Appendix 6.2-D

Assessment of the Potential Influence of Production Blasting on Slope Stability in the Aberdeen Hills Area

AJAX PROJECT

Environmental Assessment Certificate Application / Environmental Impact Statement for a Comprehensive Study

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Cont. No.:VA14-01523

Ms. Laura Smithies
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Kamloops, British Columbia
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Dear Laura,

Re: Ajax Project – Assessment of the Potential Influence of Production Blasting on Slope Stability in the Aberdeen Hills Area

1 – INTRODUCTION

This report presents the findings of a geotechnical assessment of the potential influence of production blasting at the proposed Ajax Project on slope stability in the Aberdeen Hills area of Kamloops. The Aberdeen Hills area has a history of terrain instability that dates back to before the area was developed and which is today managed with a sophisticated network of pumping wells. The pronounced landslide susceptibility of the Aberdeen Hills area has been recognized in the Environmental Assessment application by assigning 'Geology, landforms and soils' to be a Valued Component. This geotechnical assessment is intended to form part of the Effects Assessment of the project's Environmental Assessment application.

2 – SCOPE OF WORK

The scope of work includes the following:

- A review of previous slope stability assessments for the Aberdeen Hills development held by the City of Kamloops. The City of Kamloops provided the public with an overview of the history of slope stability assessments for the Aberdeen Hills area in their 2008 document titled 'Aberdeen Groundwater Area Information Summary' (City of Kamloops, 2008). Copies of the relevant geotechnical reports are listed in this document and were obtained for this study. These reports, as well as subsequent relevant documents, were obtained and reviewed. This review was completed to identify the critical slope stability region for consideration in the assessment and to establish the baseline stability condition.
- Determination of the Critical Peak Particle Velocity (the ground vibration under which the slope will be driven to the theoretical state of failure) for the critical region.
- Determination of the anticipated ground vibration from production blasting at the critical region.
- Consideration of potential blasting induced excess porewater pressures on slope stability.
- Determination of a maximum permissible PPV and excess porewater pressure at the margin of the Aberdeen Hills Area in relation to the proposed blasting

3 – SITE AND PROJECT DESCRIPTION

The Aberdeen Hills area is situated in the southwest part of the City of Kamloops, south of the TransCanada Highway and west of Highway No. 5. The development is located on the south side of the South Thompson River Valley between an elevation of 650 and 850 meters above sea level (masl); the topography slopes towards the north to northeast at an overall slope angle of approximately 8 to 9º.

The Ajax Project is a proposed open pit copper-gold development located approximately 2.9 km south-southwest of the Aberdeen Hills area in southwest Kamloops, British Columbia (refer to Drawing G0005). The project includes the expansion of two historical open pits and the development of on-site facilities to support processing of the ore, storage of the tailings and waste rock, and management of wastewater. The existing open pits were mined from 1989 to 1991 and 1994 to 1997. The maximum extent of the proposed Open Pit is shown on Drawing G0005.

The Aberdeen Hills area straddles the southern edge of a fault-bound mid-Eocene (about 50 million years old) basin containing poorly cemented sedimentary and volcanic rocks. In the Aberdeen Hills, Eocene rocks of the Kamloops Group are faulted against Upper Triassic rocks of the Nicola Group and Early Jurassic intrusions of the Iron Mask Batholith.

4 – INFORMATION REVIEW

4.1 GEOLOGICAL MODEL

Geotex Consultants Ltd. (Dr. Peter Read), working for Golder Associates on behalf of the City of Kamloops, have previously undertaken detailed geological mapping of the Aberdeen Hills area (Geotex, 1996). The findings of this mapping are summarized on Drawing G0005. The mapping indicates several geological faults in the vicinity of the Aberdeen Hills area. A northeast trending fault, referred to as the 'A Fault', extends across the central portion of the Aberdeen Hills area, and a minor north-trending fault extends along the scar of the Van Horne Slide.

A summary of the site stratigraphy is presented below:

Nicola Group metavolcanics (NG) - Triassic: The oldest bedrock at the site comprises the Triassic age Nicola Group metavolcanic rocks. The Nicola Group comprises massive medium to dark grey-green, porphyritic meta-andesite or metabasalt flows, breccias and lapilli tuffs. The rocks have undergone a regional metamorphism in the chlorite zone of the greenschist facies to produce what is commonly called a greenstone. The Nicola Group metavolcanics subcrop beneath quaternary sediments in the north part of Aberdeen Hills area, between the west northwest trending Python Lake Fault and Aberdeen Fault in the south part of the area, and to the west of the Guerin Fault in the west part of the area. The Python Lake Fault probably dips steeply to the north-northeast.

Iron Mask Batholith (IMB) - Jurassic: Rocks of the Iron Mask Batholith form the hills south of Aberdeen Hills area and extend southwards towards the proposed mine site. The bedrock comprises chloritized diorite and gabbro.

Kamloops Group – Tertiary - Tranquille Formation (Sedimentary Breccia member – KGs): The lower part of the Tertiary age Kamloops Group is a sedimentary breccia member consisting mostly of angular volcanic clasts derived from the underlying rocks of the Nicola Group. There are interbeds of felsic tuff up to approximately 5 m in thickness.

Kamloops Group – Tertiary - Tranquille Formation (Tuffaceous Member - KGt): The succeeding tuffaceous member consists of bedded, brown-weathered, tuffaceous wacke with interbedded shale and siltstone, and light grey to buff, crudely bedded felsic tuff. The fine-grained units are intensively weathered to soft montmorillonite-rich clays. The beds generally have the same northeast dip direction and similar dips as the natural slopes.

Kamloops Group – Tertiary - Dewdrop Flats Formation (Andesite Member – Eva): The upper unit of the Kamloops Group comprises fine, grey dacite and andesite.

Quaternary Sediments (Q): The surficial Quaternary sediments mostly comprise Till. The Till encountered in site investigations was generally a silty sand with some gravel and trace to some clay. Local lenses of silt and water-lain sand and gravel were encountered. The Till is believed to have been deposited in a bedrock trough formed by enhanced erosion of weak tuff and tuff breccia. The total thickness of the Quaternary units is highly variable; drill holes show that they vary in thickness from 6.1 m to 57.9 m.

