

CHILKOOT GEOLOGICAL ENGINEERS LTD.

Box 31146, Whitehorse, Yukon Y1A 5P7
chilkoot.eng@gmail.com (867) 335-5804 c



Geotechnical Evaluation – Geohazard Assessment

Moosehide Slide Area

Dawson City, Yukon – 2017



Dawson Museum Archives - View of St. Mary's Church (1906)

Prepared For: Yukon Government – Energy, Mines and Resources

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EXECUTIVE SUMMARY
Geotechnical Evaluation – Geohazard Assessment
Moosehide Slide Area
Dawson City, Yukon – 2017

Chilkoot Geological Engineers Ltd. was retained by the Yukon Government – Energy, Mines and Resources – Lands Management Branch to conduct a geotechnical evaluation in Dawson City, Yukon. The purpose of the evaluation was to conduct a geohazard assessment of the pre-historic Moosehide Slide (*Ēddhā dādhēchq*) and nearby areas to characterize their conditions and identify potential geohazards which may pose a risk to the North End Subdivision located within the townsite. This work was conducted in order to supplement our September 18th, 2016 geotechnical evaluation of the North End Subdivision where a potential risk to this area from the slide (and potentially nearby slopes) was identified along with a number of other geohazards which are typically encountered in northern permafrost settings.

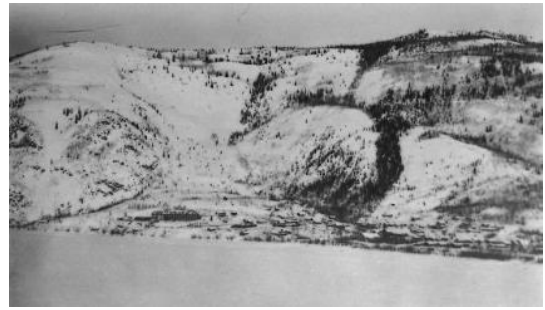


As our evaluation was preliminary in nature, our assessment was conducted from a qualitative perspective to estimate the probability of occurrence and level of severity any identified geohazard may pose. As such, our firm reviewed existing information and characterized the study area through site reconnaissance and auger drilling methodologies.

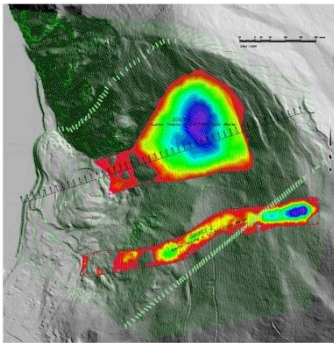
As a potential geohazard risk relating to the presence of an unstable block of soil and rock located near the headscarp of the slide had been previously identified by the *Yukon Geological Survey*, our study predominately focused upon characterizing the slide features in greater detail as the failure mechanisms associated with it are not fully understood.

Our assessment suggests the slide is the result of a single event which has been described as a pseudo-circular rock slope failure (Brideau et al) or else could, in our opinion, be related to a potential wedge failure. The failure is thought to have occurred as a combined result of high porewater pressures and the occurrence of a seismic event (Brideau et al). This event would however have been preceded and followed by other mass wasting slope processes which would have created the terrain features we see today. Our assessment verified that the movement of lower portions of Moosehide Slide are due to rock glacier mechanisms. Movement in the upper realms of the slide appear to be governed by earth flow mechanisms.

Further to our characterization of the slide feature, our firm identified the presence of additional geohazards in the form of a nearby erosion gully and previously poor slope conditions in the region of 3rd Avenue. It was apparent that the discharge area of the gully and slope corresponded to portions of the subdivision in the 3rd Avenue region. The geological information which was retained during our assessment suggested that the gully cycles through periods of instability when most of the discharged material is deposited in a brief time period. Observations of the 3rd Avenue slope noted that it is in a state of natural revegetation which would increase overall slope stability.



As a portion of our work involved working with a survey consultant, *Underhill Geomatics Ltd.* the volume of the slide event and other geological features were also estimated such that the



magnitude of the slide event could be compared with the estimated magnitudes which may correspond to the unstable blocks if they were to fail. The survey data suggests that the magnitude of debris associated with the primary slide event measured in the order of 2,225,000 m³. The total volume of potential debris which may be generated from failure of the unstable blocks was estimated to be no more than 102,000 m³ (or range between 0.6 to 4.6 % of the original slide debris magnitude).

While these geohazards may present a potential risk if the unstable blocks were to fail (en masse), or the slope conditions in the gully or above 3rd Avenue become unstable and; debris from any of these two events is able to propagate into developed regions of the townsite, from a risk stand-point, the probability of any of these events occurring is extremely remote.

As such, based upon our observations, the geomorphic conditions within the study area should allow for continued residential development in the North End Subdivision so long as the upslope conditions are monitored on a yearly basis. The geotechnical setbacks which were recommended in our September 18th, 2016 Geotechnical Evaluation Report should be observed to allow for a factor of safety from some of these potential geohazards. Additional assessment work is recommended to model the run-out path of any potential slope failure originating from the unstable blocks to determine whether or not the resulting debris could impact the townsite. Additional characterization of the region may be required if a higher risk is identified.



1.0 INTRODUCTION

Chilkoot Geological Engineers Ltd. was retained by the *Yukon Government (YG) - Energy Mines and Resources*, to conduct a geotechnical evaluation in Dawson City, Yukon.

The purpose of the evaluation was to conduct a geohazard assessment of the Moosehide Slide and nearby areas to characterize potential liabilities that may affect development of the North End Subdivision. As such, our firm retained site specific geotechnical information from the slide and nearby areas through literature review, site reconnaissance and auger drilling methodologies. In addition, our firm assisted a YG retained survey consultant, *Underhill Geomatics Ltd.* such that the volume of the slide event could be estimated.

The study area is located in Dawson City, Yukon within Tr'ondëk Hwëch'in Traditional Territory as noted in Figure 1.

Authorization to proceed with the work was granted on May 9th, 2017 by YG - *Energy, Mines and Resources - Lands Management Branch - Program Manager*, Mr.K.Fisher. The field work was conducted between May 19th and July 17th, 2017 in accordance with our April 24th, 2017 Proposal.

A description of our methodology and findings have been provided below.



2.0 SCOPE-OF-WORK

The intent of our geotechnical evaluation was to characterize the conditions within the study area and assess the stability of the slide and adjacent slopes from a qualitative perspective.

The hazard potential was to be assessed such that the probability of occurrence and level of severity they may pose upon the subdivision could be assessed as follows;

- The probability of occurrence for each of the hazards was classified as either probable, remote, extremely remote or else extremely improbable or range thereof.
- The severity of each hazard type was subsequently classified as either being catastrophic, hazardous, major, minor, having no effect or range thereof relative to the loss of life and major structural damage to residences.

While our assessment focused upon the potential geohazards related to the Moosehide Slide Area, other hazards related to flood and seismic events have also been discussed.

Recommendations have been provided to mitigate the potential geohazards where mitigation has been deemed feasible. In addition, we have utilized the retained information and provided supplemental recommendations relative to our September 18th, 2016 - Geotechnical Evaluation of the Proposed North End Subdivision.

3.0 METHODOLOGY

Our methodology was comprised of the following components;

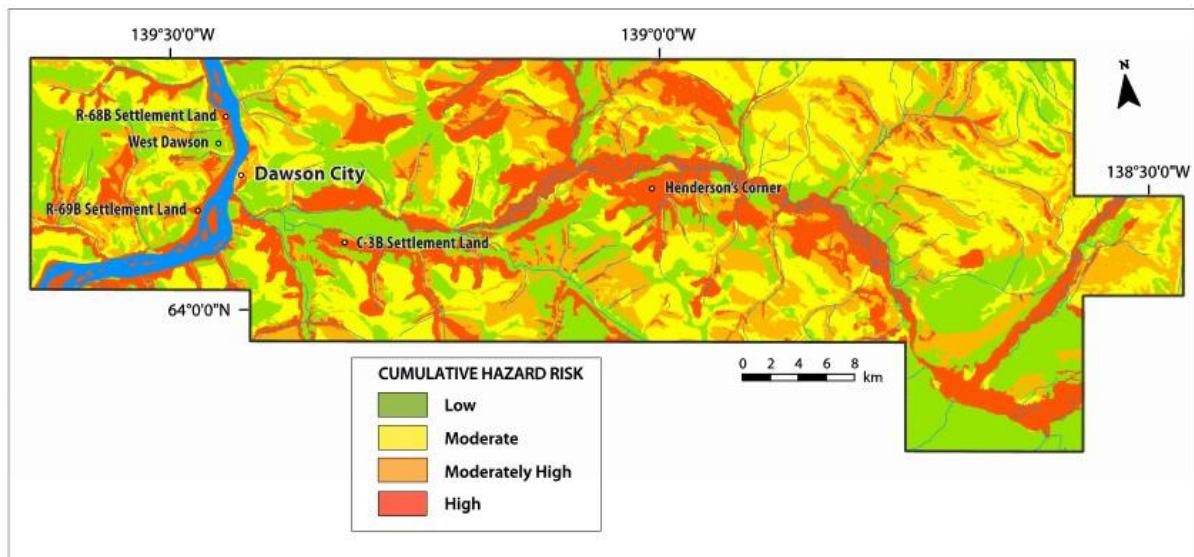
3.1 Literature Review

A literature review was conducted to provide additional information regarding of the Moosehide Slide and regional conditions. The following sources of information were reviewed;

Technical Reports

Dawson Natural Landscape Hazards – Geoscience Mapping for Climate Change Adaptation Planning prepared by the *Northern Climate ExChange – Yukon Research Center – Yukon College* - B.Benkert, K.Kennedy, D.Fortier, A.Lewkowicz, L.Roy, K.Grandmont, I.de Grandpre, S.Laxton, L.McKenna and K.Moote, 2015.

This report was compiled to serve as a baseline to allow for climate change adaptation planning as adverse effects of a warming environment have become a reality in northern Yukon. The intent was to generate a hazards map to help identify the potential for permafrost thaw, landslides and flooding. Their study area paralleled the limits of a 1:25,000 surficial geology map (Open File 2014-12) which has been described below.



Hazards Map (above) from Dawson Natural Landscape Hazards

The hazards report indicated that an approach was generated to consider local community concerns and infrastructure, disturbance history, permafrost distribution and characteristics, surficial geology conditions, hydrology and projections of future climate. Following the retention of scientific information and case studies, data related to slope angle, slope aspect, surficial materials and permafrost probability were input into a raster comprised of pixels which each represented 30 m². The hazard potential relative to each of these criteria was assigned and a map based upon a cumulative weighted risk was generated.



Figure (above) from Dawson Natural Landscape Hazards

The report was clear to indicated that while the hazard map can serve as an initial guide to local conditions, there are limitations due to site specific conditions and so detailed site studies (e.g., geotechnical or engineering studies) will still be required.

The Dawson City landslide (Dawson map area, NTS 116B/3), central Yukon prepared by M.Brideau, D.Stead, V.Stevens, C.Roots, P.Lipovsky and P.VonGaza, 2007.

This technical paper describes the slide and established a series of arrays and differential global positioning system (DGPS) pins which would allow for annual monitoring of slide movements to accuracies of < 1 cm as the slide debris is known to be moving.

The pre-historic slide is described as having occurred in altered ultramafic rocks. Although the mechanisms of movement are described as rock glacier or earth flow processes, these mechanisms could not be confirmed during the study which was undertaken. While the initial failure was thought to have been a catastrophic rock slide, their observations suggest that only small-magnitude mass movement events have occurred in the last century. Rockfall has been ongoing since the initial event to this day, as the upper part of the original debris field has since been buried by rock talus. The study noted recent signs of movement of a block of rock located upslope of the headscarp and within central portions of the slide debris where split trees provided visual

indicators of slope movement. The rate of movement in the central and lower portions of the slide debris were calculated to be ~ 4.5 cm/year.

The paper indicated that the lower realms of the debris slide had be re-contoured in the early 1980's following quarry operations.

Ongoing displacement monitoring at the Dawson City landslide (Dawson map area, NTS 116B/3) prepared by M.Brideau, D.Stead, C.Roots and P.Lipovsky, 2012.

This work summarized five (5) years of slide observations which were taken since the establishment of monitoring arrays described above in the 2007 paper. The paper indicated that time frame was not long enough to identify trends and so the risks associated with the unstable block (identified in the 2007 technical bulletin) above the headscarp, could not be determined. However, the paper quantified the volume of the unstable block which lay above the headscarp as measuring between 10,000 and 50,000 m³. This volume was based upon an assumed length of 200 meters, width of 50 meters and depth of 1-5 meters.

Engineering geology, electrical resistivity tomography and displacement monitoring of the Dawson City landslide, Yukon by M.A.Brideau, A.Bevington, A.Lewkowicz & D.Stead – 2015.

This technical paper summarized the findings of the previous studies and a more recent ~ 200 meter long electrical resistivity tomography (ERT) survey. Displacement data from a series of five pre-established monitoring arrays were also presented along with revised volume estimates of the unstable rock mass.

The report cited a 1910 study conducted by Tyrell who suggested the landform could be the results of a series of small rockfalls which resulted from frost shattering rather than being derived from a single event. The elongated nature of the colluvial deposit may have been the result of rock glacier deformation and/or seasonal ice creep which Tyrell suggested was proliferated/promoted by groundwater seepage which originated in the headscarp and in the accreting debris, a process he termed 'chrystocrene' (Brideau et al).

The ERT survey was conducted along portions of the mid-section and toe area and had a penetration depth in the order of 30 meters. The results of the

survey suggested that these portions of the slide were comprised of ice-rich permafrost which are overlain with a 3-5 meter thick active layer.

The displacement data which had been collected since 2006 (at some stations) indicated movements within a 40 meter section of the unstable block ranged between 4 and 12 cm/year and movements in the central section of the debris ranged between 9 and 27 cm/year.

The volume of the unstable rock mass was increased to 45,000-90,000 m³. This was based upon a length of 180 meters, width of 50 meters and depth between 5-10 meters.

Figure 3 below from the paper.

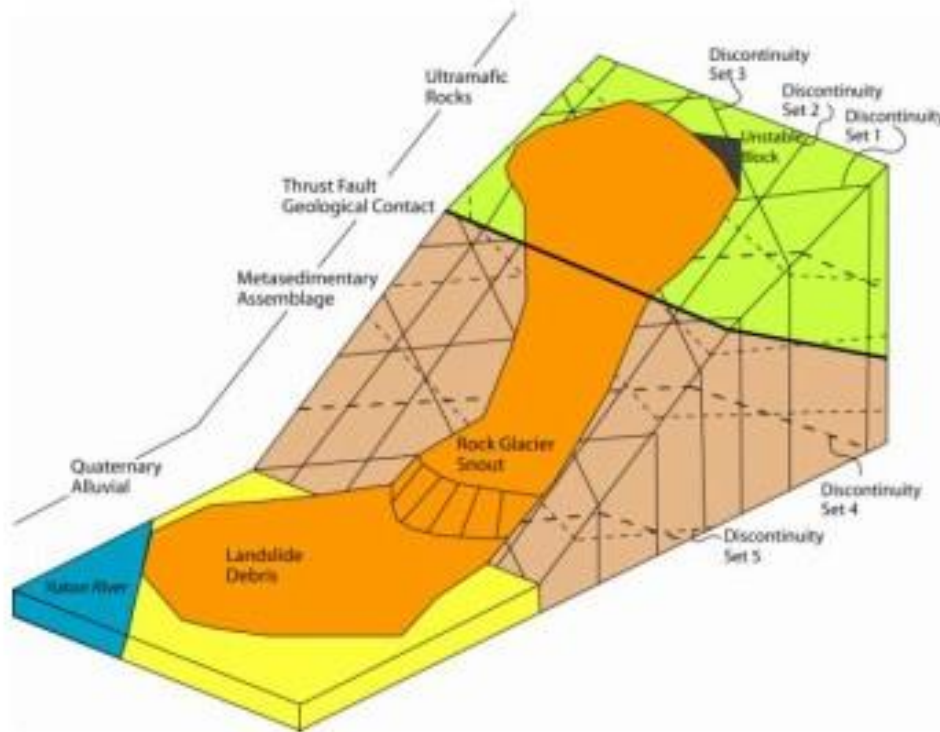


Figure 3: Conceptual block diagram of the main components of the Dawson City landslide.

Radiocarbon Dating Letter - GSC # 2781– October 25, 1979 by Owen L. Hughes

The letter was prepared by the *Geological Survey of Canada* for *Parks Canada*. In brief, the letter presented the radiocarbon dating results for a piece of wood retained from a 25 cm thick layer of peat located within the quarry which was located near the toe of the slide. The peat layer was described as



being located at an elevation of 335 meters. This elevation was approximately 1 meter above the pit floor at the time of sampling. The laboratory results suggested that the wood sample dated back to ~238 AD. The paper described the soils located below this peat horizon as being comprised of a ‘yellowish-grey-brown soil developed in rock detritus consisting mainly of serpentinized ultrabasic rock’ and that the sample was ‘overlain by 6.5 meters of unweathered rock detritus similar to that underlying the peat’. The letter suggests that based upon morphology derived from airphoto (A22199 #99-101) analysis, there were two possible subsequent stages of activity which buried the organic soil horizon.

Chilkoot Reports

A number of internal reports which were prepared for YG-EMR were reviewed to re-evaluate the stratigraphy of boreholes which were previously advanced in the region of the slide. The locations of these boreholes have been illustrated on Figure 2.

The following reports were reviewed.

- Geotechnical Evaluation – Proposed 2nd Avenue Upgrades – Dawson City, Yukon dated September 30th, 2014
- Geotechnical Evaluation – Proposed North End Subdivision – Dawson City, Yukon dated September 18th, 2016

In addition to these reports, our firm recently conducted a geotechnical evaluation by means of a site reconnaissance to characterize the potential geohazards that may affect an existing subdivision located just south of the North End Subdivision. The June 30th, 2017 report was entitled Geotechnical Evaluation – Geohazard Assessment – Block 4 North End Subdivision – Dawson City, Yukon. The location of the subdivision has been noted in Figure 1.

In brief, while geohazards related to rockfall, creep, erosion, surface drainage and the potential for localized slope failure were identified, the presence of regional geohazards (beyond the presence of permafrost) were not. Recommendations were provided to mitigate the risks associated with the geohazards which were identified.

The report reiterated that as with all subdivisions, development plans (ie site grading, surface drainage, erosion control, etc.) should be completed prior to granting development permits.

**Surficial Geology Map**

A 1:25,000 surficial geology map (Open File 2014-12) entitled Surficial Geology, Dawson Region, Yukon – Parts of NTS 115O/14 & 15 and 116B/1, 2, 3 & 4 compiled by K.McKenna and P.Lipovsky - *Yukon Geological Survey* was reviewed to provide insight into the regional geomorphology.

The map indicated that the study area lies in a region dominated by colluvial deposits. Moosehide Slide has been classified as a landslide. Fluvial deposits were identified south of the slide area.

Bedrock Geology Map

A bedrock geology map, available through the *Yukon Geological Survey*, identified the regional bedrock types and characteristics within the study area. The map was entitled Yukon Bedrock Geology Map – Yukon Geological Survey – Open File 2016-1 - 1:1,000,000 scale compiled by M.Colpron, S.Israel, D.Murphy, L.Pigage, and D.Moynihan.

Another presentation of these contacts was found on the *Yukon Geological Survey* – website. A portion of the website map, which illustrates the bedrock located in the region of the study area, has been attached in Section 4.7, below.

Aerial Photographs

A selection of aerial photographs obtained from the *YG – EMR Library* were reviewed to assess the study area.

Lidar Topographical Map

Topographical lidar data (which was collected by *McElhanney Consulting Services Ltd.* in August of 2013 and 2014), was supplied to us by *YG – Yukon Geological Survey*. The contour data on the map was generated at 5 meter contour intervals and provided sufficient detail to note subtle changes in the surface of the topography such as the presence of lineations, depressions, trails and other similar types of features.

Websites

Google Earth and the *Yukon Water Placer Atlas* were also utilized to better assess the study area through the imagery which was available.

Archives

A hand drawn picture of Dawson entitled ‘Birdseye view of Dawson’ drawn by Dr.J.Bell in 1903, was obtained from *YG’s – Department of Tourism and Culture* -



Yukon Archives. The drawing depicts Dawson and Moosehide Slide as viewed from West Dawson and has been attached as Figure 3.

