late 1990s, Kemess Mines decided to reduce stripping costs by developing 47-degree inter-ramp slopes for all the pit walls. This approach, while creating some stability challenges, deferred some of the initial capital costs and helped to ensure the viability of the operation during a period of low commodity prices.

3 Early Phase

In the early stages of mining (from 1996 to 2002), the focus was on reducing the likelihood of failures by refining the recommended slope configurations and by collecting additional geomechanical and hydrogeological information.

Geotechnical activities focussed on refining the spatial extents and characteristics of the geomechanical domains identified during the feasibility study. For the first time, mining scale rock mass performance observations were possible along the exposed pit walls and initial impressions for the controlling rock mass characteristics could be confirmed. The North Wall was the focus of many of the geotechnical investigations undertaken during this phase of the mine development.
The Asitka Sediments made up a significant portion of the North Wall and there were stability concerns associated with the clay layers and the orientation of the bedding. In order to gain a better appreciation for the characteristics of the Asitka Sediments and their impact on wall performance, a geotechnical site investigation program was conducted. The program included wall mapping along the North Wall, oriented core drilling, permeability testing, piezometer installation and laboratory testing.

The data collected during the site investigation program made it possible to better characterize the Asitka Sediments unit. This program suggested that the overall dip of the Asitka bedding varied, but was close to 45 degrees. The nature and thickness of the inter-bedded clay zones varied from medium stiff argillite up to 5 cm to soft, weak gouge of less than 1 mm. The laboratory direct shear tests suggested that the friction angles of the argillite infilled fractures ranged from 38 to 43 degrees. The overall rock mass properties of the Asitka Sediments could be represented by Hoek-Brown parameters including intact rock strength=35 MPa, $m_i=15$, and GSI=50.

With a refined understanding for the Asitka rock mass, slope stability analyses were undertaken using both limit-equilibrium (SLOPE/W - GEO-SLOPE, 1999) and distinct element modelling (UDEC - Itasca, 2000) approaches. The UDEC models were used in both back analysis and predictive modes with the main objective of better understanding the role of the clay seams and their influence on future slope performance. The SLOPE/W models were used in conjunction with the UDEC models to give insight into the effects of slope depressurisation.

The UDEC back-analyses focussed on estimating the shear strength of the Asitka bedding since the slope had yet to fail along the North Wall. The modelling results supported the assertion that the bedding friction angle was greater than 40 degrees. The calibrated strength properties were then used to better estimate achievable slope angles for the ultimate pit. The results indicated that slope instability could be expected as the pit deepened. The modelling also highlighted the fact that slope performance was likely to be sensitive to groundwater conditions and blasting disturbance.

As a result of the modelling, a groundwater depressurization scheme was recommended and implemented using horizontal drains. Controlled blasting was recommended for the excavation of the final pit slopes and piezometers were installed along the upper North Wall to monitor the effectiveness of the depressurization program. It was anticipated that pit slopes in certain sectors of the North Wall might have to be flattened to 40 degrees. A slope deformation monitoring system was recommended to provide advance warning of instabilities.
The geotechnical work completed for the North Wall is an example of how the Kemess Mines reduced the likelihood of stability issues early in mine life with the timely identification of an area of concern, followed by a focussed site investigation program and appropriate stability analyses. This work resulted in a series of proactive recommendations that improved slope performance under aggressive development.

4 Middle Phase

In the middle stages of the mine life (from 2002 to 2008), geomechanical activities continued to focus on refining the spatial distribution and characteristics of the geomechanical domains, but the emphasis started to shift towards responding to and understanding the slope failures. Risk management strategies were divided between reducing the likelihood of failures and reducing the consequences associated with failures.

During this time, moderate wall heights still allowed for the likelihood of future failures to be reduced by flattening particular regions of the slope. Efforts were also focussed on reducing blast-induced disturbances to the final walls and improving the effectiveness of early de-pressurization activities. The consequences of any failures were managed through bench maintenance and improved geotechnical monitoring. Two case studies are discussed from this period in the pit development.

4.1 Northwest Wall - Background

By May 2004, the mine had been in operation for approximately eight (8) years and had achieved a depth of approximately 100 meters. At this time, the mine experienced a 1.5 million tonne failure along the Northwest Wall (Fig. 4). This failure was the mine’s first major multi-bench instability.