The hydrogeological model for the Aberdeen Hills area is strongly influenced by the distribution and thickness of the low permeability Kamloops Group member and overlying Till. In the upslope area, groundwater is observed to discharge from the Iron Mask Batholith intrusives above the contact with the Nicola Group volcanics. Further downslope, the groundwater component flowing north is inhibited from freely seeping from the slopes by the cover of the low permeability Kamloops Group and surficial soils. As a result, piezometric levels in the Nicola Group are elevated. Piezometric levels are elevated furthest where these units are thickest, in particular in the area to the west of the 'A Fault'.

4.2 LANDSLIDES

The geological mapping identifies six landslides in the Aberdeen Hills area (Geotex, 1996). These include two widely documented landslides - 'Slide A' and the 'Van Horne Slide', the locations of which are shown on Drawing G0005. There is potential for large-scale landslides in the Aberdeen Hills area where weak strata (such as highly plastic tuffaceous clay), slope, and high groundwater pressure occur in combination. All six landslides that Geotex Consultants Ltd mapped in the Aberdeen Hills area are located in areas underlain by Kamloops Group bedrock. Most of the slides are recent, having occurred or been active in the last 30 years or so, but 'Slide A' is an ancient slide that is not known to have moved in recent times. The instability of the Kamloops Group is largely attributed to layers of volcanic ash (tuff) which alter to highly plastic swelling clays (Golder Associates, 2009). Past failures have occurred on sliding surfaces at or near the interface between the overburden (commonly Till) and underlying tuffaceous Kamloops Group Bedrock. The Geotex mapping data indicates 'Slide A' lies entirely within the Tranquille Formation. The bedrock at the landslide site is close to the contact between the Sedimentary Breccia member (KGs) and overlying or intercalated tuffs and tuffaceous sediments of the Tuffaceous member (KGt). The base of the 'Van Horne Slide' lies in the Sedimentary Breccia member (KGs) of the Tranquille Formation and involves intercalated beds of bentonitic ash of the Tuffaceous member (KGt).

4.3 INITIAL STABILITY ASSESSMENT

A site stability assessment report undertaken in 1977 by Klohn Leonoff Consultants (Klohn) for Dominion Construction Co. Ltd. identified a large slump ('Slide A') in the central part of the Aberdeen Hills area. The instability was attributed to deglaciation processes such as thawing of frozen sediments, rapid drawdown of ice marginal lakes and ponds and possibly rapid unloading. It was concluded that subsequent changes in geologic and climatic conditions had rendered the site less prone to instability.

The report includes a number of recommendations to maintain slope stability in the area including limiting infiltration and controlling drainage, preventing erosion, maintaining free drainage of existing springs and seepage points, limiting the amount of excavation and fill in the vicinity of 'Slide 'A', and limiting development near Guerin Creek.

4.4 INITIAL DEVELOPMENT AND 1995 GROUND MOVEMENT

Development of the Aberdeen Hills area began in the northern downslope area in the 1970's and gradually extended upslope. A golf course was constructed in the upslope area, the earthworks for which included the addition of significant quantities of fill. Klohn Leonoff continued to study 'Slide A' and provide recommendations as development continued. The additional studies indicated that the phreatic surface was higher than previously thought and may be rising. Dewatering wells were installed to lower the phreatic surface and increase stability.

In 1995, ground movement affected a cluster of homes south of Howe Road and just east of the Howe Road-Van Horne Drive intersection. The extent of the area of ground movement, referred to as the 'Van Horne Slide'; is shown on Drawing G0005. Emergency remedial treatment of the 'Van Horne Slide' involved installation of 13 pumping wells.

4.5 POST-1995 STUDIES

Following the 'Van Horne Slide', the City of Kamloops sought detailed reassessments of large-scale ground stability in all parts of the Aberdeen Hills area. Klohn Crippen Consultants Ltd. (Klohn Crippen), working on behalf of Bentall Real Estate Services and in cooperation with the City of Kamloops, conducted a series of investigations and stability assessments between 1996 and 2004. Geological mapping (Geotex, 1996) was used to define the limits of the study area as the extent of the area underlain by Tertiary (Eocene-age) Kamloops

Group Bedrock determines the extent of terrain that is susceptible to large scale instability under adverse conditions of slope, groundwater pressure and geology.

The assessments started with core areas and later expanded to the margins of the Aberdeen Hills area. Eleven Stability Assessment Regions were identified (Drawing G0005). The objective of the assessments was to evaluate the large-scale stability condition of each area and to recommend mitigation measures, where required, based on adopted stability objectives. The Klohn Crippen stability reviews and all subsequent studies have used the same stability assessment regions and cross-sections to assess the Factor of Safety (FoS) along the selected sliding surfaces. The purpose of the replication of the procedure and input parameters is to isolate changes in the calculated FoS that result solely from changes in the interpreted groundwater conditions. Klohn Crippen considered the primary mode of failure to be one of sliding on a slip plane near the base of the Till unit. The suitability of the interpreted geologic profiles and input parameters for the previous slope stability assessments were not reviewed as part of this assessment.

Klohn Crippen (2001), with external review by Dr. N. R. Morgenstern, selected target FoS values for the Aberdeen Hills Stability Regions. A target FoS of 1.5 was adopted for slopes that show no evidence of previous ground movement. Peak soil shear strength parameters were used for assessing the stability of these regions. For slopes that show evidence of previous movement, the stability calculations utilized lower (residual) soil shear strength parameters and a target FoS of 1.3 was adopted. The adoption of a lower target FoS for residual strength calculations was justified on the basis that there was judged to be a higher degree of confidence with the selected shear strength parameters. The Klohn Crippen studies concluded that the stability objectives were achieved for the evaluation period for the assessed areas.

While the Klohn Crippen stability studies were in progress, Golder developed a regional hydrogeological model (numerical model) for the Aberdeen Hills area. Groundwater data collected suggested that the water table increased in elevation by 6 m to 19 m in several Stability Regions over the period of 2002 to 2006. The groundwater model indicates the rise in groundwater pressure largely resulted from the expanding area of new upslope development (City of Kamloops, 2008).

By 2006, the number of pumping wells used for stability treatment had increased to 30 with 14 located in the Van Horne Stability Region and most of the others being in the vicinity of ‘Area A’. In addition, approximately 88 piezometers had been installed for monitoring the groundwater conditions and 3 inclinometers installed for monitoring ground displacements.