Dawson Museum

Historical archived photos of the Moosehide Slide dating back to 1900 were viewed to better assess the change in the slope conditions since that time. A selection of these photos have been attached herein.

The photos from the 1900's shows the slopes adjacent to the slide area were entirely deforested.

3.2 Field Work Program

The field work program was comprised of a site reconnaissance, utility locates and drilling program.

Site Reconnaissance

A site reconnaissance was conducted by the undersigned between May 19th and July 17th, 2017 to note the field conditions and geological features within the study area. The work involved traversing several hiking trails and abandoned (overgrown) mining exploration roads in order to access the study area. In some cases, off-trail hiking was required in order to explore other geological features.

Our observations were documented through a combination of field notes, GPS waypoints and photographs. A description of some of these observations have been summarized in Section 4.0 – Local Conditions.

Establishment of Survey Control

Our firm established a series of survey stakes at ~ 15 meter intervals immediately above a headscarp (near elevation 660 meters) which is associated with an unstable block (identified in the Brideau et al, 2007 paper). These stakes were established as control upon which future monitoring could be based. In addition to the survey control, notation for the terrain blocks located in the region referred to as the 'unstable block' was established for ease of reference. As each of these blocks were deemed to be unstable, the original 'unstable block' was renamed as Alpha Block to avoid confusion during discussions.

A diagram which illustrates the block notation and their approximate extent relative to the established survey stakes has been attached below.

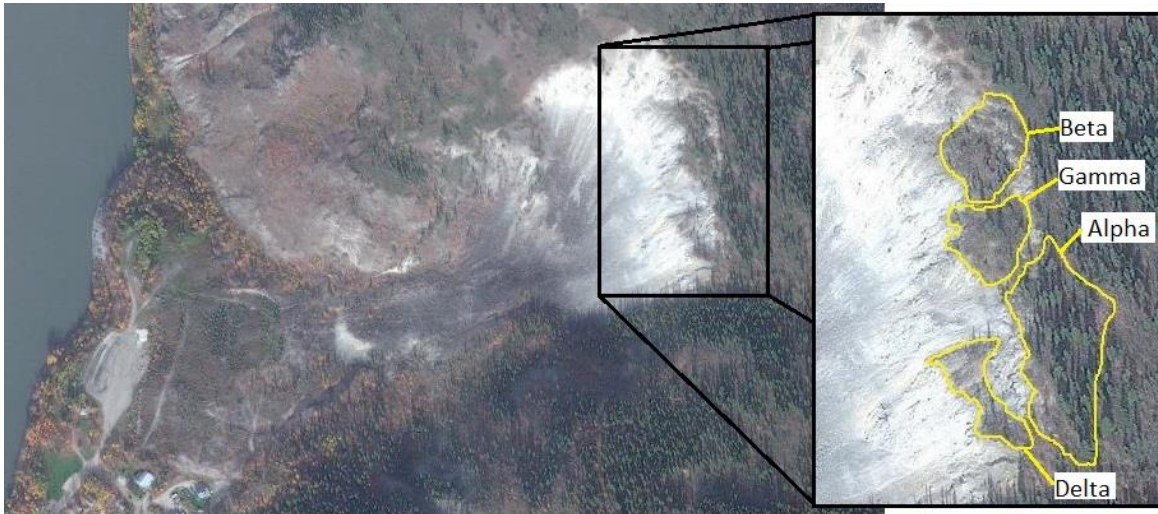


Figure (above) modified from YG – Water Placer Atlas Imagery



Photo (above) taken during traverse May 23, 2017

Establishment of Monitoring Arrays

Our firm established three monitoring arrays comprised of a series of (15M x 0.75 m) rebar. Two of the arrays (A & B) were established on the central and western portions of Alpha Block (as three arrays had already been established on the eastern half by Brideau et al). The third station (C) was established on Beta Block located to the north.

Our monitoring stations were established as follows;

Station		Block	Date	Distance to 1 st rebar	Distance to 2 nd rebar
A	0 + 093	Alpha	May 19 th , 2017	8.07 m	20.37 m
B	0 + 076.5	Alpha	May 20 th , 2017	21.13 m	NA
C	0 + 175	Beta	June 1 st , 2017	20.32 m	NA

The intent of establishing the rebar at distances in the order of 20 meters was to assess whether or not the rate of movement varies relative to the distance from the headscarp.

The failed slabs of snow avalanches commonly increase their speed where steeper slopes aspects are encountered, which are the terrain conditions in the case of the unstable blocks.

Photo of Chilkoot Station C
facing upslope (right)

Photo of Chilkoot Station B
facing south (below)



The three monitoring arrays established on the unstable block by Brideau (et al) were measured as follows;

Station		Block	Date	Distance	Distance
A	0 + 059	Alpha	May 19 th , 2017	9.50 m (to west bar)	9.15 m (to east bar)
B	0 + 038	Alpha	May 19 th , 2017	7.10 m	NA
C	0 + 025	Alpha	May 19 th , 2017	6.50 m	NA

It was not possible to calculate the rate of movement of the Brideau arrays as previous survey data was unavailable.

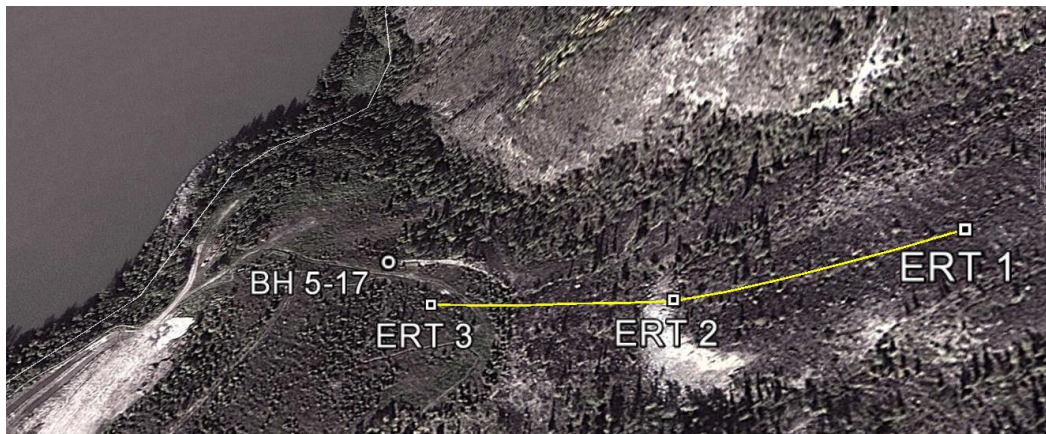
Utility Locates

Utility locates were conducted prior to drilling to confirm the proposed borehole locations were clear of potential underground hazards. This involved contacting *Northwestel*, *Yukon Energy Corporation (YEC)*, and the *City of Dawson*. No subsurface conflicts were noted.

Drilling Program

A drilling program was conducted between May 24th and 26th, 2017 by *Donjek Drilling* utilizing a CME-750 drill mounted on a 5500 Series GMC 4-wheel drive truck. The drill was employed under the direction of our firm.

The program was comprised of advancing five (5) boreholes (BH 1-17 to BH 5-17) utilizing both 150 mm Ø solid-stem and 200 mm Ø hollow-stem continuous flight augers. The augers were utilized to obtain soil samples and characterize the subsurface conditions. Boreholes BH 1-17 to BH 4-17 were drilled at the approximate locations noted in Figure 2. Borehole BH 5-17 was advanced through the slide rubble near the ERT line as noted below.



Imagery (above) modified from Google Earth

The intent of auger advancement varied.

Boreholes BH 1-17 to 4-17 were advanced within 43 meters of one another along Judge Street (between 2nd and 3rd Avenues) to characterize the soils located in this region. These boreholes were advanced to an average depth of 7.4 meters utilizing solid-stem augers.

BH 5-17 was advanced in order to install a casing and groundwater monitoring well within the slide rubble to the maximum depth allowable relative to the subsurface conditions and fiscal constraints. Both solid-stem and hollow-stem augers were utilized to attain a borehole termination depth of 15.15 meters below the ground surface. Given the coarse nature of the slide rubble, solid-stem augers were utilized to advance the borehole to a depth of 13.35 meters. The larger diameter hollow-stem augers were subsequently advanced to allow for standard penetration test (SPT) methodologies to be employed at depths of 13.41 meters and 14.94 meters below the ground surface.



Borehole BH 5-17 facing east

The SPT's allowed for the retention of relatively undisturbed soils samples to allow for a more accurate characterization of the subsurface materials which were encountered. SPT samples are retained utilizing a 50 mm diameter uncased sampler tube which is driven into the subsurface utilizing a 63.5 kg hammer which is dropped from a height of 760 mm. The number of blows required to drive the sampler tube is counted in 150 mm intervals until the sampler tube is driven a distance of 450 mm. The total number of blows required to drive the sampler tube the final 300 mm is referred to as the 'N-value' and allows for an assessment of the materials relative density/consistency based upon pre-established guidelines where thawed materials are encountered. While the approximate correlation has been presented on the 'Notes on Soil Logs' enclosed in Appendix A, as the SPT's were conducted in frozen soils a direct correlation of the soil density could not be made.

Borehole and Site Survey

Following completion of drilling, the elevations of the boreholes were surveyed (utilizing a *Leica LR Rugby* laser level) relative to the arbitrary

elevation given to the intersection of Front and Judge Street. This allowed for a more accurate comparison of stratigraphy which was encountered during previous evaluations. The relative elevations of the boreholes have been noted on the Borehole Logs enclosed in Appendix A. The geodetic elevations were cross-referenced from the topographical Lidar map and were determined to be:

Borehole	Geodetic Elevation (m)
BH 1-17	~ 330.7
BH 2-17	~ 333.3
BH 3-17	~ 331.9
BH 4-17	~ 332.8
BH 5-17	~ 347

Borehole Logs

During drilling, field soil logs were maintained by the undersigned to record the stratigraphy of the soils that were encountered. This information was utilized along with visual observations and results of the laboratory analysis in order to compile the Borehole Logs which have been enclosed in Appendix A.

Sampling Program

A total of sixty-four (64) soil samples were retained during the field work program. This included fifty-eight (58) grab samples retained from the solid-stem auger flighting (~ 2 samples per 1.5 meters), two (2) SPT samples retained during hollow-stem auger advancement and four (4) hand samples retained during the site reconnaissance.

Once the samples were retained, they were described on the field soil logs and subsequently sealed in air-tight plastic bags. Thawed soils were classified in accordance with the '*Unified Soil Classification System*'. Otherwise the '*Classification for Frozen Soils (adapted by Linnell and Kaplar, 1966)*' was utilized to classify frozen soils.

The samples were subsequently numbered in sequence and transported to our Whitehorse laboratory facilities to undergo more detailed examination as described in Section 3.3, below.

Borehole Termination

Boreholes BH 1-17 to BH 4-17 were terminated at an average depth of 7.39 meters below the existing ground surface, but varied between 6.10 meters (BH 4-17) and 9.14 meters (BH 2-17). BH 5-17 was terminated at a depth of 15.15 meters.

Other than BH 1-17 which may have encountered a boulder at a depth of 6.71 meters, refusal was not encountered.

The solid-stem boreholes were backfilled with the auger cuttings approximately 15 minutes following completion of drilling. This allowed for time to estimate rates of groundwater seepage or borehole collapse (to assess the relative degree of soil densities). With the exception of borehole BH 1-17, groundwater seepage was not encountered in any of the boreholes during this elapsed time frame.

Borehole BH 1-17 encountered possible groundwater at a depth of 5.5 meters below the ground surface at the time of drilling, however, seepage was extremely slow and only 3 cm of water was noted in the borehole following 15 minutes. Groundwater was encountered in borehole BH 2-17 as described in Section 4.4, below.

On average, 1.15 meters of borehole collapse was noted upon auger withdrawal where solid-stem boreholes were advanced on Judge Street.

A 1.0 meter thick zone of bentonite was established at a depth between ~ 1 and 2 meters in accordance with good drilling practices where solid-stem boreholes were advanced.

Monitoring Well Installations

Two wells were installed during the drilling program to allow for future monitoring of the local groundwater conditions.

These wells were comprised of;

a 2" diameter ABS monitoring well installed in BH 2-17 to depth of approximately 4.51 meters below the existing ground surface. The lower 3.1 meters of this well was screened and encased in a silt-sock to minimize the influx of fines and pro-long the life of the well.

a 1.5” diameter ABS monitoring well was installed in BH 5-17 to depth of approximately 15.03 meters below the existing ground surface.

The monitoring wells were constructed as follows;

BH 2-17 (Judge & 3 rd Ave)		BH 5-17 (Moosehide Slide)	
Well	Backfill	Well	Backfill
1.41 m of solid ABS pipe (as measured from ground surface), over	Well casing & concrete with 0.7 m thick bentonite plug, over	4.16 m of solid ABS pipe, (as measured from ground surface), over	Well casing & concrete with 1.0 m thick bentonite plug, over
3.1 m of well screen w/ silt-sock	3.3 m filter sand (10-20 Target)		0.5 m of 20 mm minus White Channel gravel, over
			1 m bentonite plug
			3.66 m of 20 mm minus White Channel gravel, over
		10.87 m of well screen	5.49 m of filter sand, over
			3.05 m of slide rubble slough

Bentonite plugs were utilized to seal the annular space in accordance with good well installation practices. Access to the wells were restricted through 4” diameter lockable steel casings which extended approximately 0.8 meters above the existing ground surface. The well casings were painted in a high visibility paint for warning purposes.

Borehole Survey

The borehole locations were surveyed utilizing a tape measure or in the case of BH 5-17, hand-held GPS unit. The elevations of the boreholes were surveyed relative to borehole BH 4-16 (located at the corner of Front and Judge Street) such that the stratigraphy could be compared to boreholes which were previously advanced in the area in 2014 and 2016. A *Leica Rugby 150LR* laser level was utilized.

The borehole locations were subsequently plotted on the Lidar topographical map such that approximations of their geodetic elevations could be made. In general, boreholes BH 1-17 to BH 4-17, advanced on Judge Street, were drilled at higher elevations which ranged from 331 to 334 meters. These boreholes were terminated at depths which corresponded to elevations of approximately 324 meters. Borehole BH 5-17 was advanced at an elevation of approximately 347 meters and was terminated near an elevation of 332 meters.

Hand Sampling Program

A hand sampling program was conducted to obtain soil and rock samples from within the study area. These samples were utilized to further characterize the conditions with the study area.

3.3 Laboratory Work Program

A laboratory work program was conducted between May 28th and June 13th, 2016 at our Whitehorse laboratory facilities in order to characterize the index properties and conditions of the retained soil samples.

The analysis was comprised of natural moisture content determination and visual laboratory classification of all six-four (64) soil samples. The moisture content analysis was conducted in accordance with ASTM D 2216-92.

Twenty-eight (28) of these samples were analyzed in greater detail through grain size distribution (in accordance with ASTM D 422-633) to allow for their classification utilizing the *Unified Soils Classification System (USCS)*. A description of the *USCS* has been provided in Appendix A.

The results of the laboratory analysis have been presented in Table I and have been summarized on the Borehole Logs enclosed in Appendix A.

3.4 Slide Volume Assessment

Our firm worked with a YG retained survey consultant, *Underhill Geomatics Ltd. (UGL)* to assess newly acquired topographical (lidar) data of the slide and nearby areas, such that an estimate of volumes located within the study area could be made.

The lidar data was collected by *McElhanney Consulting Services Ltd.* in August of 2013 and 2014 and was supplied by YG – Yukon Geological Survey.

In brief, the analysis involved calculating the volumes of the depleted mass within two source areas located within the study area. The depleted mass is defined as the volume below the original ground surface (prior to the slide, rockfall and erosion events) and above the existing (failed) surfaces in the zones of depletion.

Source Area # 1 represents the volume of material which was once located within the slide area. This includes the volume of the primary slide event along with the volume attributed to subsequent rockfalls and erosion which have occurred since that time.

Source Area # 2 represents the volume of material which was once located within the limits of Gully # 4 but has since been eroded.

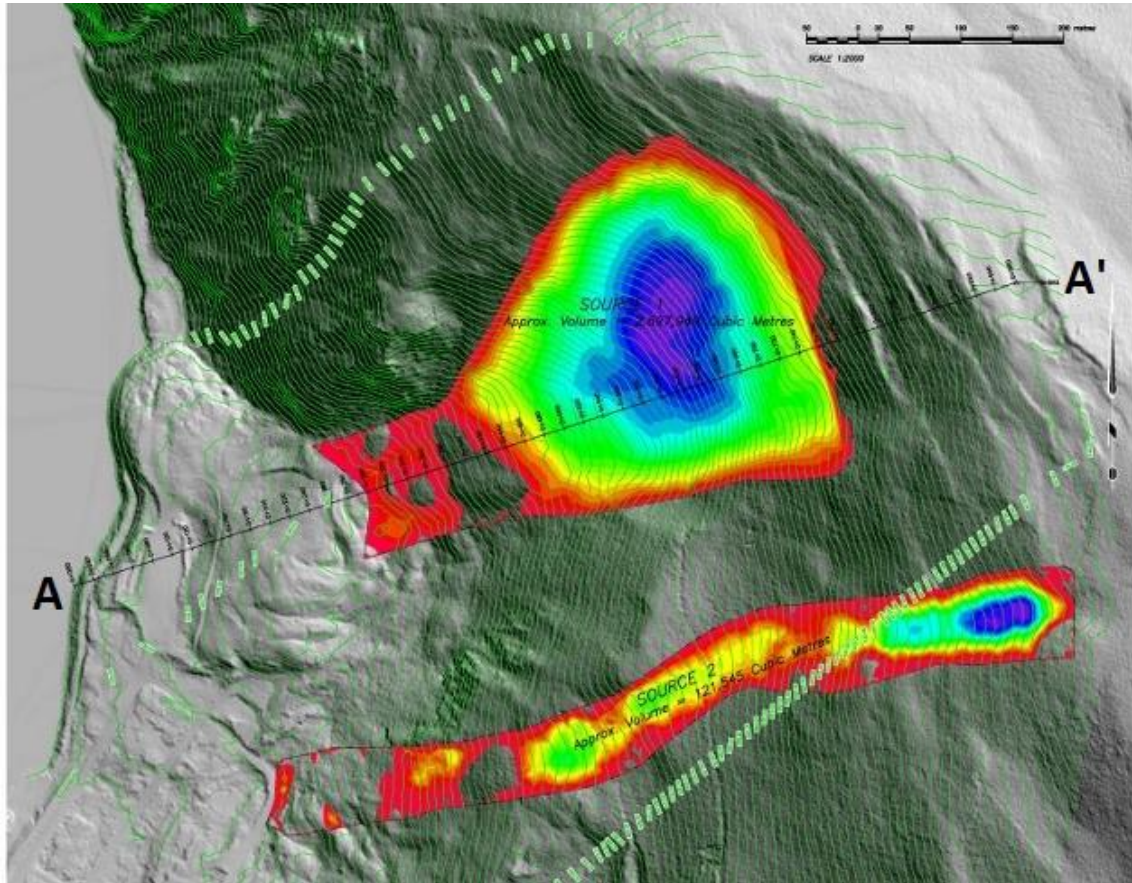
While volume calculations of the slide debris (located in the accumulation zone) was considered such that comparisons could be made with the depleted mass volume, this exercise was deemed to be too complex an undertaking relative to the scope-of-work and so this volume was not determined.

Depleted Mass Calculations

The original ground surface for the Source Areas was generated by extending the contours of the prevailing slopes located just beyond the failure zone until they intersected within the zone of depletion. This surface was used to represent what the original topography may have been prior to the slide event. The existing lidar surface which lay below the zone of depletion was subsequently subtracted from the assumed original ground surface in order to estimate the volume of the depleted mass.

The volume of the depleted mass from Source Area # 1 was estimated to be in the order of 2,697,949 m³.

The volume of the depleted mass from the selected area within Source Area # 2 (Gully # 4) was estimated to be in the order of 121,545 m³. As the gully within this area extended an approximately 100 meters beyond the iterated area, the actual volume within Source Area # 2 has been estimated to be ~137,000 m³.



Underhill Geomatics Ltd. depleted mass isopachs of Source No.1 and Source No.2 (above)

Slide Debris Volume Calculations

As the depleted mass calculations for Source Area # 1 also included the volume of rockfall and erosion which has occurred in the area since the time of the slide event, these corresponding volumes were estimated such that an order of magnitude estimate of the slide volume could be determined.