At the time of the failure, the slopes were in the process of being pushed back to their final design geometry and mining was taking place at the toe of this particular wall. This failure was the first of a number of slope stability issues within this corner of the pit. After the initial failure, the upper Northwest slope continued a slow creeping deformation with displacement rates ranging from 10 mm/day up to 150 mm/day (in late March 2006). Mining activity was forced to stop at the toe of the influence areas of instability.

The initial geological model had anticipated that the relatively competent Toodoggone Tuff units would be encountered in the northwest corner of the pit. As a result, the area had not been drilled during previous site investigations and relatively little rock mass data was available for the area. Mining activities revealed that the upper Northwest Wall was actually composed of an Epiclastic version of the Toodoggone.

Figure 4. Initial failure in Northwest Wall of the Kemess South Mine. Failure outlined in orange (April 2006).
The Epiclastic Toodoggone package was found to be a Lapilli Tuff dominated by clay-altered vitriclasts and abundant plagioclase fragments. The clay particles (Montmorillonite) swelled when exposed to water and contributed to the rapid degradation of this unit to a soil-like material. Given the importance of this unit to future slope performance, additional site characterizations were planned for the area. The program included wall mapping and diamond drill holes.

### 4.2 Northwest Wall - Analyses

A new series of limit-equilibrium (SLOPE/W GEO-SLOPE, 2004) back-analyses were undertaken with an updated geological model and an improved understanding for the Epiclastic’s material properties from the site investigations completed in 2006. The analyses were used to evaluate the impact of reduced rock mass strengths on achievable slope angles within that region of the pit.

Figures 5a and 5b show some typical slope stability analysis results for the upper Northwest Wall. The images show the existing geometry of the unstable Epiclastic material (Factor of Safety of 1.02) and the modified slope after a layback (Factor of Safety of 1.25). A variety of disturbance factors were utilized for these analyses (Hoek et. al, 2002) and in the end a D=0.85 was utilized and thought to be representative of site conditions.

![Figure 5a](image1.png)  
**Figure 5a.** SLOPE/W model of northwest slope in area of instability (*Note: FOS=1.02*).

![Figure 5b](image2.png)  
**Figure 5b.** SLOPE/W model of northwest slope instability. Slope flattened to between 27 and 33 degrees (*Note: FOS=1.25*).

### 4.3 Northwest Wall - Outcome

Stability analyses suggested that mining activities could resume at the toe of the slope once the upper northwest slope was laid back to approximately 33 degrees. At this point in the mine’s life, a layback was still preferable to a step-out that would have prevented access to part of the ore body.

Other recommendations included lowering the phreatic surface within the northwest corner of the pit with lined ditches above the slope and additional horizontal drains. In the end, flattening the slope and reducing the influence of groundwater reduced displacement rates within the lower slope to an average of 10 mm/day. However, the upper Northwest Wall continued to displace beyond acceptable rates within the weaker Epiclastic material. In the end, the Kemess Mines undertook a major pushback along the northwest corner of the pit and the Epiclastic slope was flattened to 27 degrees. Low-damage controlled blasting practices and extensive horizontal drain depressurization were also implemented along the North Wall within the adjacent Asitka Sediments unit. The Asitka walls performed very well under controlled blasting and nearly vertical bench faces were maintained for a period of time.

The layback reduced the upper slope movement rates to within acceptable ranges. The expectation of on-going displacement resulted in the installation of additional prisms, wire extensometers (for active tension cracks),
inclinometers for deep-seated failures and additional piezometers to monitor the effectiveness of the slope depressurization activities.

The Northwest Wall is an example of how the Kemess Mines managed the risks associated with its first major wall instability during the middle phases of mine development. The mine’s response included a focussed site characterization program, a modification to the slope geometry and a substantial increase in the resources allocated to slope monitoring. This approach allowed the mine to safely develop the northwest portion of the mine to its full economic potential.

4.4 Stress tests - Background

In order to support the engineering design of a nearby deeper Kemess North Open Pit, a decision was made in 2004 to determine the far-field stresses within the Kemess South Open Pit. The results of the testing did not influence the Kemess South pit slope operation, but a discussion is included in this paper as an example of techniques that can be employed to better understand the role of induced stresses as pits become deeper.

The far-field stress program involved drilling four inclined drillholes at two different locations in the floor of the Kemess South Pit. The position of the holes was selected based on the geological environment and the requirements of the overcoring (deep-doorstopper) test procedure. The holes were inclined in an effort to independently assess the vertical component of the stress field. Holes in the pit floor were utilized because initial numerical modeling suggested that the pit would not significantly modify the direction of the far-field stresses at these locations.