4.6 POST-2006 STUDIES

Golder Associates Ltd. (Golder) conducted a geotechnical review of slope stability in the Aberdeen Hills area based upon groundwater pressures recorded during the assessment period ending November 2006. The Golder stability review used the same stability assessment regions, stratigraphy, geotechnical parameters, potential sliding surfaces and calculation method as the previous assessments. Analysis of the Van Horne Stability Region was included. The stability analysis for the Van Horne Stability Region was conducted using the groundwater conditions of August 1995 (prior to treatment), May 1998 (when groundwater pressure was the lowest so far achieved), and June 2005 (when the effectiveness of some wells had declined). The August 1995 FoS value of 1.01 was assumed in back-analysis to calculate the shear strength parameters for ground which was then moving; subsequent FoS values were calculated using the ground strength values determined from the back-analysis.

The FoS values calculated in the 2006 stability analysis met or exceeded the stability targets for all the assessed areas with the exception of the Van Horne Stability Region. The FoS values determined for the Van Horne Stability Region for May 1998 and June 2005 were 1.20 and 1.13, respectively. Two additional pumping wells were installed in the Van Horne Stability Region in late 2006.

The latest stability review of the Aberdeen Hills area was undertaken for the City of Kamloops by Golder in 2010 (Golder, 2011). The results of the study are summarized in Table 1 below:

Table 1 Summary of 2010 Stability Review Results

Stability Region		'Best Estimate' Friction Angle (°)	Calculated FoS (Golder, 2010)	Target FoS	Target FoS Achieved?
1	Area 'A'	11.5	1.38	1.3	Yes
2	Dunraven	15.5	1.91	1.3	Yes
3	**Van Horne Slide**	9.5	**1.24**	**1.3**	**No**
4	Ravenwood	28.5	1.47	1.5	No (marginally)
5	Sierra Vista (Santa Rosa)	32	3.02 (2006)	1.5	Yes
6	The Links	26.5	1.96/1.83	1.5	Yes
7	Glasgow	42	2.73	1.5	Yes
8	Guerin	25	1.64	1.5	Yes
9	Gloaming Ridge	5.5	1.73	1.3	Yes
10	Sifton South	22	2.01	1.5	Yes
11	Fleming (Sifton North)	Not reported			

It can be seen from Table 1 that the target FoS was achieved in the majority of the cases, the key exception being the Van Horne Stability Region where a FoS of 1.24 was determined. A marginally acceptable FoS of 1.47 was obtained for the Ravenwood Stability Region.

Slope stabilization measures have been implemented in the Van Horne Stability Region since 1996. These measures comprise about half the de-watering wells in the Aberdeen Hills area. However, the results of the slope stability analyses undertaken indicate the Van Horne Stability Region has not met the stability target FoS of 1.3. The installed pumping well system is required to work effectively in a continuous manner in order to maintain large scale slope stability in this area. Golder's 2009 report indicates that the impact of pumped wells in reducing ground water pressures within the Van Horne Stability Region is hampered by the low permeability of the ground, resulting in the piezometric levels remaining relatively high. The report also concludes that it is unlikely that the target FoS can be achieved without a significant increase in the number of operating wells. Golder recommends that an alternate long-term mitigation strategy that is not reliant upon continuous close monitoring be identified and implemented.

4.7 EXISTING RISK MANAGEMENT PLAN

A large portion of the Aberdeen Hills area is dependent on continuous effective groundwater pumping to maintain slope stability. The number of pumping wells used for slope stability enhancement in Aberdeen has increased over time to 30. In addition to the dewatering wells, as of 2010 there were approximately 110 piezometers distributed through the Aberdeen Hills area for monitoring the groundwater conditions.

It is anticipated that ground movement could occur in some parts of Aberdeen Hills area should de-watering stop for five to ten days. The de-watering system therefore requires constant and careful monitoring as well as regular maintenance. Golder developed a Risk Management Plan (Golder, 2008) that allows City of Kamloops staff to track data and to facilitate the timely undertaking of necessary management activities. To supplement the Risk Management Plan, the City installed a backup generator in the Van Horne Stability Region in 2008. The backup generator serves a cluster of dewatering wells so that the wells can continue to function in the event of a large-scale power outage.

5 – STABILITY ASSESSMENT

5.1 CRITICAL STABILITY REGION AND BASELINE CONDITIONS

It is assumed that the baseline slope stability of the Aberdeen Hills area is represented by the interpreted critical slope profiles, geological models, geotechnical parameters and the associated output FoS values for the eleven stability regions presented in the most recent stability review undertaken for the City of Kamloops by Golder in 2010 (Golder, 2011). The Van Horne Stability Region was selected as the critical stability region as it has the lowest calculated FoS from the results of Golder's 2010 stability review (see Table 1). The baseline condition for the Van Horne Stability Region is taken to be the geological profile, groundwater conditions and geotechnical parameters used in the 2010 slope stability assessment, as summarized on the accompanying Figure 1 and in Table 2 below:

Table 2 Summary of Shear Strength Parameters used in 2010 Slope Stability Assessment for the Van Horne Stability Region

Material	Unit Weight (kN/m^3)	Friction Angle ϕ' (º)	Cohesion, c' (kPa)
Glacial Till	19.5	38	0
Clayey Tuff (Kamloops Group)	17	9.5 (residual)	0
Volcaniclastic Bedock (Nicola Group)	21	50	200

5.2 PSEUDO-STATIC ANALYSIS

Pseudo-static analyses are widely used to assess the effects of earthquake vibrations on slope stability and have been adopted to assess the effects of blasting vibrations on soil slopes (Wong and Pang, 2000). The ground vibrations are modelled as a pulse of uniform amplitude so that they can be represented as an equivalent static driving force based on the peak ground acceleration.

A baseline slope stability model, consistent with the 2010 stability review (Golder, 2011), was generated using the limit equilibrium program *Slope/W*. The model used the same method of analysis (Morgenstern-Price), ground and groundwater conditions and assumed slip surface, and yielded the same output FoS.

The ground vibration under which the slope will be just driven to the theoretical state of failure (i.e. FoS=1.0) is referred to as the yield acceleration. The yield acceleration was determined with the *Slope/W* model, and then converted to an equivalent Critical Peak Particle Velocity (PPV_c) value.