Rockfall Volume Estimate

This volume was calculated by measuring the area of the talus cone and mid-section located upslope of the moving slip-face. This area was given an average thickness based upon cross-section analysis. The average thickness of the rockfall area was estimated as being 17.9 meters thick. This thickness was estimated by projecting the prevailing (steeper and shallower) slope gradients just beyond the rockfall area underneath the existing topography in this region. This value was subsequently scaled by an arbitrary factor of 0.65 to account for thinner peripheral areas.

As such, the volume of rockfall which has occurred after the slide event has been estimated to be in the order of 415,000 m³.

Erosion Volume Estimate

This volume was estimated by pro-rating the length of Gully # 3 relative to the the length (and hence volume) of Gully # 4 (the approximate volume of which was calculated as Source No.2). In addition, as the features of Gully # 3 were not as pronounced as those within Gully # 4, an arbitrary scale factor of 0.6 was included. The estimated volume of material which may have eroded from Gully # 3 was therefore estimated to be ~ 56,000 m³.

Other erosional features within the slide area were otherwise ignored.

The total volume attributed to rockfall and erosion within the slide area was estimated to be ~471,000 m³.

Hence, the volume of slide debris which would be attributed to the primary event has been estimated as ~2,226,949 m³.

Volume of Unstable Blocks

The volume of the unstable blocks has been estimated based upon their respective areas and an assumed arbitrary slip surface in the order of 10 meters.

Block	Area (m ²)
Beta	1920
Gamma	1410
Alpha	4967
Delta	1845
Total Area	10142

As such, the total volume of the blocks could be in the order of 100,000 m³.

This total volume equates to ~4.6 % of the primary slide events estimated volume.

4.0 LOCAL CONDITIONS

4.1 Study Area

The study area, which lies on the east bank of the Yukon River within the municipal limits of Dawson City, encompassed the Moosehide Slide and nearby adjacent slopes. These slopes harbored a number of gullies which flanked either side of the slide area. Some of the gullies and portions of the slide features extend into the North End Subdivision which is located on the north side of the Dawson townsite.

4.2 Physiographic Region

The study area is part of the Boreal Cordillera Ecozone and lies within the Klondike Plateau immediately south-west of the Tintina Trench. The mountains in the region are of the Dawson Range, a sub-range of the Yukon (Mountain) Range which dominate much of central Yukon and eastern Alaska. These mountains rise to elevations in the order of 1500 meters. The terrain has been described as smooth, rolling, unglaciated terrain, which is incised by narrow, deep, V-shaped valleys.

The elevations in the region of the study area vary. The Yukon River, which flows to the north along the western periphery of the study area, lies at a relative elevation of ~ 315 meters. The top of the dike which protects the town from potential flood events was constructed to a geodetic elevation of approximately 321 meters. The prominent headscarp of the slide lies at elevations which vary between 630 to 670 meters. The highest point above the study area is the Midnight Dome which is located at an elevation of approximately 880 meters.

Regionally, the vegetation is predominately comprised of sparse boreal forest. Black spruce and birch dominate regions underlain by permafrost. The understory consists of a variety of lichen, mosses, willow, alders and shrubs. Scrub birch and willows are also prevalent from low-lying regions to areas well above the treeline. Permafrost is extensive and discontinuous.

4.3 Site Description

The slide has been described as a pseudo-circular slope failure which occurred near a thrust fault which separated older overlying ultramafic (serpentinized) rock and younger more competent metasedimentary rock (Brideau et al, 2012). The Brideau study separated the slide into four (4) distinct areas comprised of;

- a headscarp,
- an upper talus slope/cone,
- a central mid-section, and
- a lower toe area.



*View of slide and study area facing north-east.
Photo taken from road to Sunnydale in West Dawson.*

The failure is thought to have occurred as the result of high pore-water pressures and seismic activity (Brideau et al, 2012). Continued slope instability has been recorded in each of these slide areas. Rockfall is ongoing in the upper (headscarp) realms of the failure. Evidence (from Brideau et al) suggests the unstable portion of the headscarp is moving at rate of 4-12 cm/year while the mid-section of the landslide deposit is moving at higher rate of 9-27 cm/year.



June 1st, 2017 panoramic view of slide from headscarp facing south.

Headscarp

The headscarp, which measures ~ 300 meters across and 100 meters high, is comprised of weaker ultramafic (serpentinized) rock. It was apparent during our traverse that the headscarp area is an active feature which spawns rockfall and at some locations, exhibits signs of slope movement as evidenced by a series of unstable blocks.

Unstable Blocks

A series of unstable blocks, which were identified during previous YGS studies are located on the eastern flank of the headscarp between approximate elevations of 610 to 655 meters. Of the four blocks, Alpha Block was the largest. While it's approximately 120 meters in length, its width varies from predominately 35-40 meters up to 60 meters in a region where disintegrated fragments have separated from the terrace-like part of the feature.

The terrace area of Alpha Block is well treed and harbors a moss and lichen forest floor under which permafrost may prevail. While the southern parts of the Alpha Block headscarp predominately measure in the order of 2 meters in height, the scarp becomes more pronounced midway through the feature as one traverses north. Relative to the prevailing elevation of the terrace area, the height of the headscarp varies from 5 to 15 meters in height. While split trees and stretched roots are present throughout the Alpha Block feature, they become less prevalent in the other blocks (Beta/Gamma/Delta) suggesting Alpha Block may be a relatively newer feature.



May 19th, 2017 photo of split tree on Alpha Block

A comparison of photographs from 1904 (as noted in the Parks Canada Interpretative Kiosk located on the dike) and one taken during our assessment, shows how the headscarp has become more distinct above Beta, Gamma and portions of Alpha Blocks, likely due to disintegration of the vegetation and surficial cover which makes the headscarp more easily visible. While the lidar imagery suggests that the headscarp above Beta and Gamma Blocks is in the order of 20 meters in height, there does not appear to be perceptible movements relative to changes in their respective elevations when comparing the two photos. The disintegration of vegetative features is however clearly evident.



1902 Photo by Edward.C.Adams



May 22, 2017

Rockfall

The headscarp region spawns rockfall which tumbles down a 45° slope and accumulates in the talus cone area of the slide.

A traverse of the central portion of the slide rubble was conducted during rainfall on May 21st. Given the precipitation, rockfall from the headscarp area was ongoing at the time of our traverse. Several newly deposited boulders (which measured up to 1.5 meters in size) were noted within the rubble/boulder field. These new boulders were clearly identifiable as lichen had not yet begun to discolor them and as they lay upon living vegetation.

An inspection of the fall-line from where the boulders are thought to have originated noted impact marks upon other pre-existing lichen covered boulders. Shattered pieces of the parent boulders (which were predominately comprised of serpentinized rock) were clearly evident at the points of the impact.

*May 21st, 2017 – Recent boulder located in the talus cone area.*

The locations of several of the fresh boulders were marked with a hand-held GPS to better characterize the distance that they had tumbled down the debris field.

Recent boulders were noted a distance of ~ 150 meters up-slope of the mid-sections slip-face and approximately 430 meters from the shore of the Yukon River. Based upon the angle of repose of the contour data in this area, it appears that rockfall does not generally tumble further than this area (elevation ~ 450 meters).



Talus Cone Failures

The size of the rocks within the talus cone varies. The upper realm is dominated by smaller sized gravel/cobble particles. Larger clasts, in size to 1.5 meters, have tumbled further down-slope (to elevations in the order of 450 meters) where a lower angle (15°) slope serves as a catchment area. Creep mechanism appear to dominate the catchment area as rockfall debris appears to be carried down-slope forming a steady 30° slope on the upper portions of the mid-section. Lateral shear trenches, stretched roots and split trees were evident.

Signs of recent slope failures were noted on the west side of the talus cone immediately below the flume.



Mid-Section

The mid-section of the slide is located below the talus cone feature. The higher realms predominately serve as a final catchment area for rockfall which originates from the talus cone and headscarp areas located above. Earthflow mechanisms appear to dominate this area as evidenced by the formation of a slip face near its lower realms.

Slip-Face

A slip-face (which is located between elevations of 360-385 meters), is located at the base of the mid-section. The composition of the materials located within the slip-face are the result of mass wasting processes whereby the overlying (mid-section) rockfall debris has essentially disintegrated. The nature of slope movement continually spawns fresh detritus and thus prevents vegetation from become established along the slip-face.



May 21, 2017 photo of slip-face (above)

Toe Area

Located immediately below the mid-section is the toe area of the slide which contains the only visible remnants of debris which originated from the primary slide event. While the majority of the toe area has been recontoured (as it was quarried in the 1970's and 1980's), an undisturbed section (which extends approximately 50 meters beyond the toe of the mid-section slip-face) provides insight as to the nature of the original slide debris. This section shows the presence of predominately serpentinized ultramafic rocks which measure up to 1.5 meters in size and are similar to those located at higher (mid-section) elevations.

Recontoured Slide Rubble

The majority of the recontoured portions of the slide rubble had been re-graded to a slope of 14° or less. These sloped areas were generally vegetated with a variety of grasses and shrubs. Considering that quarry operations ceased by 1987, in general, the slopes present within the recontoured region of the slide appeared to be stable as signs of mass erosion and slope failures were not identified.

Toe Area Features

While the toe area of the slide extends partially into the North End Subdivision, it's contact with remnants of colluvial fan deposits in this area is poorly understood and so for purposes of discussion, the toe of the slide debris and colluvial fan deposits have been considered synonymous.

Slump features (measuring up to 5 meters long and 1-2 meters wide) were noted at the intersection between the slide rubble and the Yukon River.

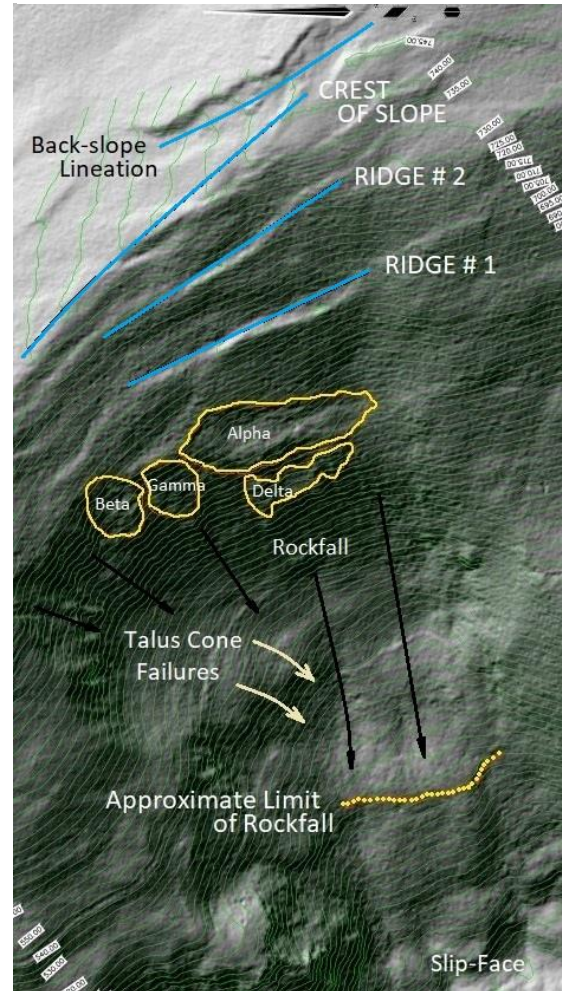
Lineations Above the Headscarp

The sequence of ridges (# 1 & # 2) which are located above the headscarp at approximately 50 meter intervals may be remnants of ancient thrust faults. These lineation features are located on a 40° slope which is poorly vegetated. The nature of their (north-south) alignment however, allows the features to intercept surface drainage which propagates down-slope to the west.

Back-Slope Lineation Feature

A lineation terrain feature located approximately 250 meters NNW of the Midnight Dome was assessed on May 22nd, 2017. This feature trended approximately north-west to south-east. The gully-like feature, which measured ~ 30 meters in width and was flanked by a 5 meter high ridge on its north side, directs local drainage towards the north-west. Although there was no sign of rock outcrops, the feature likely formed within the confines of an ultramafic discontinuity.

Figure (below) modified from Lidar imagery.



Erosion Gullies

A series of erosion of gullies are located within and just north of the study area. Four of these gullies have been numbered in sequence from north to south in the figure noted below for reference purposes.



Imagery (above) modified from Google Earth.

Gullies # 1 and # 2, which are located ~ 260 meters and 75 meters north side of the slide debris, respectively (as measured along the Yukon River), show signs of active rockfall as debris fans are present at their base. Rockfall from Gully # 1 discharges into the Yukon River while rockfall debris from Gully # 2 terminates on a sliver of alluvial deposits. Local residents (living on Albert Street) indicated that they had heard the sound of rockfall originating from these gullies in mid-May, 2017. They described the sounds of boulders plunging into the Yukon River and indicated that the event spanned the course of 15-20 minutes.

The two gully locations coincide with metasedimentary Klondike Schist.

Gully # 1 (+ 260 meters)

It was evident that rockfall from this gully was very recent as the debris had buried ice located on the shoreline of the Yukon River.

Gully # 2 (+ 75 meters)

A number of fresh fractured boulders in size to 1.5 meters were present at the base of the gully. As the gully did not directly discharge into the Yukon River, several small trees (in size to 80 mm Ø) had

clearly been hit by the rockfall. Some of these trees were pinned beneath the boulders.



May 28th, 2017 view of slide area from West Dawson ferry landing (above).

The characteristics of Gullies # 3 and # 4, which originate within ultramafic rocks, differ.

Gully # 3

This gully is in fact comprised of a series of gullies which coalesce along the southern edge of the slide. It exhibits signs of active rockfall and erosion where higher elevations and steeper slopes prevail. Otherwise the gully and its erosion features are less defined where it intersects the slide rubble.

Gully # 4

This gully was well vegetated and there were no signs of rockfall. However, seepage zones were noted when the gully was traversed on May 21st. These seepage zones were no longer visible during a subsequent traverse of the gully which was conducted on July 17th. During this time, the gully was traversed from an elevation of 490 meters to the intersection of Judge Street & 3rd Avenue (elevation 330 meters). Numerous areas within the gully were noted where tree branches had washed down-slope



and become lodged in regions where trees were more densely concentrated.

The discharge point of this gully lies at the corner of Judge Street & 3rd Avenue.

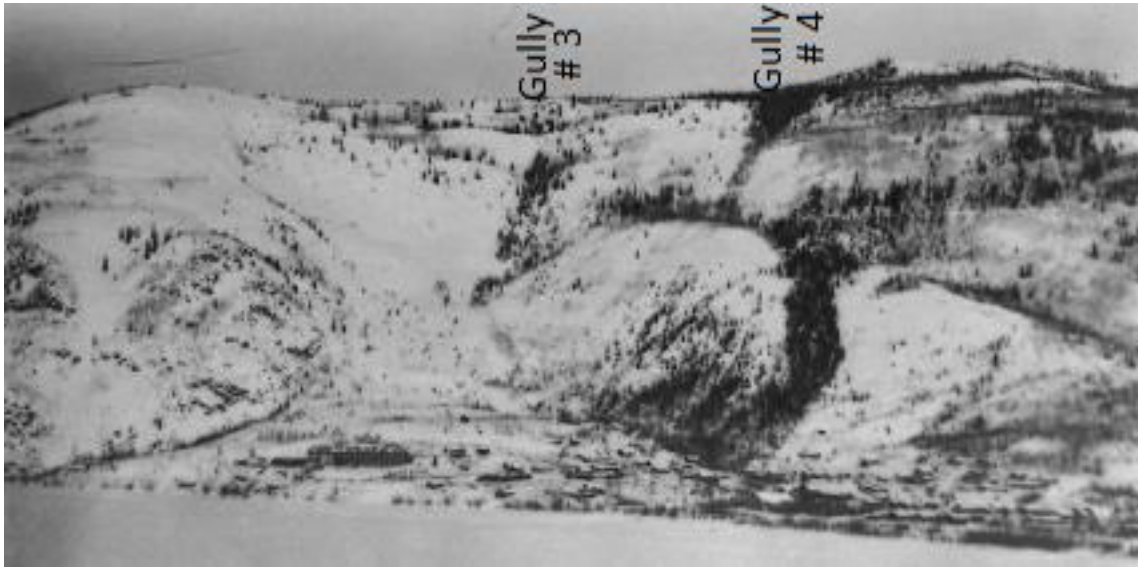


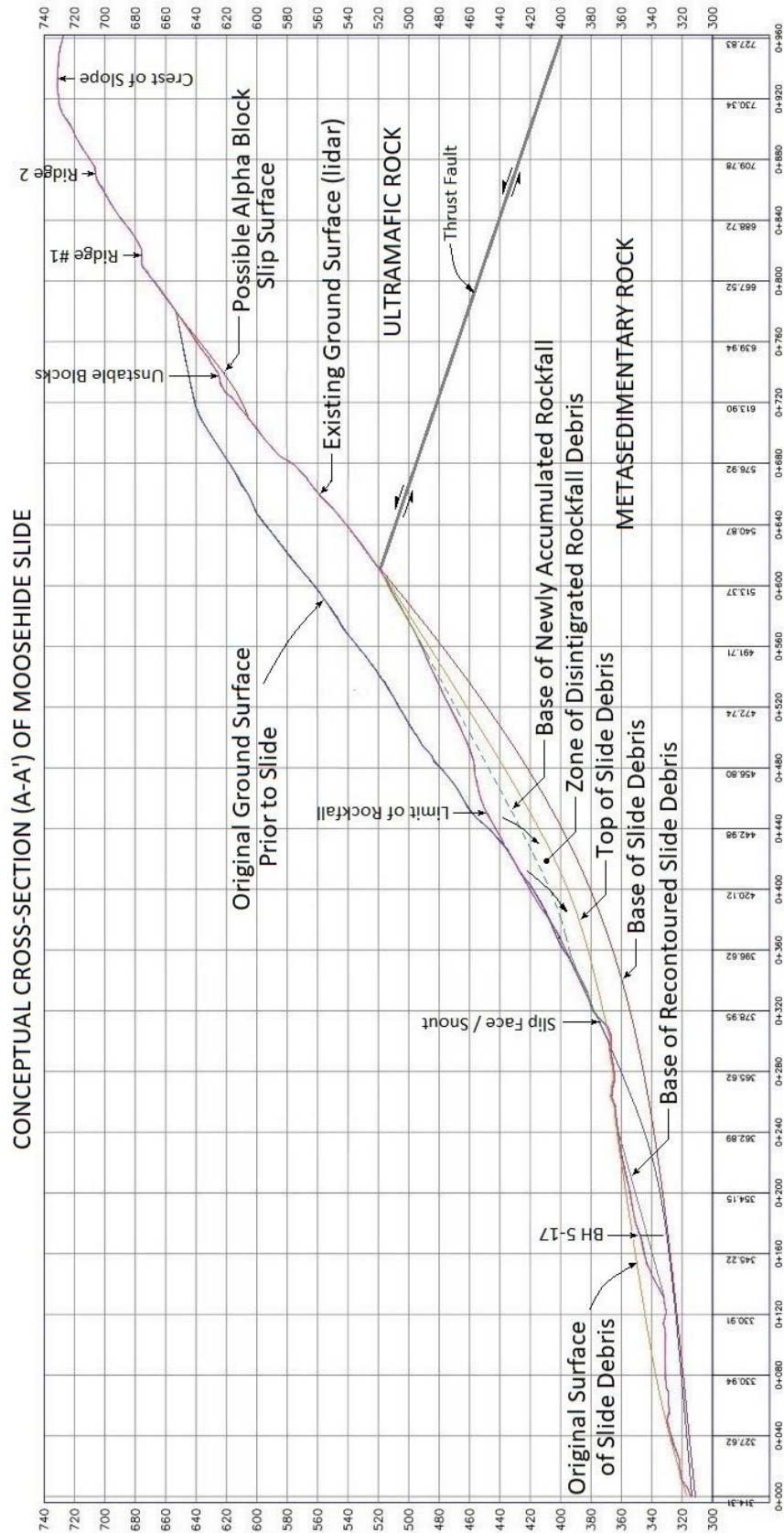
Photo (above) from Dawson Museum Archives (circa 1934)

Exploration Cut

An exploration cut feature located approximately 350 meters west-south-west (WSW) of the Midnight Dome was assessed on May 22nd, 2017. This feature (located at an elevation of 770 meters) was the remnant of an exploration pit which had been cut into the slope utilizing a bulldozer. The exposed stratigraphy was comprised of 100 mm of organic silt which overlay 2.2 m of dark brown silty sandy gravel and detritus over 3.0 meters of fractured serpentinitized ultramafic rock. While the nominal size of rock measured in the order of 200 mm, the odd rock in size to 400 mm was noted. There was no sign of intact rock outcrops within the exploration pit or else in the surrounding area.