The actual tests were undertaken at two different depths below the pit floor (i.e., 65m and at 135m) in order to assess the spatial variability in the stress field. The test locations were the deepest that could be used while staying within the ore and away from the underlying basal fault (which could distort the stress field).

4.5 Stress tests - Analyses

Since the far-field measurement program was undertaken within the zone of influence of the Kemess South Pit, it was necessary to account for this in order to back out the far-field stress values. The influence of the pit was assessed by constructing an Examine3D (Rocscience, 2004) numerical model of the Kemess South Pit and by applying a range of likely far-field stress values until the predicted results approximately matched the values observed in the field (see Fig. 6).

Figure 6a. 3D Boundary element mesh constructed for the Kemess South Pit.  
Figure 6b. Calibration exercise, numerical modelling predictions vs. field estimates.
In the end, modelling indicated that the horizontal stresses were quite low and suggested a k-ratio in the north-south direction of approximately 0.7 and a k-ratio in the east-west direction of approximately 0.5. These low values are generally consistent with the preferred extensional geological model postulated for the area.

As an artefact of the calibration exercise, it was possible to use the model and the far-field stresses to estimate the stress distribution at any point within the walls of the Kemess South Pit (Fig. 7). These stress estimates could be combined with the Hoek-Brown failure envelopes to assess the likely level of stress-induced disturbance along the walls. These results suggested that minimal stress induced disturbance was likely within the Kemess South Pit.

Figure 7a. Kemess South Pit Sigma 1 estimates (looking West).

Figure 7b. Kemess South Pit Sigma 3 estimates (looking West).

Figure 7c. Kemess South Pit Hoek-Brown Strength Factor estimates (looking West).
4.6 Stress tests - Outcome

The stress results from the Kemess South Pit were applied to the proposed deeper Kemess North Pit to assess the impact of the stresses on wall performance (see Fig. 8). The results suggested that maximum principal stresses (\(\Sigma_1\)) could be expected to be fairly low around the pit periphery, with relatively little spatial variation due to the similarities in the two far-field k-values. The minimum principal stress value (\(\Sigma_3\)) was also expected to be very low and roughly independent of depth. Some tension was predicted by the elastic model under the safety berms and ramp. Under these stress conditions, it was not expected that the stresses would disturb the rock mass, but rather that there would be an increased tendency towards ravelling type failures.

The results also suggested that stress conditions were not significantly modified by the rock mass characteristics evaluated. A non-linear (i.e., plastic) numerical model (Phase2 - Rocscience, 2004) was also utilized to comment on the suitability of two different mining sequences, one of which exposed the final pit walls earlier in the staged mine plan. The modelling results suggested that the condition of the Kemess North final walls was likely to be relatively insensitive to the mining sequence employed though exposing the final pit wall later in mine life would reduce the required stand-up time.

Understanding the influence of stress-induced disturbance will become increasingly important as pits become deeper. The far-field stress testing undertaken at the Kemess South Pit is a good example of how the Kemess Mines proactively completed the investigations needed to manage slope stability risks associated with both current and future mine operations.

5 Late Phase

During the late stages of mining at the Kemess South Mine (from 2008 to 2011), the focus of the open pit risk management strategy shifted from preventing or limiting instabilities to managing their impact on mine operations. At this point, the rock mechanics characteristics and slope performance within the various sectors of the pit were well established and few engineering resources were allocated towards further characterization. Significant modifications to the existing pit geometry were no longer practical. Reduced ore reserves re-focused attention on areas that had had stability issues earlier in the mine life. The effects of time, deformation and ongoing blasting activities reduced the effectiveness of the benches and increased the likelihood of rock fall related issues.

The Epiclastic unit within the Northwest Wall continued to creep during the final phase of the pit development. The cumulative displacement within the upper slope was measured to be over 30 m with maximum movement rates exceeding 300 mm/day (in late 2008). The Northwest Wall continued to deteriorate and it was recognized during this period that existing monitoring methods were no longer sufficient. In response to these conditions,
the risks associated with on-going and future instabilities were managed by reducing exposure to personnel, utilizing improved slope monitoring strategies and by developing entry/exit protocols.