It was determined that the yield acceleration is 0.037g. This value was converted to an equivalent PPV_c using the 'Shear Response Method' (Wong and Pang, 2000) as, in the case of the Van Horne Stability Region profile, the horizontal distance to the bedrock surface (D) is large compared to the slope height (H). The 'Multi-degree Freedom Model' was adopted in line with the guidelines presented in Wong and Pang (2000) since the ratio of the overburden shear wave velocity (S) to the horizontal distance to the bedrock surface (D) is interpreted to be $<50\ s^{-1}$ for the Van Horne Stability Region profile.

The PPVc was calculated using the following formula:

$$PPV_c = K_c g / \omega K_a \qquad \textit{eqn. 1}$$

where: PPV_c = Critical peak particle velocity of the bedrock vibration under which the slope will be just driven to the theoretical state of failure (mm/s)

K_c = Yield acceleration of the slope which will just drive the slope to the theoretical state of failure (FoS=1.0)

g = Acceleration due to gravity=9.81 m/s^2

ω = Circular frequency of ground motion = $2\pi f$ (f=input vibration frequency in Hz)
K_a = Magnification factor determined from response analysis.

The magnification factor (K_a) was determined from a graphical plot in Wong and Pang (2000) that takes into account the height of the analysed potential slope failure (y) in relation to the total height of the slope (H) and the ratio of the shear wave velocity of the material in the slide zone (S) to the total height of the slope (H). A 'y' value of 40 m and an 'H' value of 50 m were adopted based upon the Van Horne Stability Region profile. The material in the slide zone was assumed, on average, to have the geotechnical properties of a stiff soil, and a shear wave velocity of 250 m/s was assumed with reference to information presented in Wong and Pang (2000) and Adams and Halchuk (2007). The magnification factor (K_a) was determined to be between 0.05 and 0.1. Using this range of K_a values and a frequency value of 30 Hz, the PPV_c of the Van Horne Slide Stability Region was calculated to be in the range of 20 to 40 mm/s.

5.3 PREDICTED GROUND VIBRATION FROM BLASTING

Two trial blasts were completed at the Ajax Project site by Orica Canada Inc. (Orica) on February 19, 2011, one in bedrock and one in overburden (Orica, 2011). The following blast vibration attenuation relationship for bedrock at the site was developed based on the results of the trial blast in bedrock:

$$PPV = 1092\left(d/\sqrt{w}\right)^{-1.68} \qquad \textit{eqn. 2}$$

where: PPV = Peak Particle Velocity (mm/s)

d = radial distance from the point of blasting detonation (m)

w = mass weight of explosive detonated per delay (kg)

Orica estimated that the dominant frequency of the blast vibrations was approximately 8 to 12 Hz at a distance of 500 m.

Blasting Analysis International (BAI) undertook a comprehensive blast review for the Ajax Project in 2014 (BAI, 2014). BAI conservatively adopted the generalized blast attenuation relationship presented in the 175th edition of the DuPont Blasters handbook:

$$PPV = 1143\left(d/\sqrt{w}\right)^{-1.60} \qquad \textit{eqn. 3}$$

BAI reviewed the production blast design in light of all of the sensitive receivers in the vicinity of the site and concluded that the production blasts could have the following properties:

- blast hole diameter: 311 mm
- maximum charge weight per delay (w): 1020 kg
- maximum bench height: 15 m
- minimum delay between holes: 8 ms

The attenuation relationships presented in the two blasting reports were used to predict the PPV value at the Critical Slope Stability Region (Van Horne) using BAI's maximum charge weight per delay (1020 kg). The analysis was also undertaken for the Area A Stability Region, as it is the closest Stability Region to the proposed Open Pit. The results of the analyses are summarized in Table 3 below:

Table 3 Summary of Predicted PPV Values Generated from Open Pit Production Blasting

Stability Region	Distance (km)	Predicted PPV Based upon Orica Vibration Attenuation Relationship (mm/s)	Predicted PPV Based upon BAI Vibration Attenuation Relationship (mm/s)
Area A	2.9	0.6	0.8
Van Horne	3.5	0.4	0.6

It can be seen from Table 3 that there is a negligible difference in the predicted PPV values for the two regions, confirming the Van Horne Stability Region to be the critical Stability Region in terms of the blasting impact effects assessment. There is negligible difference in the results obtained with the BAI and Orica blast attenuation relationships. Reliance is placed upon the results obtained using the BAI blast attenuation relationship since the Orica trial blast was undertaken with a blast design, which is no longer representative of the design of the proposed production blast. Also, the BAI blast attenuation relationship is more conservative. The PPV value predicted for the Van Horne Stability Region is approximately 0.6 mm/s. This is substantially lower than the calculated PPVc value of 20 to 40 mm/s. Using eqn. 1, above, a PPV of 0.6 mm/s at the Van Horne Stability Region is estimated to be approximately equal to a response acceleration of 0.001g, assuming K_a=0.1 and f=30 hz.

5.4 CONSIDERATIONS OF POTENTIAL EFFECT OF BLASTING INDUCED EXCESS POREWATER PRESSURES ON SLOPE STABILITY

A couple of case scenarios were modelled to investigate the sensitivity of the FoS of the Van Horne Stability Region to increases in porewater pressure (PWP). Hypothetic excess PWP’s of 5, 10, 15, 20 and 50% were modelled and the results of these analyses are presented in Table 4 and on Figure 2. Considering the distance between the proposed Open Pit and the Aberdeen Hills area, any increases in PWP at the Van Horne Stability Region are expected to occur after the region experiences the blast vibration so that the two effects would act independently of one another. It can be seen from Figure 2 that the FoS could reduce to 1.1 if the excess PWP in the slope were to reach 40%.