Conceptual Cross-Section of Moosehide Slide

A conceptual cross-section of Moosehide Slide which highlights geotechnical points of interest and the various layers it may be comprised of, has been shown below.



4.4 Anthropogenic History

As steep slopes generally dominate the study area, anthropogenic activities have been limited to lower elevations of the toe-area where shallower gradients prevail. The lower realms of the slide was once historically developed between the early 1900's and 1940's and harbored St.Mary's Catholic church, hospital and school along with numerous wall tents.



Photo of St.Mary's Church (above) from Dawson Museum Archives (circa 1906)

This region has since lain predominantly dormant relative to housing development. The region was subsequently quarried between the late 1960's to the late 1980's as the slide rubble was utilized as general purpose fill around the townsite and to construct the protective dike.

One of the roads located at the toe of the slide (noted in 1951 to 1987 airphotos) has since been covered by slide debris. As the road is clearly visible in the 1987 airphoto when the quarry appears to have already been closed (as evidenced by the presence of a series of



1984 Airphoto noting quarry operations

boulders which were established at the toe of the recontoured slope), it appears the road has become covered as a result of the ongoing movement of the slide. The rate of movement of this northern lobe of the slide debris is likely quite high relative to other regions as surface and groundwater are concentrated in this area due to morphological constraints.

4.5 Geomorphology

The geomorphology is complex as fluvial deposits derived from the Yukon River intersect both colluvial and slide deposits within the study area.

The Yukon River has been depositing a sequence of fluvial deposits in the region of the townsite along its eastern banks (to elevations in the order of 317.5 meters above sea level). As with all fluvial deposits, channel infilling may have occurred during deposition. These fluvial deposits intersect (and at some locations are partially overlain with) colluvial apron deposits. In the region of the slide (generally north of George Street), the fluvial deposits are overlain by a sequence of slide rubble and colluvial fan deposits. The colluvial and slide deposits are derived from a variety of (mass wasting) slope processes.

Regionally, the townsite has been filled to an elevation of 319 meters. As such, spatially, the fluvial deposits (and fills) tend to intersect colluvial deposits (to the east) and slide deposits (to the north) where higher elevations (near 320 meters) are encountered. Higher elevations (beyond 340 meters) are generally bedrock controlled.

Glaciation

Evidence shows that the Dawson area and Klondike Plateau have probably not been glaciated since Pre-Reid advances (2.65 Ma to > 200 Ka).

Permafrost

Dawson and the study area lies within the zone of extensive discontinuous permafrost (50-90%). The permafrost can vary from poorly bonded soils with non-visible ice to massive ice lenses ranging in size to tens of meters.

Regionally the permafrost is probably more than 100 m thick with taliks (thawed subsurface) present beneath large rivers and lakes and beneath south-facing slopes. While thawed areas may also be encountered where the region has been previously cleared permafrost is generally widespread throughout the study area.

Watercourses

The Yukon River flows to the north along the western periphery of the study area.

Surface Drainage

Surface drainage through the study area varies. Within the limits of the slide, the drainage is generally undefined due to the coarse permeable nature of the rubble. Beyond the limits of the slide, the surface waters are concentrated in a series of gullies and draws. One of these primary gullies parallels the south-east side of the slide debris.

4.6 Surficial Geology

The distribution of the surficial deposits within the study area have been illustrated in the surficial geology map of Dawson (Open File 2014-12).

The map described the deposits within the study area as being comprised of colluvial and fluvial materials. Both types of materials are geomorphologically modified through various mechanisms such as erosional, fluvial, mass movement and/or periglacial processes such as cryoturbation and permafrost processes.

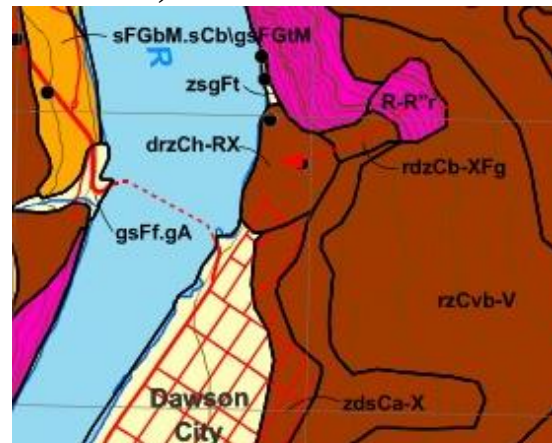


Figure (above) from Surficial Geology Map (File 2014-12)

Colluvium Deposits

Colluvial fan and apron deposits are located within the study area. These deposits are located at higher elevations and are comprised of differentially weathered and unsorted detritus. These materials have accumulated along the base of nearby bedrock controlled slopes. The gradients of the colluvial fan and aprons deposits differ between 8 and 12 percent, respectively. The lower gradient of the colluvial fan deposit is likely due to the presence of higher groundwater flows which help transport sediment greater distances away from the slope.

The surficial geology map (Open File 2014-12) described the colluvial materials within the region of the study area as follows;

“Colluvium on uplands and slopes is generally derived from weathered bedrock and loess, resulting in a silt-rich diamicton containing angular, local bedrock clasts. On

steeper slopes, colluvium is generally coarser grained, as it has been deposited by rapid mass wasting processes such as rock fall, debris flow and avalanches. Slower processes such as sheetwash, solifluction and creep occur on gentler slopes, which in conjunction with greater accumulations of loess and the presence of near-surface permafrost, result in finer grained colluvium. Colluvial aprons found on lower slopes and the uphill sides of terraces are commonly ice-rich and are primarily composed of re-sedimented loess and peat (muck)”.

Colluvial Slide Deposits (drzCh-RX) which are hummocky and comprised of mixed fragments, rubble and silt materials which are ‘transported by down-slope, gravity-driven processes such as creep, solifluction, landslide and snow avalanches’. Permafrost is widespread throughout these deposits.

Colluvial Apron Deposits (zdsCa-X) which are comprised of silt, mixed fragments and sand colluvium. The surficial geology map describes colluvial aprons as being found on lower gentle slopes where slower mass wasting processes such as sheetwash, solifluction and creep occur. These regions are commonly fine-grained and ice-rich. Permafrost is widespread.

Colluvial Fan and Apron Deposits (rCfa) which are comprised of colluvial rubble. As these deposits are found on moderate slopes, the material is ‘generally derived from weathered bedrock and loess, resulting in a silt-rich diamicton containing angular, local bedrock clasts’.

Fluvial Deposits

The fluvial deposits in the Dawson area are comprised of Klondike River Valley Deposits. These deposits are characterized by a thin veneer (< 1 m) of organics/peat which overlie ice-rich silts which contain minor amounts of sand and gravel. These fine-grained deposits are known to extend to depths in the order of 4 meters but can extend to depths of 8 meters near the Yukon River. These materials overlie predominately clean, coarse grained sand and gravel materials (where the dredge tailings are derived). The granular deposits are predominately frozen and extend to underlying bedrock which is known to be located at depths of 12-18 meters below the prevailing grade of the townsite.

The surficial geology map (Open File 2014-12) described the fluvial materials within the region of the study area as follows;

Fluvial Plain Deposits (szgFp-X) which are comprised of sands, silts and gravels. These materials have been deposited by modern rivers and are subject to frequent flooding. Permafrost is widespread throughout these deposits.

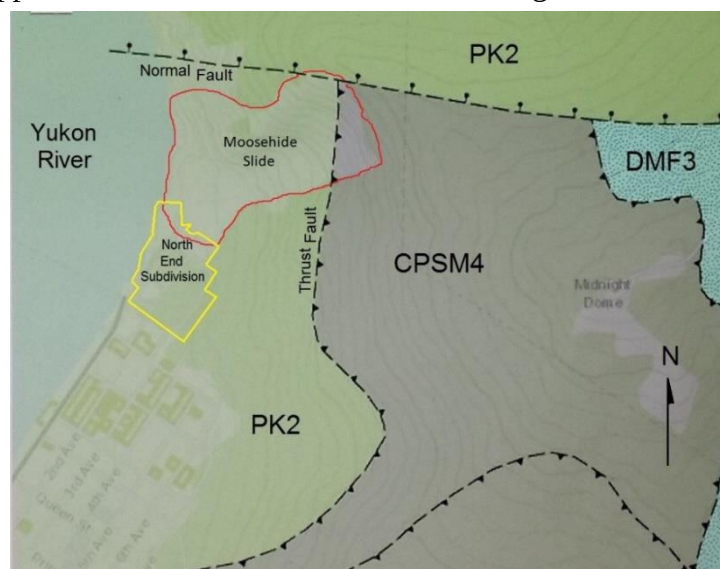
Fluvial Terrace Deposits (zsgFt) which are comprised of well sorted sands, silts and gravels. These materials have been deposited by modern rivers and are subject to frequent flooding.

Fills

In addition to the above noted native soil deposits, fills have been imported into the townsite to facilitate both historical and recent development due to the poor founding nature of the fluvial deposits. The fills overlie the above noted deposits and are typically coarse grained but may also contain appreciable amounts of fines and deleterious organic materials. These fills typically measure in the order of 1.5 meters thick.

4.7 Bedrock Geology

The regional geology in the Dawson area is comprised of two complex assemblages comprised of the Intermontane (Yukon-Tanana) and Slide Mountain Terrane. These assemblages consist of an intensely deformed, variably metamorphosed and sheared group of ultramafic, igneous and metamorphosed rocks which include serpentine, diorite, amphibolites and schist (Yukon-Tanana) and a weakly deformed assemblage comprised of shale, siltstone and sandstone which contains some phyllite (Slide Mountain). We have modified a *Yukon Geological Survey* website map of the area noting the approximate distribution of these assemblages as follows;



Government of Yukon - EMR
Geotechnical Evaluation – Geohazards Assessment
Moosehide Slide Area
Dawson City, Yukon – 2017

The corresponding rock assemblages are described in the Yukon Bedrock Geology Map (Open File 2016-1) legend, as;

Yukon Tanana Terrane (metasedimentary)

DMF3 - Finlayson – assemblage of minor quartzite, metavolcanic clastic rocks

PK2 - Klondike Schist – felsic metavolcanic rocks intercalated with metaclastic rocks.

Slide Mountain Terrane (ultramafic)

CPSM4 - Slide Mountain - oceanic assemblage of chert, argillite, minor sandstone and variably serpentinized ultramafic rocks; metapyroxenite, dunite and harzburgite.



In addition to these assemblages, the undersigned is aware of a plutonic contact (which harbors granitic rock) located on the Dome Road. This contact is located as noted in the modified *Yukon Geological Survey* – website map (right).

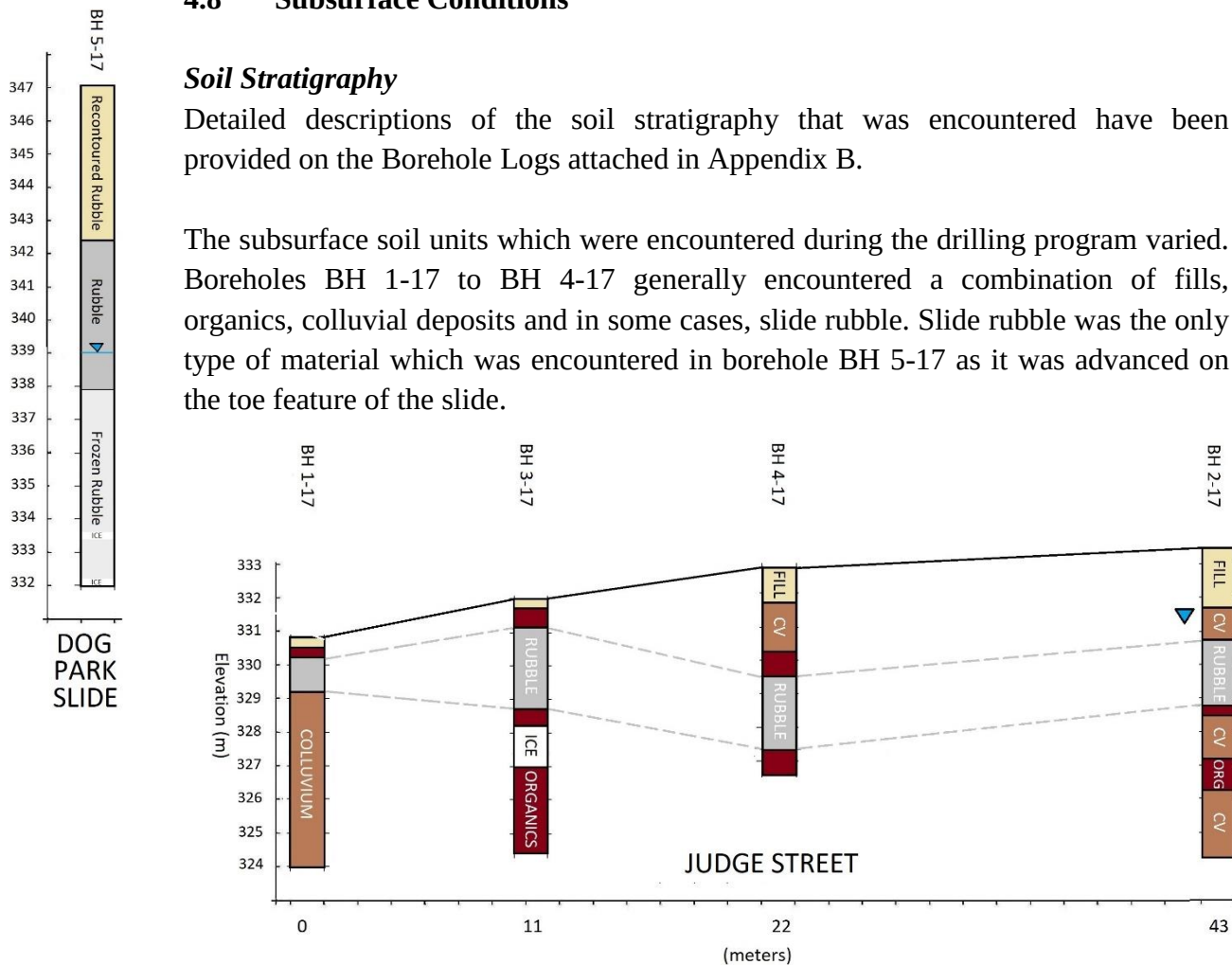


4.8 Subsurface Conditions

Soil Stratigraphy

Detailed descriptions of the soil stratigraphy that was encountered have been provided on the Borehole Logs attached in Appendix B.

The subsurface soil units which were encountered during the drilling program varied. Boreholes BH 1-17 to BH 4-17 generally encountered a combination of fills, organics, colluvial deposits and in some cases, slide rubble. Slide rubble was the only type of material which was encountered in borehole BH 5-17 as it was advanced on the toe feature of the slide.



A summary of each of these soil units has been described as follows.

Fills

Fills were encountered at the ground surface in each of the four (4) boreholes (BH 1-17 to BH 4-17) which were advanced on Judge Street.

The fills were comprised of predominately coarse grained granular materials which were utilized to construct the road base. While the fill thickness measured on average 0.73 meters, the fills in BH 1-17 and BH 3-17 were considerably thinner (0.1 meters).

BH 5-17 encountered fill comprised of recontoured slide debris to a depth of 4.57 meters below the ground surface.

Organics

Organics soil units were encountered in BH 1-17 to BH 4-17. These soil units were comprised of organics and organic silts which contained varying amounts of rootlets, organic inclusions and in some instances, tree branches.

0.5 meter thick organic deposits were interbedded between colluvial and slide rubble deposits in boreholes BH 2-17 and BH 4-17 at similar elevations. Borehole BH 3-17 encountered 4.4 meters of ice-rich organic deposits which were frozen and ice rich. The borehole was terminated within these organic deposits at a depth of 7.62 meters.

Colluvial Deposits

Excluding the colluvial slide rubble, these deposits were encountered in boreholes BH 1-17, 2-17 & 4-17 advanced along Judge Street. These deposits were predominately comprised of a sand and gravel mixture which contained varying amounts of silt, organic inclusions, fractured detritus, cobbles and potential boulders. As these deposits are the result of slope erosion processes, they can be similar in appearance to the slide rubble, having been derived from the same origin. A trace of asbestos fibres were noted within some of the retained samples.

Slide Debris/Rubble

Slide debris/rubble was encountered in each of the five boreholes.

The slide rubble in boreholes BH 1-17 to BH 4-17 advanced on Judge Street measured 2.0 meters thick on average (with a standard deviation of 0.42 meters). The rubble was located at a similar elevation (329 m) in each of the four (4) boreholes. The rubble directly overlay organic deposits in three (3) of the four (4) boreholes (BH 2-17 to BH 4-17). Organic deposits subsequently overlay the rubble in three (3) of the four (4) boreholes.

Borehole BH 5-17, which was advanced on the toe feature of the slide encountered slide rubble through-out borehole advancement. However, the upper 4.6 meters of material was comprised of re-contoured debris which were remnants of the former quarry.

While the drill action and SPT N-Values suggest the rubble is dense to very dense, it is in fact extremely unconsolidated as evidenced by a lack of auger cuttings.

The slide rubble likely contains cobble to boulder sized materials. The gravel sized materials within the rubble was comprised of fractured serpentinized rock. The fine-grained constituents of the slide debris is fibrous in nature and contained asbestos.

BH 5-17 - Sample No.59 - Depth = 13.41-13.59 meters

USCS = GM (Silty Sandy Gravel)

Moisture Content = 67.5% Silt = 31.2% Sand = 22.1% Gravel = 46.7%

NRC = Ice & Rubble Ice Volume by visual estimate = 40%

This SPT sample required 105 hammer blows to penetrate 180 mm into the slide rubble.

In brief, the sample was comprised of;

- 25 mm of highly fractured green serpentine rock which overlay,
- 30 mm of light brown (silty) granulated ice which encased a 3 mm thick by 13 mm wide lens of clear ice, which overlay,
- 125 mm of light grey fractured rock interspersed with light grey (silty) ice with some rock particles coated in up to 3 mm of clear ice.



BH 6-17 - Sample No.60 - Depth = 14.94-15.15 meters

USCS = GM (Silty Sandy Gravel)

Moisture Content = 23.0 % Silt = 22.4% Sand = 18.1% Gravel = 59.5 %

NRC = Vr & Vc Ice Volume by visual estimate = 25%

This SPT sample required 107 hammer blows to penetrate 210 mm into the slide rubble as follows;

Penetration (mm)	Hammer Blows
0-50	1
50-100	8
100-150	40
150-210	58



In brief, the sample was comprised of;

80 mm of highly fractured green serpentine rock which overlay,
50 mm of light brown (dirty) granulated ice and fractured serpentine rock
which encased clear ice lens which measured in size to 5 mm, which overlay,
30 mm fractured serpentine encased in clear and dirty granulated ice, over
50 mm of light grey fractured rubble.



Groundwater

Groundwater was initially encountered in BH 2-17 at the time of drilling at a depth of 0.6 meters below the ground surface. The soil conditions suggest this is a perched watertable as dense soils are located approximately 2.44 meters below the ground surface.

While the well installed in borehole BH 5-17 advanced into the slide rubble was dry immediately following its May 26th installation and on June 6th, groundwater was noted in this borehole at a depth of 8.1 meters when the well was checked again on July 17th. This depth corresponds to an elevation approximately 1 meter above the permafrost elevation in this borehole.

Observations of the monitoring wells installed in the region noted the following:

Well	Elevation (m)	Groundwater		Groundwater		Groundwater		Groundwater	
		Depth	Elevation	Depth	Elevation	Depth	Elevation	Depth	Elevation
		July 23, 2014		October 17, 2014		July 25, 2016		July 17, 2017	
1-14	320.2	Dry	NA	NA	NA	NA	NA	NA	NA
3-14	325.7	NA	NA	Dry	NA	Dry	NA	Dry	NA
3-16	320.0	NA	NA	NA	NA	4.20	315.8	4.26	315.74
4-16	329.5	NA	NA	NA	NA	Dry	NA	5.80	323.70
2-17	334.3	NA	NA	NA	NA	NA	NA	4.40	329.90
5-17	347.0	NA	NA	NA	NA	NA	NA	8.05	338.95

Perched groundwater conditions would likely prevail at higher elevations due to the presence of underlying fine-grained materials and other impermeable boundaries (i.e. bedrock, permafrost, etc.).