Working in conjunction with the applicable regulatory agencies, several measures were implemented in order to allow mining to continue safely, including the following:

- **Slope Stability Radar (SSR) Monitoring** – An SSR system (GroundProbe) was installed to provide near continuous displacement monitoring along the Northwest and North Walls of the pit. Measurement intervals were 3 to 5 minutes and the results were automatically analyzed. Based on experience and earlier monitoring data, displacement limits were set at 5 mm/hr (120 mm/day) for the North Wall and 15 mm/hr (360 mm/day) for the Northwest Wall. If displacement rates exceeded these values, an alarm would sound. The Kemess Mines set up two warning levels for the SSR system. When a movement rate reached the designated threshold, the mine would first send a pit supervisor to inspect the area. The inspection resulted in the area being cleared, the area being blocked-off or a request for a geotechnical inspection. If the visual inspection suggested that a failure was imminent, the mine would broadcast the evacuation order and all personnel would immediately leave the pit.

  The SSR system provided a number of warnings during 2009, typically giving between 12 and 36 hours of notice prior to a failure. Figure 9a shows a typical photo taken by the radar system of the Northwest Wall of the pit. The image clearly shows the displacement within the Epiclastic material. Figure 9b shows the slope velocity for the same area. The images give a sense for the resolution that is possible with these types of slope monitoring systems.

- **Prisms Survey** - Additional prisms were installed to provide more detailed coverage of the pit slopes. Reading frequencies were adjusted, depending on the observed slope behaviour. On a routine basis, the majority of the prisms were checked once a day. The data collected was used to confirm the results and to monitor the areas of the pit not covered by SSR.

- **Visual Inspections** - A full time geotechnical specialist made visual inspections twice a day during this time. The inspections encompassed the entire pit and included observations of tension cracks, rock fall hazards, groundwater conditions and the identification of potential failures. These inspections were particularly effective in managing the risks associated with small-scale bench failures, since these failures were often too small to be picked up by the SSR or the prisms. The geotechnical engineers also worked with mine staff to evaluate all of the monitoring data and to help determine when personnel could safely re-enter the pit after an evacuation.

- **Rock Fall Analyses** – These analyses, undertaken to evaluate the consequences associated with deteriorating wall conditions, included a 2D statistical analysis of rock fall projections for areas of concern using RocFall (Rocscience, 2009). A typical result is provided as Figure 10. Slope geometries were modified based on the results of these analyses, including the introduction of step-outs, catch berms and the addition of a full-time spotter.

- **Seasonal and Daylight Restrictions** - The enhanced slope monitoring instrumentation suggested that slope movements increased in the spring due to snowmelt and additional precipitation. As such, mining activities were scheduled to occur in the center of the pit during this time. Mining operations were also confined to daylight hours so that visual inspections could be undertaken.
The Kemess South Mine completed mining operations in the first quarter of 2011 and successfully recovered the majority of the ore. Late in mine life, the risks associated with on-going instabilities could not have been managed without the comprehensive monitoring program that was implemented by the mine. The SSR system was particularly effective in this role.
6 Summary

The Kemess South Open Pit Mine was recently closed after approximately 14 years of continuous mine operations. The mine managed the risks associated with a number of slope stability issues during the mine life. Some of these issues were anticipated from early engineering studies, while others developed over time. As mining progressed, the risk management strategies employed by the mine evolved to reflect changes in mining flexibility and in economic realities.

The risk management strategies employed were discussed in the context of four case examples. These case examples were typical of the stability issues encountered during each phase of the mine development. The strategies employed initially focused on reducing the likelihood of stability issues and evolved to focus on minimizing the consequences associated with instabilities.

Efforts to reduce the likelihood of slope failures or to control the slope failures included:

- Improvements to the 3D lithological model and to the geological environment.
- Diamond drilling, wall mapping and laboratory testing to better define rock mass characteristics.
- Implementation of a control blasting program.
- Installation of horizontal drains for slope de-pressurization.
- Modifications to the pit slope geometry (push-backs, step-outs and adjustments to the bench design).
- Detailed testing to better assess the impact of stress induced disturbance.

Efforts to reduce the consequences of any on-going or future failures included:

- Upgraded wall displacement monitoring system (visual inspections, prisms, extensometers and SSR).
- Development of workplace exit and entry protocols based on inspections and monitoring.
- Enhanced workforce training.
- Mining only during daylight hours.
- The use of rock fall spotters and protection berms.
- Changing mining locations within the pit depending on the season.

The engineering and mining operations changed significantly throughout the life of the Kemess South Mine. Through the continuous evolution of available risk management strategies, the Kemess Mines was able to effectively maximize ore recovery while ensuring the safety of their workforce for the entire mine life.

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8 References