Table 4 Summary of Results for Van Horne Stability Section

Static Analysis	Psuedo-Static Analysis		Sensitivity of Static FoS to Excess Pore Water Pressure						Anticipated Stability During Production Blast Based on Predicted PPV of 0.6 mm/s		Sensitivity of FoS to Excess Pore Water Pressure Including for the Predicted Blast Vibration of 0.6 mm/s					
FOS	Yield Acceleration (ie. FoS=1.0) (g)	Estimated Equivalent Critical Peak Particle Velocity, PPV_c (mm/s)	0%	5%	10%	15%	20%	50%	Equivalent Response Acceleration (g)	FOS	0%	5%	10%	15%	20%	50%
1.23	0.037	20-40	1.23	1.22	1.20	1.18	1.17	1.07	0.0010	1.22	1.22	1.21	1.19	1.18	1.16	1.06

Consideration was given to the likelihood of such relatively large excess PWP’s developing at the Van Horne Stability Region during blasting. Charlie et al (1983) reviewed various case studies with the aim of assessing possible threshold particle velocities below which blast-induced porewater pressure increases should not occur. The lowest PPV at which he found evidence of residual porewater pressure increases was approximately 10 mm/s. Considering the anticipated PPV in the Van Horne Stability Region is only, 0.6 mm/s, the production blasting is therefore not expected to have a significant effect on porewater pressures at the Van Horne Stability Region. Additional consideration was given to the likelihood of excess PWP being generated in relation to the geology at the Van Horne Stability Region. The critical slip surface for the Van Horne Stability Region occurs within the Tuffaceous member (KGt) of the Kamloops Group, which includes bentonitic ash. Site investigation work undertaken for the City of Kamloops in the Van Horne Stability Region in 1997 (Klohn Crippen, 1998) described these soils as hard clays of high plasticity. A study by Egglezos and Bouckovalas (1998) presents the results of statistical analyses on the results of 173 cyclic triaxial and cyclic simple shear tests on sands, silts and clays and indicates that sands develop 2.5 to 7.7 times higher excess pore pressures than clay. This, therefore, substantiates the finding that negligible blast-induced excess PWP's are expected in the Aberdeen Hills area.

Consideration was also given to the possible cumulative effect of successive blasts on the PWP and slope stability, the possibility being that there is insufficient time for excess PWP to dissipate between successive blasts. An additional set of sensitivity analyses were run assuming there is no dissipation of excess PWP generated in an initial blast at the time of the succeeding production blast. In this case, the predicted response acceleration of 0.001g was included in the model along with the same range of excess PWP values. It can be seen from Table 4 that there is negligible difference in the FoS values. These results further support that the effect of blasting vibrations on slope stability at the Van Horne Stability Region is anticipated to be negligible.

6 – LIMITATIONS AND UNCERTAINTIES

The existing slope stability management system for the Aberdeen Hills area is focused on the effects of changes in groundwater conditions on slope stability, whereas, changes in slope loading (adding surcharge in the upper areas and removing toe support by excavating in the lower areas) can have significant additional effects.

The methodology used to determine the PPVc value for the Van Horne Stability Region in relation to the proposed production blasting assumes a blast vibration of 30 Hz. Considering that frequency measurements of 8 to 12 Hz were made at a distance of 500 m during the Orica trial blast and that the distance of the Van Horne Stability Region to the proposed Open Pit (approximately 3.5 km), it is possible that blast vibrations will have attenuated to frequencies lower than 30 Hz at the Van Horne Stability Region. The published methodology used in this assessment (Wong and Pang, 2000) does not account for blast frequencies of <30 Hz; nonetheless, it is possible to gauge the expected influence of using a frequency of 15 Hz on the PPVc by determining the difference in the output K_a value for the single degree of freedom model. For the single degree of freedom model, the output K_a value is determined from a plot of K_a vs. S/H for a horizontal bedrock model, where S= shear wave velocity and H = slope height. At the S/H value (5 s^{-1}), there is negligible change in K_a and, hence, a negligible change in PPV_c when the input frequency reduces from 30 Hz to 15 Hz for the single degree of freedom model. Based upon this comparison, the output K_a value and PPV_c values obtained with the multi-degree of freedom model are unlikely to change significantly for the lower far-field frequencies.

Another limitation of the methodology used in this assessment is that it assumes the input bedrock vibration to be a simple harmonic motion with a singular frequency.

7 – RECOMMENDATIONS

It is recommended that the limitations and uncertainties described above be managed by setting conservative alarm levels for blast vibrations and excess PWP and by undertaking monitoring throughout production blasting as part of an adaptive management plan that facilitates immediate changes to the blast design to account for the possibility of these levels being exceeded.

BAI proposed that a linear array of three permanent seismographs be installed between the Open Pit and the Aberdeen Hills area to monitor vibrations throughout production blasting (BAI, 2014). In addition, it is recommended that the closest seismograph to the City of Kamloops be installed at the margin of the Aberdeen Hills area, along with a vibrating wire piezometer. Vibration data and PWP measurements should be collected during every production blast. Opportunities should also be sought to collaboratively make use of the existing groundwater installations in the Aberdeen Hills area to monitor the groundwater table during production blasting. The vibration data collected in the initial production blasts should be used to develop a site-specific blast vibration attenuation relationship. The charge weight/delay in these initial blasts should be kept well below the maximum value of 1020 kg. The predicted vibrations in the Aberdeen Hills area should then be re-calculated using the site-specific blast vibration attenuation relationship and the blast design should be reviewed by a Qualified Professional.

In the unlikely event that a blast vibration PPV of >5 mm/s is recorded at the seismograph at the margin of the Aberdeen Hills area, and/or an excess PWP of >10% is recorded in the adjacent vibrating wire piezometer during production blasting; blasting should cease immediately and the blast design should be modified by a Qualified Professional in order to maintain the vibrations and excess PWP's below the alarm levels.

8 – DISCUSSION AND CONCLUSIONS

An assessment has been undertaken of the potential influence of production blasting at the proposed Ajax Project Open Pit on slope stability in the Aberdeen Hills area. Slope stability analyses are routinely undertaken for the City of Kamloops for eleven 'Stability Regions'. Ground models and critical slip surfaces have been established for each region; successive analyses model the influence of changes in the groundwater conditions on slope stability. The continuous operation of a sophisticated network of de-watering wells is needed to prevent slope instability in several of the stability regions.

The Van Horne Stability Region has been determined to be the critical region. This region has a baseline FoS of 1.24 based upon the results of the most recent slope stability assessment undertaken in 2010 for the City of Kamloops (Golder, 2011). In our study, the pseudo-static approach was used to determine the ground acceleration required to drive the critical slope stability profile to a FoS of 1.0. This yield acceleration was converted to an equivalent PPV_c value using the 'Shear Response Method' and the 'Multi-degree Freedom Model'. The equivalent PPV_c value was calculated to be between 20 and 40 mm/s, whereas the predicted vibration at the Van Horne Stability Region from the production blast is only approximately 0.6 mm/s. Slope stability analyses undertaken as part of this study, show that an excess PWP associated with the blasting of greater than 50% is needed to drive the slope to a FoS of 1.0, whereas a review of published literature suggests negligible excess PWP from the production blasting would be expected at Aberdeen Hills based upon the predicted vibrations. Additional slope stability analyses indicate the cumulative effect of blasting vibrations on PWP and slope stability is also expected to be negligible.