Permafrost

Permanently frozen soils were noted in each of the boreholes except BH 2-17.

The frozen soils were classified in accordance with the *National Research Council Classification System*, as;

Ice & OL - ice greater than 25 mm thick with soil inclusions.

Nbn –segregated ice not visible by eye, well bonded with no excess ice.

Nbe - segregated ice not visible by eye, well bonded with excess ice.

Vr - segregated ice visible by ice less than 25 mm – random or irregularly oriented ice formations,

Vc – segregated ice visible by ice less than 25 mm – ice coatings on soil particles,

Vx – indicating individual ice crystals or inclusions < 1 mm in size and approximately 1 % ice saturation by volume.

Seasonal Frost

The surficial soils would generally be exposed to seasonal frost to depths of approximately 1.8 meters. This depth of penetration would vary depending upon the thickness of organic strata and overlying fills which act as insulation for the underlying soils.

Bedrock

There was no indication of bedrock within any of the boreholes which were advanced. Based upon the undersigned's experience, it's understood bedrock may be encountered in the order of 20 meters below the prevailing grades of the townsite near an elevation of 300 meters.

Regionally, the surface of the bedrock is known to be fractured and in a state of decomposition due to weathering and periglacial processes. The degree of fracturing and decomposition varies depending upon the origin of the parent rock and local setting.

4.9 Geohazards

The Dawson Natural Landscape Hazards report provided a description of the types of natural (geo)hazards in the Dawson region. These hazards were classified as being related to either seismicity, mass wasting, floods and/or permafrost related processes.

A description of each of these hazards has been summarized as follows;

Seismic Events

According to the *National Building Code*, Dawson City lies within a region classified as having a moderate potential for seismic activity. The report indicated that *Natural Resources Canada* (2013) had recorded thirty-four (34) earthquakes $\leq$ a magnitude of 4.0 within 50 km of Dawson since 1980. Larger earthquakes were not observed over this time frame.

Aside from seismic accelerations which will impact infrastructure that result from earthquakes, they may also induce landslides (as described below) and cause liquefaction to occur.

Liquefaction is a condition whereby the soil mass loses its strength due to an increase in pore water pressures. The presence of saturated fine grained soils would make regions more susceptible to this type of hazard.

Mass Wasting

Mass wasting is the result of downslope movement of rock, debris and soil caused by gravity. These slope movements occur when the shear stress exceeds the shear strength of materials over an essentially continuous failure surface. The process may be either extremely rapid or else take place over the course of years to centuries. The affected materials will move along either a shallow or else potentially deep-seated failure zone.

Slope movements can occur through falls, topples, landslides, lateral spreads, flows (which include avalanches, solifluction, slope wash and creep) mechanisms or else combinations thereof. Once the failed materials come to rest, the resulting slope is generally more stable than that which had existed prior to the failure.

A description of the prominent failure modalities which may be present within the region have been described as follows;

Landslides

Landslides are the result of rapid downslope movement of rock, debris and soil which is driven by gravity. They are commonly associated with steep to moderately steep slopes and can be triggered as a result of seismic activity, permafrost degradation, increase in pore water pressure from surface and/or groundwater, forest fires, formation of ice lenses and extension cracks and other similar types of factors.

Rock Glacier

Rock glaciers are generally lobes or tongues of rock which are frozen along with interstitial ice, ice lenses and fine grained debris. Although the mechanisms of movement are poorly understood, it's thought that movement is the result of plastic deformation.

Earth Flow

Earthflows are the rapid to slow downslope viscous movement of generally fine-grained plastic to non-plastic materials. The rates of movement within earth flows are higher than that of creep.

Creep

Creep is caused by the repeated expansion and contraction of the upper part of the regolith (weathered bedrock surface) or other colluvial derived materials through repeated freeze/thaw and/or wetting/drying cycles. Combined with gravitational forces, this intermittent/seasonal process results in slope movement in generally steep terrain, although even shallow angled slopes may exhibit this behavior. While the rate of movement in colluvial materials is almost imperceptible (in the order of 1-5 cm/year), its effects can be seen in the form of deformed tree trunks, tilted fences and other similar types of indicators. The movement commonly occurs across the entire slope and does not extend much greater than 1 meter below the ground surface. The movement can be exaggerated in regions of permafrost which are undergoing thaw degradation as water cannot drain through the underlying frozen soils thus increasing pore water pressures and a greater potential for movement. Undercutting the toe features of these failures can increase the rate of movement significantly.

Literature suggests the colluvial slide deposits are moving at a rate which may range between 4 to 27 cm/year in the central regions of the slide.

Rockfall

Rockfall results from the release of rocks from a competent mass which progresses down-slope due to gravity. While the hazards generally originate from the slide headscarp and accumulate in the upper talus zone, they may also originate from and impact lower elevations.

Floods

As with the majority of Dawson, the lower realms of the study area would be prone to flood events if it were not for the protective dike which was established in the 1980's. The higher elevations in the proposed North End Subdivision will make these areas less susceptible to flood events in the event of overtopping or else rise in groundwater levels.

The majority of Dawson has been flooded prior to the establishment of the dike on a repeated basis, given its proximity to the Yukon River and floodplain setting. Historically, these flood events have stemmed from the formation of ice dams located in either the Klondike or Yukon Rivers.

Permafrost

As permafrost is prevalent throughout the region, thaw degradation due to climate change and anthropogenic processes impacts the soil stability, particularly in regions where the soils are ice rich and not thaw stable.

5.0 DISCUSSIONS

5.1 Geohazard Assessments

Geohazard assessments are complex undertakings which involve comprehensive monitoring of site conditions through a variety of means. In this setting, the instrumentation would include the installation and monitoring of;

- slope-inclinometers,
- thermistor strings,
- monitoring wells / pore pressures,
- electronic distance measuring devices, and
- other similar types of geotechnical instrumentation.

The retained information is often integrated into detailed terrain modeling software to better assess the hazard potential where the potential for slope failure has been identified and where there may be a risk to human life. Ideally, most of this instrumentation would provide ‘real-time’ data which would be integrated into the engineers interpretation of the conditions following comprehensive geotechnical characterization of the region (primarily through means of drilling). As these means of assessment have not yet been carried out or been established, the preliminary nature of our findings should be recognized.

5.2 Risk Perspective

In assessing the risks associated with the geohazard potential of any given area, one must recognize the regional setting such that the risks are viewed from the proper perspective.

Those who dwell in the north are not risk averse. Some of us live or else delve amongst geohazards on a daily basis. In perspective, these geohazard risks are generally considered to be negligible when compared to other risks that we face on a daily basis.

5.3 Site Specific Observations

In the case of Moosehide Slide, the primary reason for failure was due to the presence of weak ultramafic rocks. As such, it’s important to characterize regional occurrences of ultramafic rocks relative to the distribution of slope failures. These occurrences

were mapped during the Dawson Natural Landscape Hazards – Geoscience Mapping for Climate Change Adaptation Planning report (prepared by the *Northern Climate ExChange – Yukon Research Center – Yukon College*) as follows;

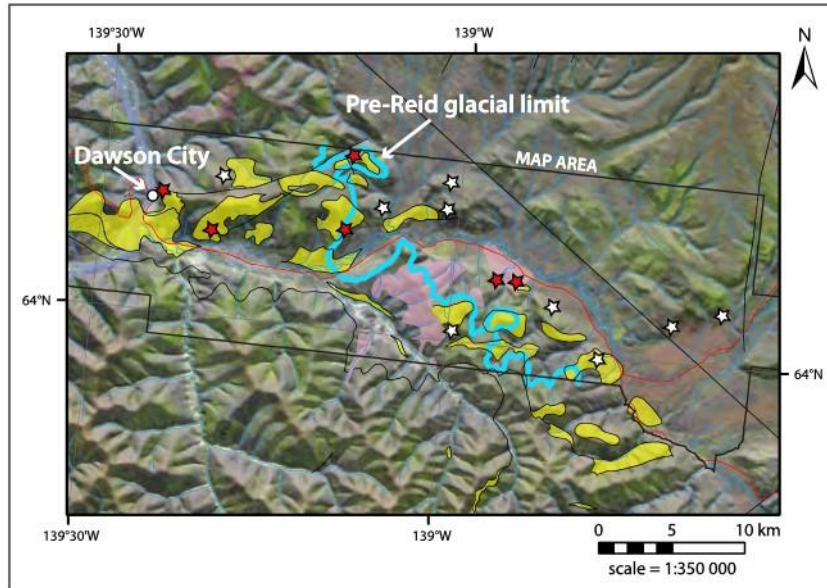


Figure 45. Map area illustrating ultramafic Slide Mountain terrane rocks (yellow), volcanic rocks (pink) and landslides (stars). Red stars indicate deep-seated bedrock slides; and white stars are small landslides, and landslides in glacial moraine material.

Nature of the Event

The confluence of thrust and normal fault systems at the Moosehide Slide area, combined with the presence of nearby plutonic contacts (located on the Dome Road) appears to have concentrated weak fluid derived serpentinized rock at the intersection between the two fault systems. These serpentinized ultramafic rocks are predominately comprised of weakly bonded materials which are geotechnical liabilities where rock-slope failures can occur.

The Moosehide Slide is regionally one of many examples in the Klondike where a failure of these bonds has occurred, resulting in what has been described as a ‘pseudo-circular rock-slope failure’ (Brideau et al 2006) or else potentially, a wedge failure. The failure in this case is thought to have occurred as a combined result of high porewater pressures and the occurrence of a seismic event (Brideau).

While suggestions have been made (by Hughes, 1979) that the slide may have been the result of two separate events, in our opinion the slide is likely the result of a single event. We have defined the primary event as the single episode which resulted in the mass failure of the original slope. We feel this event would however, been preceded by other slope processes which would have created colluvial apron and fan deposits at

the toe of the slope similar to those which are present in the area today. Similar mass wasting types of slope processes have continued since the primary event and may have included smaller secondary rock failures which spawned from the original rupture surface creating the terrain features noted today.

The 1979 GSC Paper # 2781 by Hughes described an organic soil horizon (which was carbon dated) as being underlain by yellowish-grey-brown soil developed from serpentinized ultrabasic rock detritus and covered with unweathered detritus derived from rock similar to that which underlay the organics. While the apparently weathered nature of the underlying materials suggests they may be comprised of colluvial fan deposits, the possibility that it may be the weathered remnants of an ancient slide event cannot be ruled out. The overlying unweathered serpentinized rock would be slide rubble/debris which originated from what we've described as the primary event.

Age of Moosehide Slide

Based upon photographic evidence, it appears the moving slip-face of the mid-section has advanced approximately 80 meters in the past 115 years (or so). As the run-up path (as measured from the base of the steeper section of the prevailing slope to the present-day location of the slip-face) measures in the order of 280 meters, the rate of advancement suggests the slip-face feature may have only formed in the order of 400 years ago (assuming the rate of advancement has remained unchanged) as there would not have been run-up path available for it to have existed prior to this time. Assuming however, it may have taken several hundred years for the rockfall to have accumulated sufficient mass before this feature of the slide formed and began to move, this slide feature may be in the order of 600-700 years old. The slide would have occurred shortly before this time.

This value differs from the GSC # 2781 paper where the results of carbon dating suggests the slide may have occurred approximately 1780 years ago.

The differing values are likely due to errors in our methodology and potentially the carbon dating (which commonly results in the determination of an age which is considerably older than what the true age may in fact be).

Estimated Volumes of Local Features

The approximate volumes of various local features were estimated as follows;

DESCRIPTION	ESTIMATED VOLUME (m ³)	
Primary Event	2,225,000	
Rockfall & Erosion since Primary Event (includes Gully # 3)	471,000	
Gully # 3	56,000	
Gully # 4	137,000	
Unstable Blocks	101,510	
Alpha	49,760	
Beta	19,200	
Gamma	14,100	
Delta	18,450	

The total volume of the unstable blocks equates to approximately 4.5 % of the estimated volume of the primary slide event.

Scour

While the presence of an organic soil horizon which was overlain with slide debris in boreholes BH 1-17 to BH 4-17 suggests that scour of the pre-existing soil deposits did not occur in the peripheral regions of the slide, the possibility that scour occurred in the central realms of the slide path should not be ruled out given the magnitude of the slide debris. The presence of scour should reduce the potential that a slip surface may develop at the base of the slide debris.

Deforestation

As the entire slope above and surrounding Dawson was deforested during the Gold Rush Era, the lack of vegetation would have greatly increased the amount of surface water run-off. Groundwater porewater pressures would have been increased during this time increasing the instability of the region.

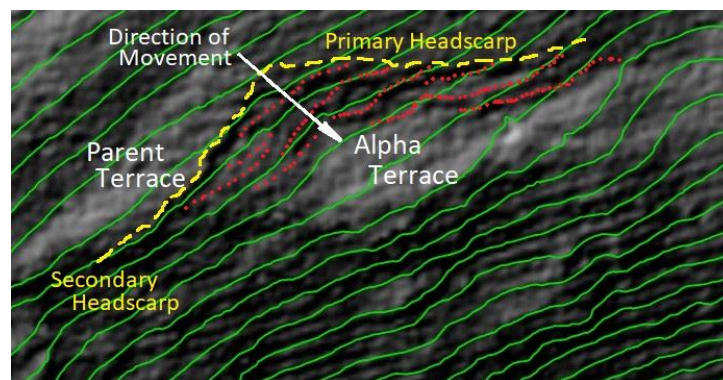
Unstable Blocks

The unstable blocks are essentially pulling away from the headscarp through (potentially shallow rotational movements) as can be noted by comparing photos from the 1900's with those taken today. Beta, Gama and Delta Blocks have been calving off of the headscarp area, likely since the time of the original slide event. Alpha Block is likely a more recent event. The deforestation which occurred during

the Gold Rush Era likely accelerated these slope movements due to increased porewater pressures and lack of surface cover. Surface erosion would have been high.

The headscarp associated with Alpha Block is not likely to propagate much further east as the slope aspect becomes shallow and the presence of permafrost (and hence potential for thaw-degradation) appears to be absent based upon the noted vegetation. Hence, more stable conditions are encountered to the south-east.

As per Moosehide Slide, Alpha Block appears to have a similar headscarp configuration, having both a primary and secondary scarp feature. The Alpha Block terrace feature appears to have propagated approximately 15 meters (in elevation) downslope from the parent terrace where it originated. Fragments of parent material appear to successively separate from the Alpha Block terrace (at 5 meter intervals) as it pulls further away from the parent terrace area. These features and the possible direction of movement have been noted in the figure noted below;



Subtle remnants of failure features, which extend to elevations above the recognized headscarp can be noted above the parent terrace in the lidar topography.

Periods of Stability/Instability

It's evident that regions of Dawson which are located near steeper slopes are subjected to alternating periods of stability and instability. The soil stratigraphy which was encountered in the boreholes advanced on Judge Street shows repeated interbedded sequences of colluvial (fan/rubble) and organic deposits. The organic soil horizons would have been established at times of relative stability.

Regions of Competent Rock

In comparing recent and historical photos, some central areas within the headscarp and above the flume appear to have remained unchanged throughout the past 115

years. This suggests these areas may in fact harbor relatively competent bedrock outcrops.

Erosion Gullies

A series of erosion gullies have formed on either side of the slide feature. Most of them (Gullies # 1-3 & # 4A) spawn rockfall on a regular basis. They pose no hazard upon the townsite however hikers would be at peril navigating through these zones. Death would be likely if they were to be struck by rockfall which emanate from these areas.

Gullies # 3, # 4 and # 4A are located south of the slide feature.

While gullies # 3 and # 4A are less active than # 1 & # 2 (located to the north), rockfall is ongoing at higher elevations within these features. Their lower realms however, intersect depressions and pond(s) and so from an instability perspective, collection is available to minimize the potential for depositional release into the townsite in periods of renewed slope activity. That said, the topography presented in the lidar data, suggests that there has indeed been a significant amount of debris emanating from Gully # 3 and # 4A, some of which has manifested in the forms which appear to be related to primary slide event, but are likely the results of more recent activity.

Of these gully features, based upon visible signs of failure, # 4 appeared to be the most inert. However, the four (4) boreholes advanced through its discharge area, shows that it cycles through periods of stability and instability, like most other things in Dawson. The presence of seepage zones and collections of vegetative debris, show that this gully is also active, but currently in a different phase of stability.

Channel Incising

The amount of the organic rich deposits encountered in borehole BH 3-17 suggests that this region was once incised by surface waters. The resulting channel subsequently infilled with the organic rich soils. The porous nature of the organic materials has allowed groundwater to flow through the deposit creating ice-rich conditions over time.

Other regions along the fringes of the toe-area also appear to have been incised and subsequently filled with colluvial detritus.

Thrust Fault

The nature of the thrust fault provides toe support to the overlying weaker ultramafic (serpentinized) rock.

Flume

The cut-slope of the flume likely captures moisture which is propagating down-slope and hence its presence can be noted as a light-colored lineation, even where it is buried.

As rock originating from the west side of the headscarp is generally comprised of more competent meta-sedimentary rock, coarser rubble appears to have tumbled past the flume and accumulated along the west side of the talus cone. The east side of the headscarp is predominately fine-grained in nature and in a heavier state of disintegration and so the east side of the flume has generally been buried.

Hollow-Stem Advancement (Borehole BH 5-17)

Prior experience in drilling the deposit in 2014 and 2016 suggested that hollow-stem auger advancement would be restricted due to the coarse nature of the slide debris. As such, as the intent was to attain maximum amount of penetration into the deposit, solid-stem augers were initially employed to essentially pre-drill the borehole. The hollow-stem augers were subsequently advanced once logistical and fiscal constraints dictated to allow for the retention of relatively undisturbed samples at a depth.

Borehole BH 5-17 was unique relative to all other boreholes which have been advanced by the undersigned and drilling sub-contractor as there were essentially no auger cuttings during the course of drilling operations. Typically, auger cuttings which are driven to the surface (due to the nature of auger advancement) need to be continuously cleared from around the drill-stem in order to maintain a clean working area. In the case of BH 5-17, the total amount of auger cuttings measured in the order of 0.1 m³.



Borehole BH 5-17 Well and Casing

SPT Sample Retrieval

The two SPT samples (No.59 & No.60) retained from borehole BH 5-17 each had similar blow counts relative to the amount of sampler tube penetration.

Sample No.	# of Blows	Penetration (mm)
59	105	180
60	107	210

From a logistics standpoint, consideration typically needs to be given in the field where blow counts are high and penetration is low. This is due to the nature of very dense soils as retrieval of the sampler tube becomes problematic. However, in this case, additional effort to dislodge the sampler tube from the soil mass after it was driven was not required. This is likely due to the ice-rich nature of the deposit.

SPT Ice Lenses

The presence of the clear ice lenses which were encased in (silty) granulated ice suggests that void spaces are being created as the slide debris creeps down-slope. Specifically, in this case, it appears that the clear ice lenses once formed and the ensuing voids which resulted from movement due to potential plastic deformation allowed for subsequent episodes of groundwater migration. This water subsequently refroze as silty granulated ice, encapsulating the older clear ice lenses.

Permafrost

The frozen nature of the lower portions of borehole BH 5-17 verify Brideau et al's 2015 theory that the lower portion of the slide is comprised of a rock glacier.

Although the borehole location was overlain with 4.6 meters of recontoured slide debris, the 9.1 meter depth at which the permafrost was encountered suggests the permafrost may be in a state of thaw. Typically, stable permafrost extends to the depth of the active layer (generally ~2 meters below the ground surface) such that the influence of winter temperatures can help maintain the permafrost in its frozen state. However, the extremely loose nature of the overlying slide deposits may serve as an insulating layer.

The onset of global/local warming will increase the rate of thaw and hence rate of movement may likely increase.

Organic Soil Horizon

Although the GSC Paper # 2781 described the carbon dating sample as being retained from an elevation of ~335 meters an organic horizon was not encountered during advancement of the exploratory borehole which was terminated at an elevation of ~332 meters.

3rd Avenue Hazards

The Dawson Natural Landscape Hazards – Geoscience Mapping for Climate Change Adaptation Planning prepared by the *Northern Climate ExChange* noted the hazard risk for the 3rd Avenue area as being high. This was likely due to the presence of steep terrain which was once in a state of heavy erosion, particularly during the Gold Rush Era when it was deforested.