In conclusion, there is not expected to be any significant adverse effect of the proposed production blasting for the Ajax Project on the existing slopes in the Aberdeen Hills area. Inevitably, there are some limitations with the method of assessment used in this study as well as the method used in the City of Kamloops' risk management plan. The former limitations are, to some extent, countered by the fact that the use of the pseudo-static approach tends to produce somewhat conservative results when applied to blast vibration scenarios since blast vibrations are characterized by relatively high frequencies compared with earthquakes (as discussed in Wong and Pang, 2000). However, considering the relatively large distance from the Open Pit, the production blast vibration frequencies at the Van Horne Stability Region might be somewhat less than the interpreted value of 30 Hz. The published methodology used in this study does not account for undertaking analyses for frequencies of < 30 Hz. The output K_a and PPV_c values for a blast vibration frequency of 15 Hz are not expected to vary significantly from those for a blast vibration frequency of 30 Hz based upon a sensitivity assessment for the single degree of freedom model. Nonetheless, in order to account for the uncertainties in blasting vibration frequency and the excess PWP attenuation relationship, it is proposed to provide additional mitigation by developing an adaptive management plan that sets conservative alarm levels for blast vibration PPV (5 mm/s) and excess PWP (10%) at the margin of the Aberdeen Hills area during blasting, and facilitates immediate changes to the blast design to account for the possibility of these levels being exceeded. During production blasting, in the unlikely event that a blast vibration PPV of >5 mm/s is recorded at the seismograph at the margin of the Aberdeen Hills area, and/or an excess PWP of >10% is recorded in the adjacent vibrating wire piezometer; blasting should cease immediately and the blast design should be modified by a Qualified Professional in order to maintain the vibrations and excess PWP's below the alarm levels.

We trust that the information presented herein meets your requirements at this time. Please do not hesitate to contact the undersigned should you have any questions, comments or concerns.

Yours truly,
Knight Piésold Ltd.

ORIGINAL SIGNED

ORIGINAL SIGNED

Prepared:	Reviewed:
James Haley, P.Eng Senior Geotechnical Engineer	Daniel Yang, P.Eng. Specialist Geotechnical Engineer

Approval that this document adheres to Knight Piésold Quality Systems:

Attachments:

Table 4 Rev A	Summary of Results for Van Horne Stability Section
Figure 1 Rev A	Baseline Van Horne Slope Stability Profile
Figure 2 Rev A	Sensitivity of the Van Horne Stability Region to excess porewater pressure
Drawing G0005 Rev 0	EA Effects Assessment – Aberdeen Hills Terrain Stability

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TABLE 4
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AJAX PROJECT
ABERDEEN HILLS STABILITY ASSESSMENT IN RELATION TO PRODUCTION BLAST

SUMMARY OF RESULTS FOR VAN HORNE STABILITY SECTION

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Static Analysis	Psuedo-Static Analysis		Sensitivity of Static FoS to Excess Pore Water Pressure					Anticipated Stability During Production Blast Based on Predicted PPV of 0.6 mm/s		Sensitivity of FoS to Excess Pore Water Pressure Including for the Predicted Blast Vibration of 0.6 mm/s				
FOS	**Yield Acceleration (ie. FoS=1.0) (g)**	**Estimated Equivalent Critical Peak Particle Velocity, PPV_c (mm/s)**	**5%**	**10%**	**15%**	**20%**	**50%**	**Equivalent Response Acceleration (g)**	**FOS**	**5%**	**10%**	**15%**	**20%**	**50%**
1.23	0.037	20-40	1.22	1.20	1.18	1.17	1.07	0.0010	1.22	1.21	1.19	1.18	1.16	1.06

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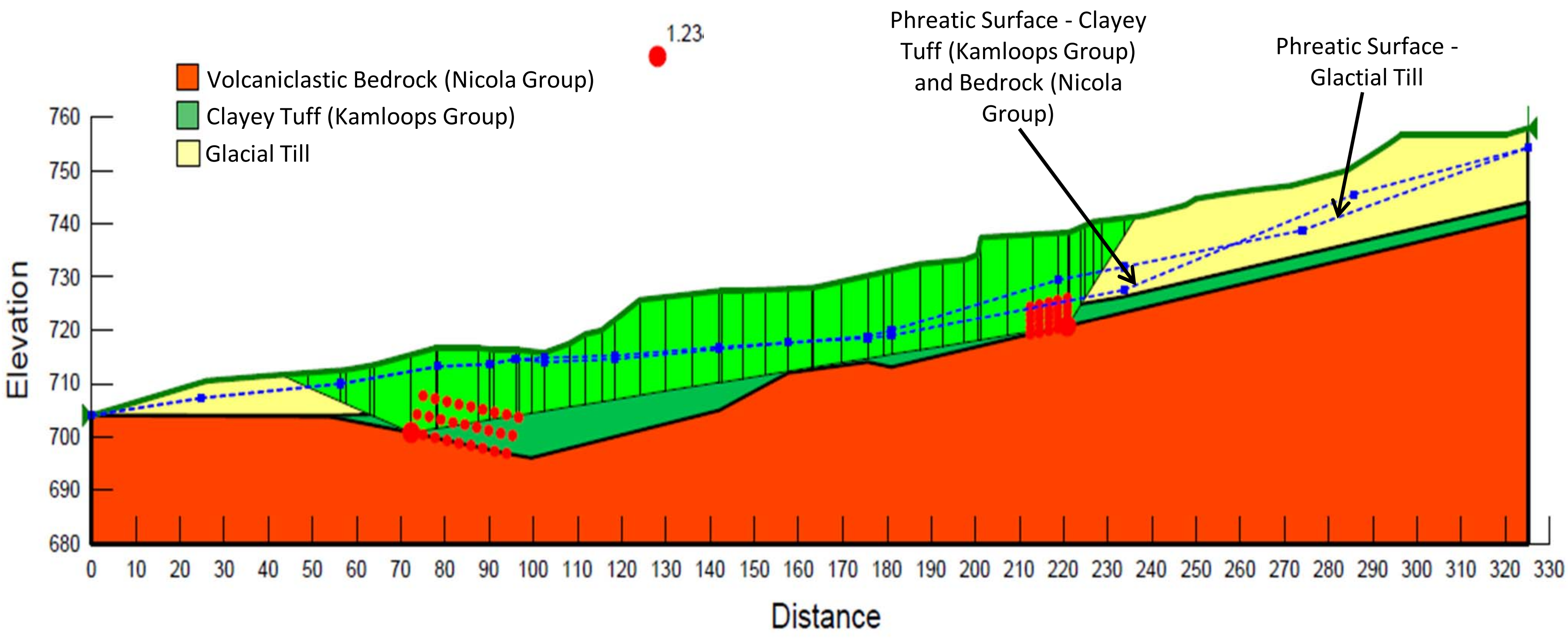

NOTES:

1. SECTION REPLICATED FROM THE 2010 STABILITY REVIEW (GOLDER, 2011).

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AJAX PROJECT

BASELINE VAN HORNE SLOPE STABILITY PROFILE

Knight Piésold
CONSULTING

P/A NO.
VA101-246/34

REF. NO.
1

FIGURE 1

REV
A

A	05DEC'14	ISSUED WITH LETTER	AMM	JEH	KJB
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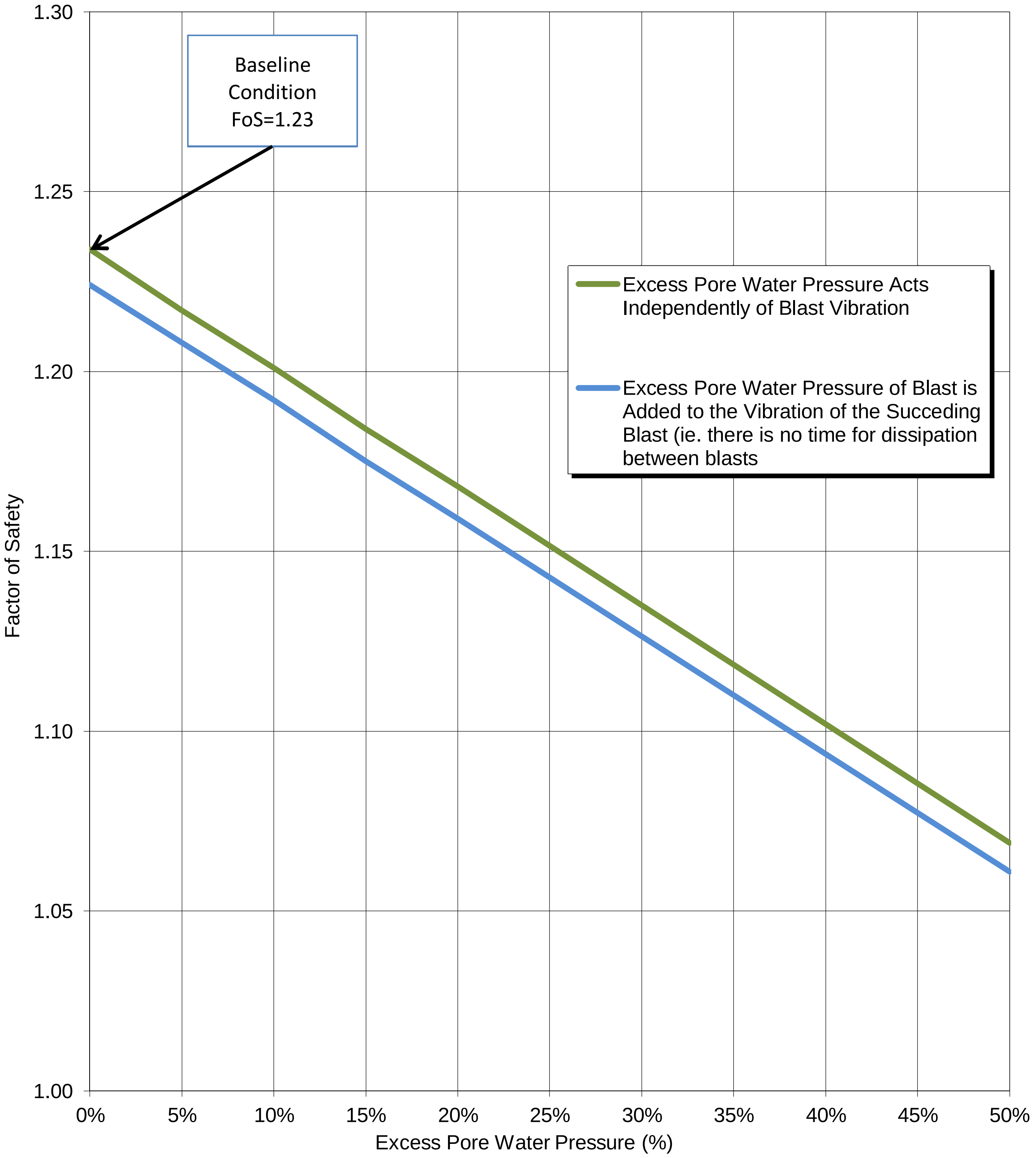

KGHM AJAX MINING INC.