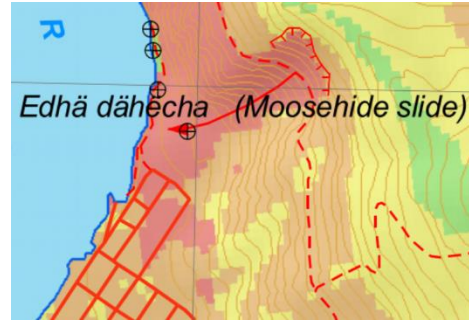


Figure (above) from
Dawson Natural Hazards Planning study

This region appears to have since stabilized through natural revegetation. As such, our assessment did not identify any hazard beyond those identified in Section 5.4, that would preclude development of this area so long as slope drainage is well controlled. Additional revegetation would assist in promoting the long-term stability of this region.



1902 photo (above) by Edward C.Adams from Interpretive Kiosk

5.4 Geohazards

Relative to the North End Subdivision, three primary geohazards associated with the Moosehide Slide and adjacent slopes were identified relative the safety of the townsite. These include;

the presence of an unstable block(s) of material located at the head-scarp of the slide,
the nature of material deposition at the discharge area of Gully # 4, and
previously poor slope conditions overlying 3rd Avenue.

Although the likelihood of these types of geohazards impacting the Dawson townsite would be considered extremely remote these features create potential liabilities which are related to slope failure(s) and in the case of the gully, impacts from surface waters and possible debris flows.

A detailed description of other potential natural hazards which may be present from a regional perspective, their probability of occurrence and level of risk to the townsite have been provided below.

Hazard	Probability of Occurrence	Level of Risk (to townsite)	Mitigation
Earthquakes	Moderate Potential	5-15% chance significant damage will occur every 50 years (Natural Hazards Report)	Follow National Building Code of Canada
Floods	Remote	Major	Maintain Dike and Monitor River/Ice Conditions
Failure of Unstable Block (en masse)	Extremely Remote	Unknown	Conduct computer modeling and monitor site conditions
Failure of Unstable Block (through erosion)	Ongoing	None	None / Monitor site conditions
Debris Flows	Extremely Remote	Major to Catastrophic	Establish setbacks in runout paths / Monitor upslope conditions
Surface Waters	Probable	Minor	Establish drainage / Monitor site conditions
Thaw-Degradation of Permafrost	Probable	Minor to Major	Utilize proper design and construction methodologies
Rockfall	Ongoing	None (Catastrophic to trail users)	Establish warning signs
Erosion	Ongoing	Minor	Establish drainage / Monitor site conditions
Creep/Solifluction	Ongoing	Minor	Monitor infrastructure and maintain as necessary

6.0 RECOMMENDATIONS

The following recommendations have been provided further to those noted in our September 18, 2016 Geotechnical Evaluation Report prepared for the North End Subdivision. Where recommendations differ, those contained herein supersede those otherwise previously provided.

6.1 Geotechnical Setbacks

The geotechnical setbacks which were established in the North End Subdivision Report should be maintained. The locations of these setbacks (noted in Figure 10 of the report) were established in three primary zones described as Areas 11, 18 and 45.

These geotechnical setbacks should be observed to allow for a factor of safety from potential long-term geotechnical hazards related to the proximity to the Yukon River (Area 11), higher rates of slope movements (Areas 11 & 45) and potential discharge from Gully # 4 (Area 18). A reduction in the width of Area 18 (from 30 meters to 15 meters) could be considered so long as the drainage ditch through this region maintains adequate capacity to accommodate peak flows and storm events. The design criteria period (ie 1 in 100 year event, etc.) should be increased for design purposes. The use of an impermeable liner should be considered so long as it is covered with rock to reduce its thermal impact upon the underlying permafrost. The use of an exposed black liner is not recommended.



Figure 10 (above) from North End Subdivision
Geotechnical Report

6.2 Area 16 & 21 (Figure 10)

Residential development of these two areas could be considered, however, the homeowners should be made aware of the increased level of maintenance that will be required given the higher rates of creep that these areas are likely undergoing given their proximity to (what we've described as) the toe of the slide debris.

Given the scale of mapping and limited scope of work which has been undertaken to date, the toe of the slide debris should be considered synonymous with the toe of the colluvial fan deposits.

6.3 Topographical Survey

A detailed survey (1 meter contour intervals) of the North End Subdivision should be conducted such that the topography of the terrain is considered in the design. This is particularly important as cuts should be avoided during subdivision development and so maintenance of natural pre-existing drainage courses and road alignments will be advantageous where possible.

6.4 Drainage & Erosion Control

As with all subdivisions and developed areas, it's important to control surface drainage to minimize the impacts of erosion and improve the long-term stability of the region.

The use of interceptor trenches which incorporate perforated drains encased in drain rock and filter fabric, should be considered in the regions where near surface groundwater flows are anticipated or appear. This type of trench system should be installed (to depths of ~2 meters) at the intersection between Gully # 4 and the existing developed areas of the townsite. Caution should be exercised such that the discharge does not cause soil erosion or other problems down-gradient.



The installation of interceptor trenches at other areas should be considered on a case-by-case basis (such as regions above and below 3rd Avenue) where steeper slopes and seasonal springs are encountered.

The culvert at the corner of Judge Street and 3rd Avenue should be oversized to allow for potentially higher discharge volumes than would ordinarily be expected. Several large culverts should be installed in this area and throughout the remainder of Area #18 discharge path.

6.5 Signage

Signage should be established on the hiking trails which traverse the slide and gully areas to warn users of the potential rockfall hazards.

6.6 Subdivision Plans

As with all subdivisions, development plans should all be completed prior to approval of the subdivisions and lot developments as deemed appropriate by qualified personnel. These plans should be comprised of (but not limited to) site grading/fill, drainage and erosion control plans.

6.7 Design

Civil engineering design should take into account site specific features and avoid 'neat-line' drawings. This may include maintaining the existing road alignments and widths as deemed beneficial in keeping with the community setting.

6.8 Additional Assessments

Annual Monitoring of Moosehide Slide Area

The Moosehide Slide Area should be monitored on an annual basis by qualified geotechnical personnel to better characterize movement of the unstable blocks and assess the conditions of Gullies # 3, # 4, # 4A and the slopes above the 3rd Avenue area.

Modeling of Unstable Blocks

The unstable blocks which have been identified should be modeled by qualified personnel to identify whether or not the blocks pose a hazard to the townsite if they were to fail en masse (or as individual blocks). The coarse-grained nature of the

existing slide debris located in the potential run-out path(s) may need to be considered as it should help reduce the run-out distance of any failed mass.

Revegetation

Qualified personnel should identify the native plant species and make recommendations such that regrowth of vegetation in regions above 3rd Avenue (and potentially other areas) can be assisted. These regions should be revegetated based upon their recommendations. While the intent would be to protect exposed soils from the infiltration of surface waters, caution should be exercised such that the increased run-off is controlled and does not create erosion down-slope. The retained horticulturist should work together with a geotechnical consultant to verify the design intent is met.

Install Thermistor String

A thermistor string and datalogger should be installed in borehole BH 5-17 casing to allow for thermal monitoring of the slide debris. This information should be assessed by qualified personnel to better characterize the thermal regime of the slide. Entities such as *The Northern Climate Exchange* would be ideally suited to conduct this facet of work.

Geotechnical Drilling

The advancement of a borehole through the entire slide mass for scientific purposes should be considered as we deem this to be possible in the toe area of the slide.

7.0 CONCLUSIONS

7.1 General

Our geohazard assessment identified three primary concerns further to those noted in our September 18th, 2016 Geotechnical Report of the North End Subdivision (and as outlined in the regional geohazards identified in Section 4.9, above).

These geohazard concerns are related to the presence of;

- unstable block(s) of soil and rock located on the headscarp of the slide,
- the run-out path of gully # 4 which bisects the North End Subdivision, and
- presence of previously poor slope conditions above 3rd Avenue.

Failure of the unstable blocks (en masse) may pose a hazard if the debris is able to propagate into developed regions of the townsite. The presence of gully # 4 and the slope above 3rd Avenue may pose a hazard if the upslope regions become unstable.

From a risk stand-point, the probability of either of these events occurring is extremely remote. The ongoing natural revegetation of gully # 4 and the slope above 3rd Avenue further reduces the risk potential in this area.

As such, based upon our observations, the geomorphic conditions within the study area should allow for continued residential development in the North End Subdivision.

7.2 Other Geohazards

While rockfall associated with the headscarp, talus cone and gullies # 1-3 & # 4A areas do not pose a hazard upon the townsite, hikers would be at peril navigating through these zones. Death would be likely if they were to be struck. As such, signage should be established in these areas along the trails to warn people of the hazards.

7.3 Geotechnical Setbacks

The geotechnical setbacks which were recommended in our September 18th, 2016 Geotechnical Evaluation Report for the North End Subdivision should be observed to allow for a factor of safety from some of the potential geohazards which have been identified.

7.4 Nature of Event

The slide is likely the result of a single event. We feel this event would however been preceded by other slope processes which would have created colluvial apron and fan deposits at the toe of the slope similar to those which are present in the area today. Similar mass wasting types of slope processes have continued since the primary event occurred and may have included smaller secondary rock failures which spawned from the original rupture surface creating the terrain which is noted today.

The movement of the lower portions of Moosehide Slide can be attributed to rock glacier mechanisms. Earth flow mechanisms likely dominate the types of movement noted in the upper realms of the slide.

7.5 Estimated Volumes of Local Features

The approximate volumes of various local features were estimated as follows;

DESCRIPTION	ESTIMATED VOLUME (m ³)	
Primary Event	2,225,000	
Rockfall & Erosion since Primary Event (includes Gully # 3)	471,000	
Gully # 3	56,000	
Gully # 4	137,000	
Unstable Blocks	101,510	
Alpha	49,760	
Beta	19,200	
Gamma	14,100	
Delta	18,450	

7.6 Maintenance

Regular maintenance will be required to maintain utilities and re-level structures to ensure that movements are kept within tolerable amounts. A higher frequency and degree of maintenance should be anticipated in the North End Subdivision.

7.7 Notification

Civil and structural design consultants should be made aware of our findings for their consideration. Our geohazard report should be made available to the existing/future lot owners and residents who reside in the area.

8.0 LIMITATIONS

This report is intended for the sole use of the *Yukon Government*.

No portion of this report may be used as a separate entity; it is intended to be read in its entirety.

Any use of this report by a third party is the responsibility of such third party.

The recommendations provided are based upon the subsurface conditions encountered at the time of our evaluation, current construction techniques and generally accepted engineering practices. The recommendations have been provided without considering the effects of deep and long-term thaw of local/regional permafrost which may stem from global warming, building/utility construction, or other causes.

The content within this report reflects our best judgment in light of the information available to our firm at the time of report preparation. The information presented herein should supersede information provided in our previous studies.

Any references to construction methods contained herein, express our opinion and are not intended to direct contractors on how to carry out construction. Prospective contractors should be aware that the data presented may not be sufficient to assess all factors that may have an effect upon construction.

It is important to emphasize our evaluation is in fact, based upon random sampling/results obtained at the borehole locations and where observations were noted during our reconnaissance. Due to the geomorphological nature of the deposits encountered, interpolations of subsurface conditions between the borehole locations have not been made or been implied.

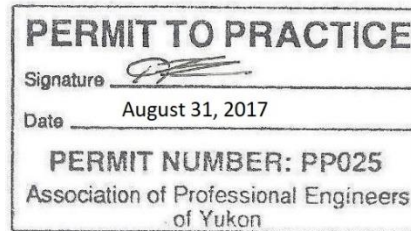
Should unexpected conditions be encountered during construction, our firm should be notified immediately in order to confirm the suitability of our recommendations. If required, our firm may alter or modify our recommendations and conclusions at such time.

9.0 CLOSURE

Thank you for allowing our firm to provide you with the above noted evaluation. While we trust the information will suit your purposes, please feel free to contact the undersigned if you have any questions or concerns.

Respectfully Submitted,

CHILKOOT GEOLOGICAL ENGINEERS LTD.



Tares Dhara, P.Eng.
Senior Geotechnical Engineer

TD/td



Geotechnical Evaluation – Geohazard Assessment
Moosehide Slide - Dawson City, Yukon - 2017

Figure 1 – Study Area





Geotechnical Evaluation – Geohazard Assessment
Moosehide Slide Area
Dawson City, Yukon – 2017

Figure 2
Borehole Locations

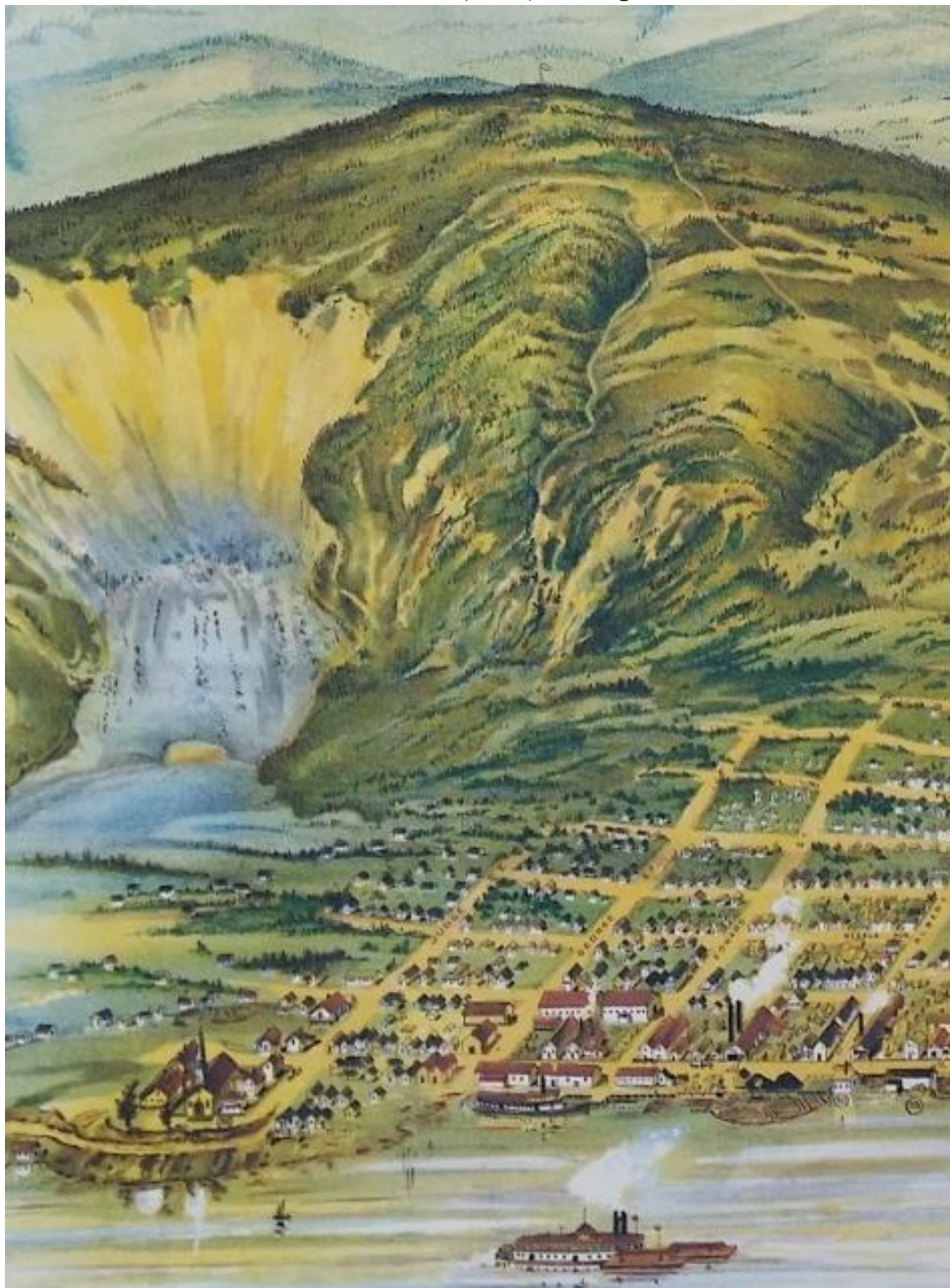




Geotechnical Evaluation – Geohazards Assessment
Moosehide Slide Area - Dawson City, Yukon – 2017

Figure 3

Historical (1903) Setting



CHILKOOT GEOLOGICAL ENGINEERS LTD.

Geotechnical Evaluation - Geohazard Assessment
Moosehide Slide Area - Dawson City, Yukon - 2017



Table I - Summary of Laboratory Analysis

Borehole	1-17	1-17	1-17	2-17	2-17	2-17	3-17	3-17	4-17	4-17	4-17	4-17
Sample No.	2	5	9	13	14	20	24	27	34	35	38	39
Depth (m)	0.91	3.66	6.4	2.44	3.66	7.92	0.91	2.44	1.83	2.13	4.27	4.88
Soil Unit	Slide Rubble	Colluvium	Colluvium	Slide Rubble	Slide Rubble	Colluvium	Slide Rubble	Slide Rubble	Colluvium	Colluvium	Slide Rubble	Slide Rubble
Moisture	6.5	17.0	16.4	6.1	10.0	10.6	14.0	15.2	19.2	43.8	9.1	22.2
Gravel	61.3	35.5	32.3	43.6	36.3	46.7	35.3	16.8	21.0	4.0	42.4	38.4
Sand	19.4	30.6	42.1	38.5	36.1	34.8	39.4	52.5	40.6	28.0	35.5	34.2
Silt	19.3	33.9	25.6	17.9	27.6	18.5	25.3	30.7	38.4	68.0	22.1	27.4
Description	Sandy Silty Gravel	Silty Sandy Gravel	Gravelly Silty Sand	Sandy Silty Gravel	Sandy Silty Gravel	Sandy Silty Gravel	Gravelly Silty Sand	Silty Gravelly Sand	Silty Gravelly Sand	Sandy Silt	Sandy Silty Gravel	Sandy Silty Gravel
USCS	GM	GM	SM	GM	GM	GM	SM	SM	SM	ML	GM	GM
Sieve Size (mm)	% Passing											
40	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
28	73.4	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
20	48.7	89.1	100.0	100.0	88.1	100.0	85.4	100.0	100.0	100.0	86.6	100.0
12.5	44.9	79.6	92.0	84.1	78.8	75.4	79.5	100.0	92.9	100.0	86.6	82.4
10	44.9	74.4	87.8	77.4	73.3	67.6	74.8	97.5	89.4	98.9	79.5	74.9
5	38.7	64.5	67.7	56.4	63.7	53.3	64.7	83.2	79.0	96.0	57.6	61.6
2.5	34.4	58.0	48.0	44.1	53.5	41.2	55.1	70.1	68.7	91.1	46.9	52.4
1.25	30.3	52.4	38.5	36.0	46.3	33.9	46.4	58.0	60.6	85.8	38.8	44.7
0.63	27.1	46.9	33.1	29.7	40.4	28.5	38.9	48.0	53.5	80.8	32.6	38.9
0.315	24.6	41.7	30.2	25.4	35.6	24.2	33.6	41.2	47.9	76.1	28.8	33.5
0.16	22.2	37.6	27.8	21.5	31.4	21.0	29.0	35.4	42.5	71.8	25.2	29.7
0.08	19.3	33.9	25.6	17.9	27.6	18.5	25.3	30.7	38.4	68.0	22.1	27.4

- Indicates prence of asbestos fibres

All values are in % unless otherwise noted.

CHILKOOT GEOLOGICAL ENGINEERS LTD.