AJAX PROJECT

SENSITIVITY OF THE VAN HORNE STABILITY REGION TO EXCESS POREWATER PRESSURE

Knight Piésold CONSULTING

P/A NO. VA101-246/34

REF. NO. 1

FIGURE 2

REV A

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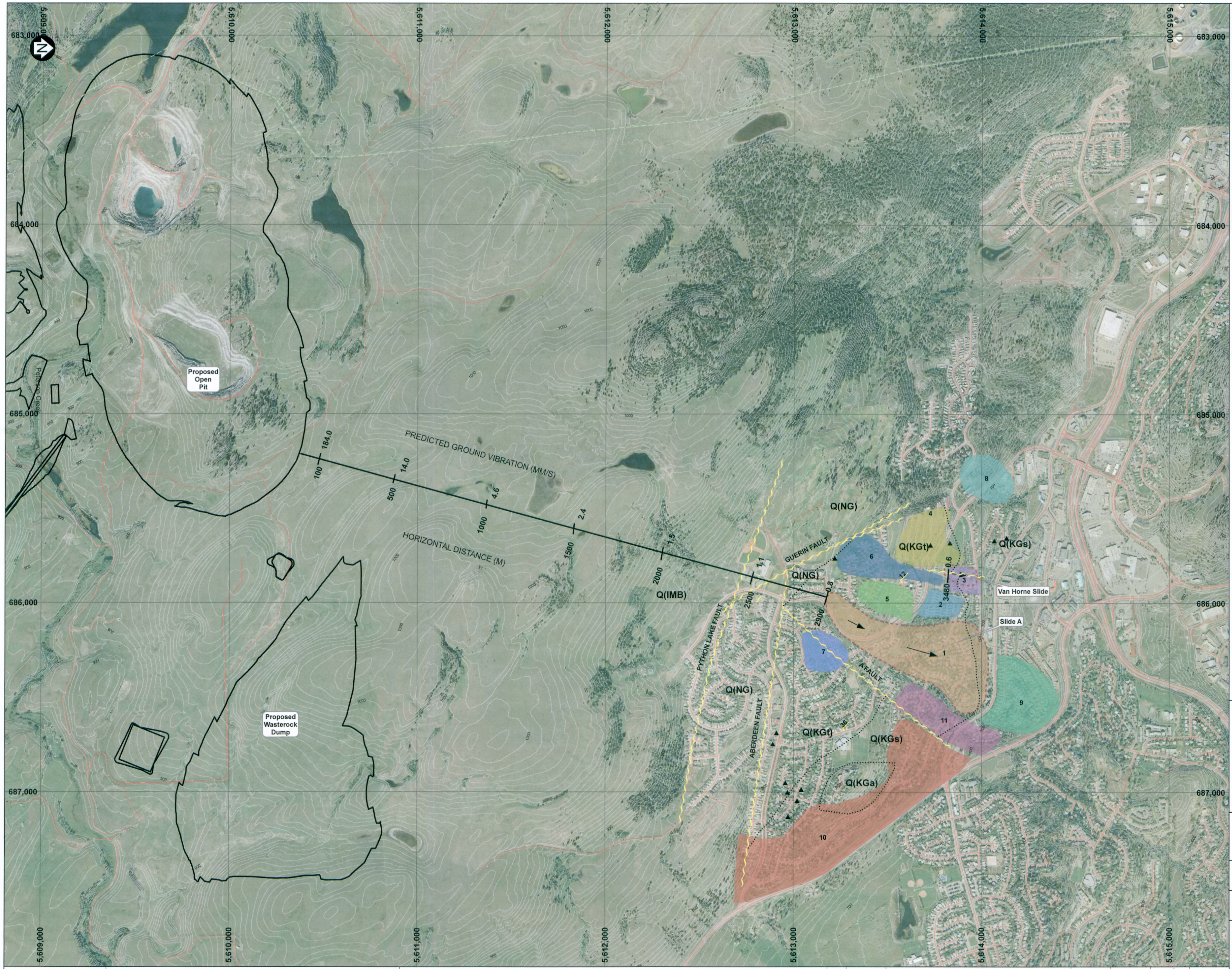

LEGEND:

GENERAL

- KINDER MORGAN PIPELINE
- ROAD
- RIVER/CREEK
- 🟦 LAKE
- CONTOUR 5M LIDAR
- CONTOUR 100M LIDAR
- CONTOUR 20M TRIM

PROPOSED FACILITIES

- MINE INFRASTRUCTURE

GEOLOGY

- ▲ SPRING
- FAULT LINE
- INCINED BEDDING
- ········ GEOLOGICAL BOUNDARY
- → LANDSLIDE

STABILITY ASSESSMENT REGIONS

1	AREA 'A'
2	DUNRAVEN
3	VAN HORNE SLIDE
4	RAVENWOOD
5	SIERRA VISTA (SANTA ROSA)
6	THE LINKS
7	GLASGOW
8	GUERIN
9	GLOAMING RIDGE
10	SIFTON
11	FLEMING (SIFTON NORTH)

GEOLOGY OF ABERDEEN HILLS AREA

QUATERNARY

Q(KG)	UNCONSOLIDATED SEDIMENTS UNDIVIDED; COLLUVIUM AND ALLUVIUM; FEW IF ANY OUTCROPS; PROBABLE SUBCROP UNIT WITHIN PARENTHESES

BEDROCK GEOLOGY

TERTIARY

KGa	KAMLOOPS GROUP - DACITE / ANDESITE FLOWS
KGt	KAMLOOPS GROUP - TUFFACEOUS MEMBER. BROWN WEATHERING, TUFFACEOUS (BENTONITIC) SEDIMENTS, MINOR TUFF
KGs	KAMLOOPS GROUP - SEDIMENTARY MEMBER (BRECCIA)

JURASSIC

IMB	IRON MASK BATHOLITH. GREY GREEN CHLORITIZED DIORITE AND GABBRO

TRIASSIC

NG	NICOLA GROUP - GREY - GREEN PORPHYRITIC META-ANDESITE AND METABASALT FLOWS AND PYROCLASTIC ROCKS

FOR INFORMATION ONLY

NOTES:

1. COORDINATE GRID IS IN METRES. COORDINATE SYSTEM: NAD 1983 UTM ZONE 10N.
2. THIS FIGURE IS PRODUCED AT A NOMINAL SCALE OF 1:10,000 FOR 24x36 ("D" SIZE) PAPER. ACTUAL SCALE MAY DIFFER ACCORDING TO CHANGES IN PRINTER SETTINGS OR PRINTED PAPER SIZE.
3. FACILITIES BASED ON AUG'14 VERSION OF THE GENERAL ARRANGEMENT.
4. GEOLOGY OF ABERDEEN HILLS AREA FROM GEOTEX CONSULTANTS LTD. MAPPING (READ, P.B., 1996).

200 100 0 200 400 600 800 1,000 m

SCALE

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PROFESSIONAL ENGINEER
J. E. HALEY
33730

J. Haley AUG 25, 2015

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KGHM AJAX MINING INC.

AJAX PROJECT

EA EFFECTS ASSESSMENT
ABERDEEN HILLS TERRAIN STABILITY

P/A NO.	DRAWING NO.	REVISION
VA101-246/34	G0005	0

REFERENCE DRAWINGS

DRG. NO.	DESCRIPTION
-	-

REVISIONS

REV	DATE	DESCRIPTION	DESIGN	DRAWN	CHK'D	APP'D

REVISIONS

REV	DATE	DESCRIPTION	DESIGN	DRAWN	REVIEWED	APPROVED
0	25AUG'15	ISSUED FOR INFORMATION	JEH	AMD	~~EAY~~	KJB

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