Geotechnical Evaluation - Geohazard Assessment
Moosehide Slide Area - Dawson City, Yukon - 2017



Table I - Summary of Laboratory Analysis

Borehole	5-17	5-17	5-17	5-17	5-17	5-17	5-17	5-17	5-17	5-17	5-17	5-17	H1	H2	H3	H4
Sample No.	42	44	46	48	50	52	53	55	57	58	59	60	Sta 0+76	Sta 0+105	Detritus	Front of Slow Moving Debris
Depth (m)	0.91	2.44	3.96	5.49	7.01	8.53	9.45	10.97	12.5	13.11	13.41	14.94	Headscarp	Headscarp	Surface	
Soil Unit	Recontour Rubble	Recontour Rubble	Recontour Rubble	Slide Rubble	Slide Rubble	Slide Rubble	Slide Rubble	Slide Rubble	Slide Rubble	Slide Rubble	Slide Rubble	Slide Rubble	Colluvium	Colluvium	Slide Rubble	Slide Rubble
Moisture	4.7	6.4	8.1	5.7	11.8	13.7	17.0	17.6	18.1	20.0	67.5	23.0	14.9	8.5	6.5	6.9
Gravel	72.4	65.0	53.7	64.2	57.9	40.8	43.8	28.6	31.4	43.3	46.7	59.5	41.2	47.0	53.0	45.0
Sand	18.7	24.2	32.2	24.0	24.9	37.7	35.8	42.5	42.0	31.7	22.1	18.1	25.2	20.2	34.3	39.6
Silt	9.0	10.8	14.1	11.8	17.2	21.5	20.4	29.0	26.6	25.0	31.2	22.4	33.6	32.8	12.7	15.4
Description	Sandy Gravel trace Silt	Sandy Gravel some Silt	Sandy Gravel some Silt	Sandy Gravel some Silt	Sandy Silty Gravel	Sandy Silty Gravel	Sandy Silty Gravel	Silty Gravelly Sand	Gravelly Silty Sand	Sandy Silty Gravel	Silty Sandy Gravel	Silty Sandy Gravel	Silty Sandy Gravel	Silty Sandy Gravel	Sandy Gravel some Silt	Silty Sandy Gravel
USCS	GP-GM	GP-GM	GM	GP-GM	GM	GM	GM	SM	SM	GM	GM	GM	GM	GM	GM	GM
Sieve Size (mm)	% Passing															
40	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
28	100.0	75.0	100.0	89.1	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	85.3	100.0	100.0
20	74.7	75.0	84.5	79.7	90.6	81.2	100.0	100.0	100.0	100.0	100.0	85.7	100.0	71.3	90.7	95.5
12.5	50.7	59.0	76.0	61.8	72.7	77.6	86.5	93.4	92.2	86.4	79.3	70.1	88.7	65.6	72.6	85.6
10	42.9	52.8	68.8	52.2	62.6	73.7	81.8	90.4	87.9	75.6	72.4	62.4	67.1	59.9	62.3	78.3
5	27.6	35.0	46.3	35.8	42.1	59.2	56.2	71.4	68.6	56.7	53.3	40.5	65.2	53.0	47.0	55.0
2.5	21.0	24.9	32.2	26.8	32.3	47.1	39.5	57.9	52.5	43.9	43.3	31.5	58.8	48.6	35.5	41.0
1.25	17.0	19.4	25.3	21.7	27.2	37.7	32.6	47.9	42.6	36.8	38.6	27.7	53.8	45.1	28.1	32.8
0.63	14.1	16.2	21.2	18.0	23.6	31.2	28.4	41.0	36.3	32.3	35.7	25.4	49.7	41.9	22.6	26.1
0.315	12.0	13.8	18.1	15.5	20.9	26.9	24.9	35.6	32.1	29.1	33.7	24.1	45.9	39.6	18.6	21.5
0.16	10.2	12.0	15.8	13.4	18.8	23.9	22.1	31.7	28.9	26.7	32.2	23.1	42.8	37.1	15.1	17.7
0.08	9.0	10.8	14.1	11.8	17.2	21.5	20.4	29.0	26.6	25.0	31.2	22.4	39.6	32.8	12.7	15.4

 - Indicates prence of asbestos fibres

All values are in % unless otherwise noted.



APPENDIX A

Borehole Logs



NOTES ON SOIL LOGS

Soil Description

The soil is named after its principal component and modified by other components as follows;

<u>Percent of Component</u>	<u>Modifier</u>
> 15 %	XXX - ey
11% to 15%	some XXX
5% to 10%	trace XXX

Examples;

<u>SILT</u>	<u>SAND</u>	<u>GRAVEL</u>	<u>Description</u>
6	32	62	Sandy Gravel trace Silt
55	6	39	Gravelly Silt trace Sand
43	36	21	Silty Gravelly Sand

Note: In the cases where the coarse fraction (sand & gravel) comprise > 50% of the sample, then the larger component of the coarse fraction becomes the principal component.

Undrained Shear Strength of Cohesive Soils

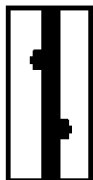
Consistency	Undrained Shear Strength	
	p.s.f	kN/m ²
Very Soft	< 375	<20
Soft	375-750	20-40
Firm	750-1500	40-75
Stiff	1500-3000	75-150
Very Stiff	3000-6000	150-300
Hard	>6000	<300

**Relative Density (Qualitative Classification)****Cohesive Soils**

- | | |
|------------|---|
| Very Soft | - Exudes between fingers when squeezed by hand |
| Soft | - Moulded by light finger pressure |
| Firm | - Moulded by strong finger pressure |
| Stiff | - Cannot be moulded by fingers – Can be indented by thumb |
| Very Stiff | - Can only be indented by thumbnail |
| Hard | - Cannot be indented by thumbnail |

Granular Soils

- | | |
|--------------------------|--|
| Very Loose | - Considerable sidewall sloughage noted |
| Loose | - Some sidewall sloughage noted – Easy digging |
| Compact/
Medium-Dense | - Unimpeded excavation – little to no sidewall sloughage |
| Dense | - Considerable effort required during excavation – Stable vertical sidewalls |
| Very Dense | - Extreme difficulty in excavation |

Soil Log - Sample Type**Symbol****Test Pitting****Drilling****Grab Sample**Retained from
excavation sidewall
or base**Auger Sample**Retained from
Auger flighting**Bucket Sample**Retained from
leading edge of
excavator bucket**Split-Spoon Sample**Retained from
Split-Spoon Sampler
tube

**Relative Moisture**

Described as - *dry, damp, moist, wet* or *saturated* - relative to the principal soil matrix.

For example, a moisture content of 10 percent may be classified as '*moist*' for a coarse grained soil (sand or gravel) but '*damp*' for a fine grained (silt) soil.

The moisture content is recorded as a percentage (%) of the weight of water within the soil sample relative to the dry weight of the sample.

Recovery

Refers to the (linear) amount of sample retained after driving the Split Spoon (SPT) sampler tube 18 inches.

Recorded as a percentage (i.e. 12 inch sample/18 drive = 66 %)

N-Value

Refers to the total number of blows required to drive the Split Spoon sampler tube the final 12 inches of the 18 inch drive.

Relative Density based upon SPT 'N' Value

Non-cohesive (Granular) Soil		Cohesive (Clayey) Soils	
Relative Density	Blows per Foot (N-value)	Consistency	Blows per Foot (N-value)
<i>Very Loose</i>	< 5	<i>Very Soft</i>	0 to 2
<i>Loose</i>	5 to 9	<i>Soft</i>	3 to 4
<i>Compact</i>	10 to 29	<i>Firm</i>	5 to 8
<i>Dense</i>	30 to 50	<i>Stiff</i>	9 to 15
<i>Very Dense</i>	> 50	<i>Very Stiff</i>	16 to 30
		<i>Hard</i>	> 30

Unified Soil Classification System (ASTM Designation D-2487)					
Major division	Group Symbols	Typical Names	Classification Criteria		
Coarse-grained soils More than 50% retained on No. 200 sieve	Gravels 50% or more of coarse fraction retained on No. 4 sieve	GW	Well-graded gravels and gravel-sand mixtures, little or no fines	$C_u = D_{60}/D_{10}$ Greater than 4 $C_z = \frac{(D_{30})^2}{D_{10} \times D_{60}}$ Between 1 and 3 Not meeting both criteria for GW	
		GP	Poorly graded gravels and gravel-sand mixtures, little or no fines		
		GM	Silty gravels, gravel-sand- silt mixtures		
		GC	Clayey gravels, gravel- sand-clay mixtures		
	Sands More than 50% of coarse fraction passes No. 4 sieve	SW	Well-graded sands and gravelly sands, little or no fines	$C_u = D_{60}/D_{10}$ Greater than 6 $C_z = \frac{(D_{30})^2}{D_{10} \times D_{60}}$ Between 1 and 3 Not meeting both criteria for SW	
		SP	Poorly graded sands and gravelly sands, little or no fines		
	Sands with fines	SM	Silty sands, sand-silt mixtures	Atterberg limits plot below "A" line or plasticity index less than 4	
		SC	Clayey sands, sand-clay mixtures		Atterberg limits plot above "A" line and plasticity index greater than 7
	Fine-grained soils 50% or more passes No. 200 sieve	Silt and Clays Liquid limit 50% or less	ML	Inorganic silts, very fine sands, rock flour, silty or clayey fine sands	Check plasticity chart
			CL	Inorganic clays of low to medium plasticity, gravelly clays, sandy clays, silty clays, lean clays	
Silt and Clays Liquid limit greater than 50%		OL	Organic silts and organic silty clays of low plasticity		
		MH	Inorganic silts, micaceous or diatomaceous fine sands or silt, elastic silts		
		CH	Inorganic clays of high plasticity, fat clays		
		OH	Organic clays of medium to high plasticity		
Highly organic soils	Pt	Peat, muck and other highly organic soils	Fibrous organic matter; will char, burn, or glow		

Classification on basis of percentage of fines
GW, GP, SW, SP
GM, GC, SM, SC
Borderline classification
requiring use of dual symbols

Less than 5% Pass No. 200 sieve
More than 12% Pass No. 200 sieve
5% to 12% Pass No. 200 sieve

$C_u = D_{60}/D_{10}$ Greater than 4

$C_r = \frac{(D_{30})^2}{D_{10} \times D_{60}}$ Between 1 and 3

Not meeting both criteria for GW

Atterberg limits plot below "A"
line or plasticity index less than 4

Atterberg limits plot above "A"
line and plasticity index greater
than 7

$C_u = D_{60}/D_{10}$ Greater than 6

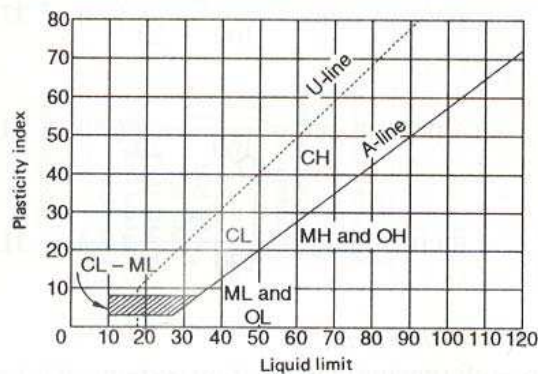
$C_r = \frac{(D_{30})^2}{D_{10} \times D_{60}}$ Between 1 and 3

Not meeting both criteria for SW

Atterberg limits plot below "A"
line or plasticity index less than 4

Atterberg limits plot above "A"
line and plasticity index greater
than 7

Check
plasticity
chart



Note: U-line represents
approximate upper
limit of LL and
PI combinations
for natural soils

Plasticity chart for the classification of fine-grained soils.
Tests made on fraction finer than No. 40 sieve.

Unified Soil Classification System

Figure 18. UNIFIED SOIL CLASSIFICATION SYSTEM

Table 1.2 Description and classification of frozen soils (adapted from Linnell and Kaplar, 1966)

I: Description of soil phase (independent of frozen state)	Classify soil phase by the unified soil classification system				Classify soil phase by the unified soil classification system		
	Major group		Subgroup		Field identification	Pertinent properties of frozen materials which can be measured by physical tests to supplement field identification	Thaw characteristics
II: Description of frozen soil	Description	Designation	Description	Designation			
	Segregated ice not visible by eye	N	Poorly bonded or friable	NI	Identify by visual examination; to determine presence of excess ice, use procedure under note (3) and hand magnifying lens as necessary; for soils not fully saturated estimate degree of ice saturation (medium, low); note presence of crystals or of ice coatings around larger particles	In-place temperature Density and void ratio a. In frozen state b. After thawing in place Water content (total H ₂ O, including ice) a. Average b. Distribution Strength a. Compressive b. Tensile c. Shear d. Adfreeze Elastic properties Plastic properties Thermal properties Ice crystal structure (using optical instruments) a. Orientation of axes b. Crystal size c. Crystal shape d. Pattern of arrangement	Usually thaw-stable
			Well bonded	Nb			
	Segregated ice visible by eye (ice 25 mm or less thick)	V	No excess ice	n	For ice phase, record the following as applicable Location Size Orientation Shape Thickness Pattern of arrangement Length Spacing Hardness Structure } per part III below Color		Usually thaw-unstable
			Excess ice	e			
			Individual ice crystals or inclusions	Vx			
			Ice coatings on particles	Ve			
III: Description of substantial ice strata	Ice greater than 25 mm thick	ICE	Pandom or irregularly oriented ice formations	Vr	Estimate volume of visible segregated ice present as percent of total sample volume		
			Stratified or distinctly oriented ice formations	Vs			
			Ice with soil inclusions	ICE + soil type	Designate material as ice and use descriptive terms as follows, usually one item from each group, as applicable: Hardness: hard, soft (of mass, not of individual crystals) Structure: clear, cloudy, porous, candied, granular, stratified Color: colorless, gray, blue Admixtures: contains few thin silt inclusions	Same as part II above, as applicable, with special emphasis on ice crystal structure	
			Ice without soil inclusions	ICE			

CHILKOOT GEOLOGICAL ENGINEERS LTD.

5B Bennett Road, Whitehorse, Yukon
(867) 335-5804 chilkoot@northwestel.net



BOREHOLE LOG

Client : Yukon Government - Energy, Mines & Resources
Location : Moosehide Slide - Dawson, Yukon
Project : Geotechnical Evaluation - Geohazards Assessment
Date Drilled: May 24, 2017

Elevation : 111.74 meters
BH Termination Depth: 6.71 meters
Instrumentation: NA
Weather: 18 C - Partly Cloudy

BOREHOLE

1-17

Sheet 1 of 2

Elev. (m)	Depth		Stratigraphic Description	Type	Field Sample					Laboratory Results (%)					USCS/NRC Depth (m)	Symbol	Elev. (m)
	ft	m			Number	Temperature (degrees C)	Recovery %	Penetrometer (kg/cm ²)	SPT 'N'	4.6	20	40	60	80			
111.5	1.0	0.10	dense		1	NA	NA	NA	NA	4.6	20				FILL		111.74
		0.20	soft compact												OL		111.64
																	111.54
111.0	2.0	0.5															111.0
110.5	4.0	1.0			2	NA	NA	NA	NA	6.5	19.6				RUBBLE		110.5
																	110.37
110.0	5.0	1.37	dense														110.14
109.5	6.0	1.80	dense														109.5
109.0	7.0	2.0			3	NA	NA	NA	NA	21.7							109.0
108.5	8.0	2.5			4	NA	NA	NA	NA	25.2							108.5
108.0	9.0	3.0															108.0
107.5	10.0	3.5															107.5
107.0	11.0	4.0			5	0.0	NA	NA	NA	17.0							107.0
106.5	12.0	4.5			6	NA	NA	NA	NA	8.9							106.5
106.0	13.0	4.88			7	NA	NA	NA	NA	11.5							106.0
105.5	14.0	5.0			8	NA	NA	NA	NA	15.4							105.5
105.0	15.0	5.49															105.0
104.5	16.0	5.5															104.5
104.0	17.0	6.0															104.0
103.5	18.0	6.0															103.5

Drilled By : Donjek Drilling
Drill Type : CME 750

Auger Type : 150 mm Solid Stem
Bit Type : Fish Tail

Water Level(s)
During Drilling
After Drilling
At End of Drilling

Logged By : T.Dhara, P.Eng.
Date : May 24, 2017

Data Entry By : T.Dhara, P.Eng.
Date : July 5-8, 2017

Reviewed By :
Date : July 11, 2017

CHILKOOT GEOLOGICAL ENGINEERS LTD.

5B Bennett Road, Whitehorse, Yukon
(867) 335-5804 chilkoot@northwestel.net



BOREHOLE LOG

Client : Yukon Government - Energy, Mines & Resources
Location : Moosehide Slide - Dawson, Yukon
Project : Geotechnical Evaluation - Geohazards Assessment
Date Drilled : May 24, 2017

Elevation : 111.74 meters
BH Termination Depth: 6.71 meters
Instrumentation: NA
Weather: 18 C - Partly Cloudy

BOREHOLE

1-17

Sheet 2 of 2

Elev. (m)	Depth		Stratigraphic Description	Field Sample					Laboratory Results (%)				USCS/NRC Depth (m)	Symbol	Elev. (m)
	ft	m		Type	Number	Temperature (degrees C)	Recovery %	Penetration (kg/cm²)	SPT N	▲ - FINES	● - SAND MC	■ - GRAVEL			
105.5	20.0		compact (continued)												(continued)
			COLLUVIUM -												
			GRAVELLY SILTY												
			SAND - poorly												
			graded, fine-grained,												
			grey-green/dark												
			brown - possible												
			groundwater												
			- as above but traces												
			of asbestos												
			- Refusal												
			Borehole terminated												
			at 6.71 m. below the												
			existing ground												
			surface.												
105.0	22.0	6.71			9	NA	NA	NA	NA	16.4	25.6	32.3	42.1		
104.5															
104.0															
103.5															
103.0															
102.5															
102.0															
101.5															
101.0															
100.5															
100.0															

Drilled By : Donjek Drilling
Drill Type : CME 750

Auger Type : 150 mm Solid Stem
Bit Type : Fish Tail

Water Level(s)
 During Drilling
 After Drilling
 At End of Drilling

Logged By : T.Dhara, P.Eng.
Date : May 24, 2017

Data Entry By : T.Dhara, P.Eng.
Date : July 5-8, 2017

Reviewed By:
Date : July 11, 2017

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BOREHOLE LOG

Client : Yukon Government - Energy, Mines & Resources
Location : Moosehide Slide - Dawson, Yukon
Project : Geotechnical Evaluation - Geohazards Assessment
Date Drilled : May 24, 2017

Elevation : 114.26 meters
BH Termination Depth: 9.14 meters
Instrumentation: 2" Monitoring Well
Weather: 18 C - Partly Cloudy

BOREHOLE

2-17

Sheet 1 of 2

Elev. (m)	Depth		Stratigraphic Description	Relative Density	Relative Moisture	Field Sample					Laboratory Results (%)				USCS/NRC Depth (m)	Symbol	Elev. (m)
	ft	m				Type	Number	Temperature (degrees C)	Recovery %	Penetration (kg/cm2)	SPT 'N'	▲ - FINES	● - SAND	■ - GRAVEL			
114.0	1.0	0.10	dense compact		moist												114.26
			FILL - SANDY GRAVEL some SILT - poorly graded, fine to medium grained, beige		moist												114.16
113.5	2.0	0.5	compact		wet												113.65
			FILL - GRAVELLY SAND some SILT - poorly graded, fine-grained, orange-brown - oxidized		wet												113.26
113.0	4.0	1.0	compact														113.0
			Groundwater @ 0.6 m														112.61
112.5	6.0	1.5	compact		wet												112.5
			FILL - SLIDE RUBBLE - SILTY SANDY GRAVEL - poorly graded, fine-grained, grey-green														112.0
112.0	7.0	2.0															111.82
			COLLUVIUM - GRAVEL some SAND - poorly graded, coarse-grained, rock fragments in size to 20 mm - odd organic inclusion - grey-black-green well washed		damp												111.5
111.5	9.0	2.5	very dense														111.21
			SLIDE RUBBLE - SANDY SILTY GRAVEL - poorly graded, fine-medium grained, grey-green - fractured gravel particles - Hard Grindy Drill to 3.05 m		moist												111.0
111.0	11.0	3.0	dense														110.5
			SLIDE RUBBLE - SANDY SILTY GRAVEL possible trace of CLAY - poorly graded, fine to medium grained, trace asbestos fibres blue-grey/green		moist												110.0
110.5	12.0	3.5															109.84
			ORGANICS & ORGANIC SILT - rootlets, black		damp												109.5
110.0	14.0	4.0															109.0
			COLLUVIUM - SILTY SANDY GRAVEL - poorly graded, fine-medium grained, grey-green - fractured oxidized gravel particles in size to 35 mm		moist												108.68
109.5	16.0	5.0	soft														108.5
			dense														108.0

Drilled By : Donjek Drilling
Drill Type : CME 750

Auger Type : 150 mm Solid Stem
Bit Type : Fish Tail

Water Level(s)

During Drilling
After Drilling
At End of Drilling

Logged By : T.Dhara, P.Eng.
Date : May 24, 2017

Data Entry By : T.Dhara, P.Eng.
Date : July 5-8, 2017

Reviewed By :
Date : July 11, 2017

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BOREHOLE LOG

Client : Yukon Government - Energy, Mines & Resources
Location : Moosehide Slide - Dawson, Yukon
Project : Geotechnical Evaluation - Geohazards Assessment
Date Drilled : May 24, 2017

Elevation : 114.26 meters
BH Termination Depth: 9.14 meters
Instrumentation: 2" Monitoring Well
Weather: 18 C - Partly Cloudy

BOREHOLE

2-17

Sheet 2 of 2

Elev. (m)	Depth		Stratigraphic Description	Relative Moisture	Field Sample						Laboratory Results (%)				USCS/NRC Depth (m)	Symbol	Elev. (m)
	ft	m			Type	Number	Temperature (degrees C)	Recovery %	Penetration (kg/cm²)	SPT N	▲ - FINES	● - SAND	■ - GRAVEL	PL MC LL			
108.6	20.0	6.10	- as above but increasing moisture content - oxidized fragments of serpentine in size to 30 mm	wet		17	NA	NA	NA	NA							108.16
107.5	21.0	6.5	SILTY GRAVELLY SAND & ORGANICS - dark brown/black - organic inclusions and tree branches - easy drilling to 7.62 meters	wet		18	NA	NA	NA	NA							107.5
107.0	22.0	7.0	COLLUVIUM - SANDY SILTY GRAVEL - poorly graded, fine-grained, fractured serpentine rock in size to 30 mm - grey-green/dark brown	moist		19	NA	NA	NA	NA	16.4						107.25
106.5	23.0	7.5	- as above but grey-green	wet		20	NA	NA	NA	NA	10.6	18.5	34.8	46.7			106.64
105.5	24.0	7.62	- as above but with fractured serpentinized rock in size to 80 mm			21	NA	NA	NA	NA	13.0						105.76
104.5	25.0	8.0	Groundwater Encountered - Monitoring Well Installed to 4.51 meters														105.27
103.5	26.0	8.5	Borehole terminated at 9.14 m. below the existing ground surface.														105.12
102.5	27.0	9.0															105.0

Drilled By : Donjek Drilling
Drill Type : CME 750

Auger Type : 150 mm Solid Stem
Bit Type : Fish Tail

Water Level(s)

During Drilling After Drilling
At End of Drilling

Logged By : T.Dhara, P.Eng.

Date : May 24, 2017

Data Entry By : T.Dhara, P.Eng.

Date : July 5-8, 2017

Reviewed By:

Date : July 11, 2017

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BOREHOLE LOG

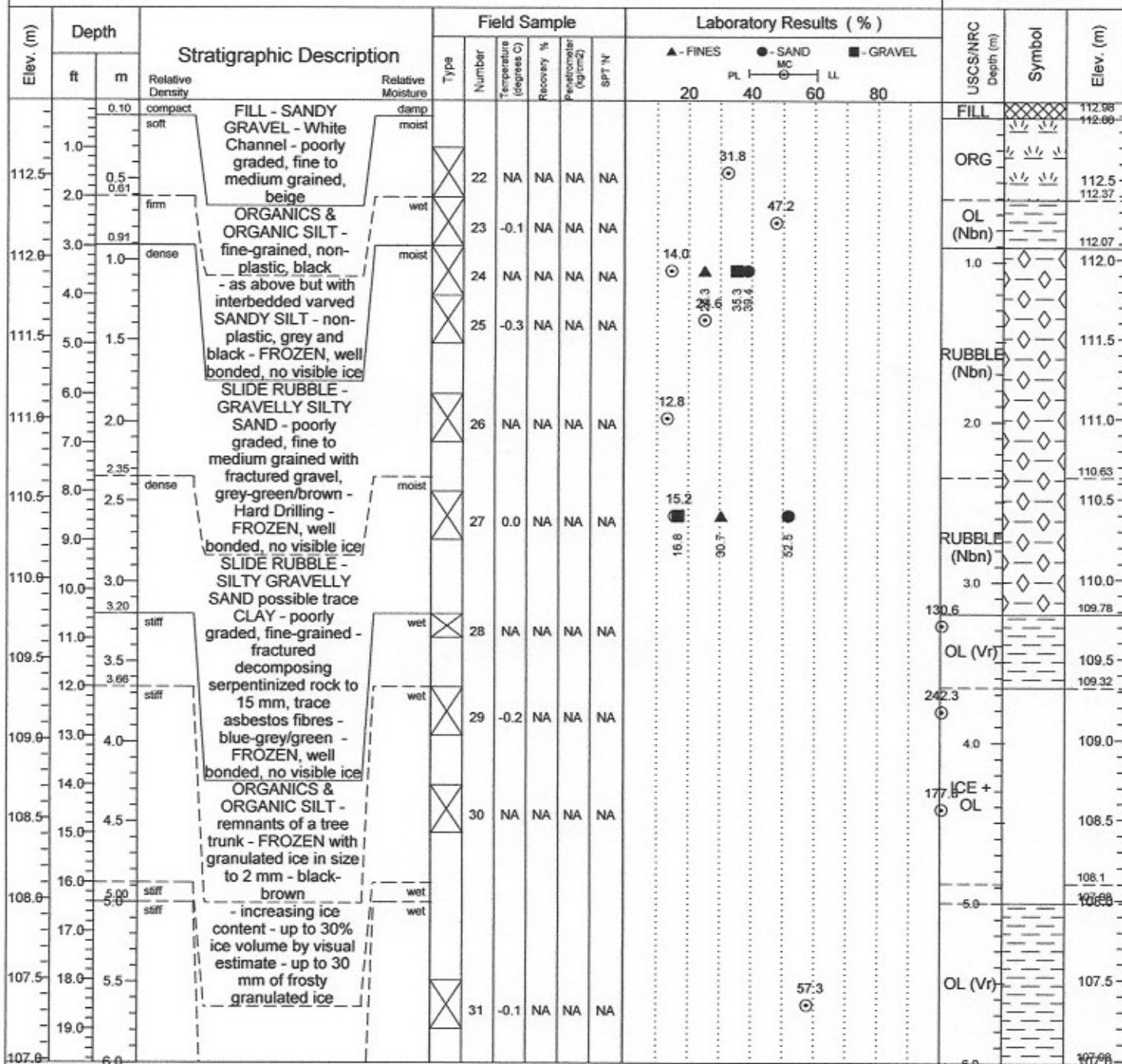
Client : Yukon Government - Energy, Mines & Resources
Location : Moosehide Slide - Dawson, Yukon
Project : Geotechnical Evaluation - Geohazards Assessment
Date Drilled : May 24, 2017

Elevation : 112.98 meters
BH Termination Depth: 7.62 meters
Instrumentation: NA
Weather: 18 C - Partly Cloudy

BOREHOLE

3-17

Sheet 1 of 2



Drilled By : Donjek Drilling
Drill Type : CME 750

Auger Type : 150 mm Solid Stem
Bit Type : Fish Tail

Water Level(s)

During Drilling After Drilling
At End of Drilling

Logged By : T.Dhara, P.Eng.
Date : May 24, 2017

Data Entry By : T.Dhara, P.Eng.
Date : July 5-8, 2017

Reviewed By :
Date : July 11, 2017

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BOREHOLE LOG

Client : Yukon Government - Energy, Mines & Resources
Location : Moosehide Slide - Dawson, Yukon
Project : Geotechnical Evaluation - Geohazards Assessment
Date Drilled: May 24, 2017

Elevation : 112.98 meters
BH Termination Depth: 7.62 meters
Instrumentation: NA
Weather: 18 C - Partly Cloudy

BOREHOLE

3-17

Sheet 2 of 2

Elev. (m)	Depth		Stratigraphic Description	Field Sample					Laboratory Results (%)				USCS/NRC Depth (m)	Symbol	Elev. (m)
	ft	m		Type	Number	Temperature (degrees C)	Recovery %	Penetration (kg/cm ²)	SPT N'	▲ - FINES	● - SAND	■ - GRAVEL			
			Relative Density							PL	MC	LL			
			stiff (continued)							20	40	60	80		
106.5	20.0		stiff												(continued) 106.98
		6.5													106.5
106.0	21.0		- Difficult Drilling due to organic fines on lead bit - Changed Lead Bit and advanced to 7.62 meters - Difficulty in auger withdrawal												106.0
		7.0	- as above but decreasing ice content - granulated ice inclusions in size to 5 mm												105.5
105.5	22.0		- No samples retained beyond 6.0 meters												105.38
		7.5													105.0
105.0	23.0		No Groundwater Encountered Borehole terminated at 7.62 m. below the existing ground surface.												104.5
		7.62													104.0
104.5	24.0														103.5
															103.0
104.0	25.0														102.5
															102.0
103.5															101.5
103.0															101.0
102.5															
102.0															
101.5															
101.0															

Drilled By : Donjek Drilling
Drill Type : CME 750

Auger Type : 150 mm Solid Stem
Bit Type : Fish Tail

Water Level(s)
During Drilling
After Drilling
At End of Drilling

Logged By : T.Dhara, P.Eng.
Date : May 24, 2017

Date Entry By : T.Dhara, P.Eng.
Date : July 5-8, 2017

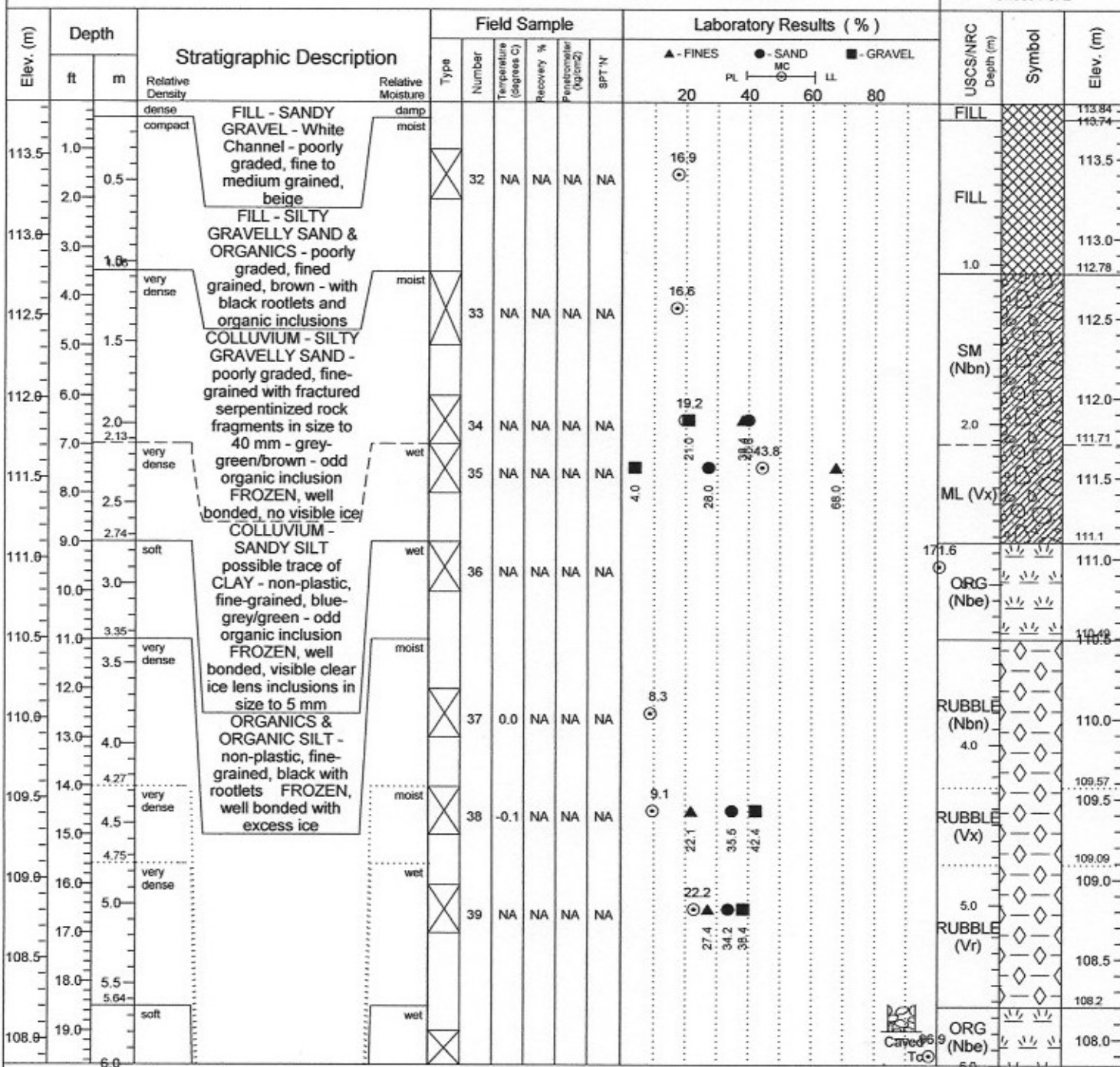
Reviewed By:
Date : July 11, 2017

BOREHOLE LOG

Elevation : 113.84 meters
BH Termination Depth: 6.1 meters
Instrumentation: NA
Weather: 18 C - Partly Cloudy

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Sheet 1 of 2



Auger Type : 150 mm Solid Stem
Bit Type : Fish Tail

 During Drilling  After Drilling
 At End of Drilling

Data Entry By : T.Dhara, P.Eng.

Reviewed By: 

Date : July 5-8, 2017

Date : July 11, 2017

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(867) 335-5804 chilkoot@northwestel.net



BOREHOLE LOG

Client : Yukon Government - Energy, Mines & Resources
Location : Moosehide Slide - Dawson, Yukon
Project : Geotechnical Evaluation - Geohazards Assessment
Date Drilled: May 24, 2017

Elevation : 113.84 meters
BH Termination Depth: 6.1 meters
Instrumentation: NA
Weather: 18 C - Partly Cloudy

BOREHOLE

4-17

Sheet 2 of 2

Elev. (m)	Depth		Stratigraphic Description	Field Sample						Laboratory Results (%)				USCS/NRC Depth (m)	Symbol	Elev. (m)
	ft	m		Type	Number	Temperature (degrees C)	Recovery %	Penetrometer (kg/cm2)	SPT N	▲ - FINES	● - SAND	■ - GRAVEL				
20.0	6.10		SLIDE RUBBLE - SANDY SILTY GRAVEL possible trace of CLAY - poorly graded, fine- grained - serp rock fragments to 30 mm - blue-grey/green w/ white decomposed (powdery and fibrous) rock inclusions - FROZEN, no visible ice - as above but with clear ice lens inclusions in size to 2 mm - as above but increasing ice content - Estimate 15% ice volume by visual estimate ORGANICS & ORGANIC SILT - non-plastic, fine- grained, black with rootlets FROZEN, well bonded with excess ice No Groundwater Encountered Borehole terminated at 6.10 m. below the existing ground surface.	X	40	NA	NA	NA	NA	20	40	60	80	5.79		107.74
107.5																107.5
107.0																107.0
106.5																106.5
106.0																106.0
105.5																105.5
105.0																105.0
104.5																104.5
104.0																104.0
103.5																103.5
103.0																103.0
102.5																102.5
102.0																102.0

Drilled By : Donjek Drilling
Drill Type : CME 750

Auger Type : 150 mm Solid Stem
Bit Type : Fish Tail

Water Level(s)

During Drilling
 After Drilling
 At End of Drilling

Logged By : T.Dhara, P.Eng.
Date : May 24, 2017

Data Entry By : T.Dhara, P.Eng.
Date : July 5-8, 2017

Reviewed By:
Date : July 11, 2017

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BOREHOLE LOG

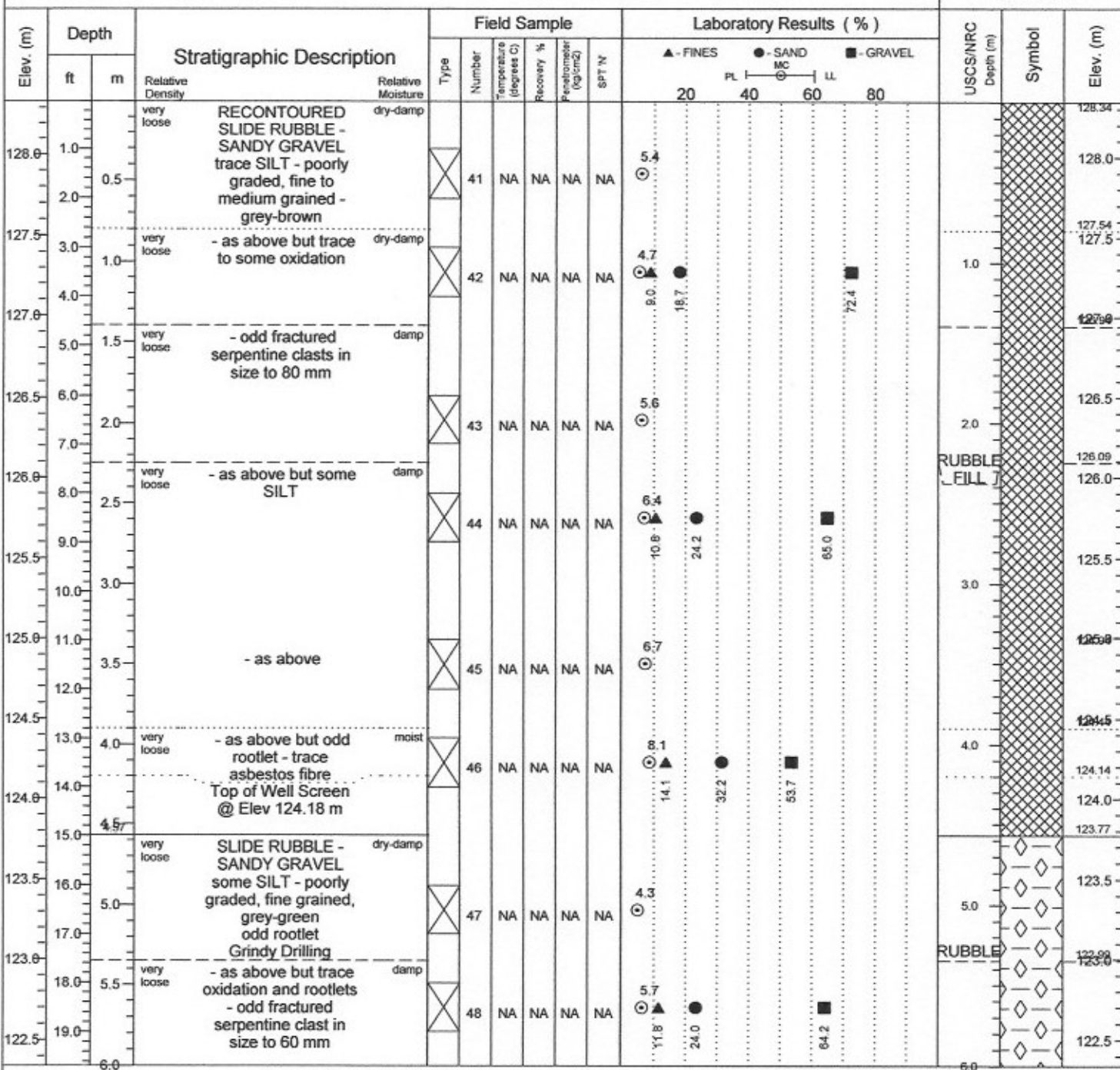
Client : Yukon Government - Energy, Mines & Resources
Location : Moosehide Slide - Dawson, Yukon
Project : Geotechnical Evaluation - Geohazards Assessment
Date Drilled : May 25 & 26, 2017

Elevation : 128.34 meters
BH Termination Depth: 15.15 meters
Instrumentation: 1.5" ABS Well & Casing
Weather: 16 C - Showers

BOREHOLE

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Sheet 1 of 3



Drilled By : Donjek Drilling
Drill Type : CME 750

Auger Type : 150 mm Solid-Stem and 200 mm Hollow-Stem
Bit Type : Fish Tail / Carbide Button

Water Level(s)
☐ During Drilling
☐ After Drilling
☐ At End of Drilling

Logged By : T.Dhara, P.Eng.
Date : May 25 & 26, 2017

Data Entry By : T.Dhara, P.Eng.
Date : July 5-8, 2017

Reviewed By :
Date : July 11, 2017

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BOREHOLE LOG

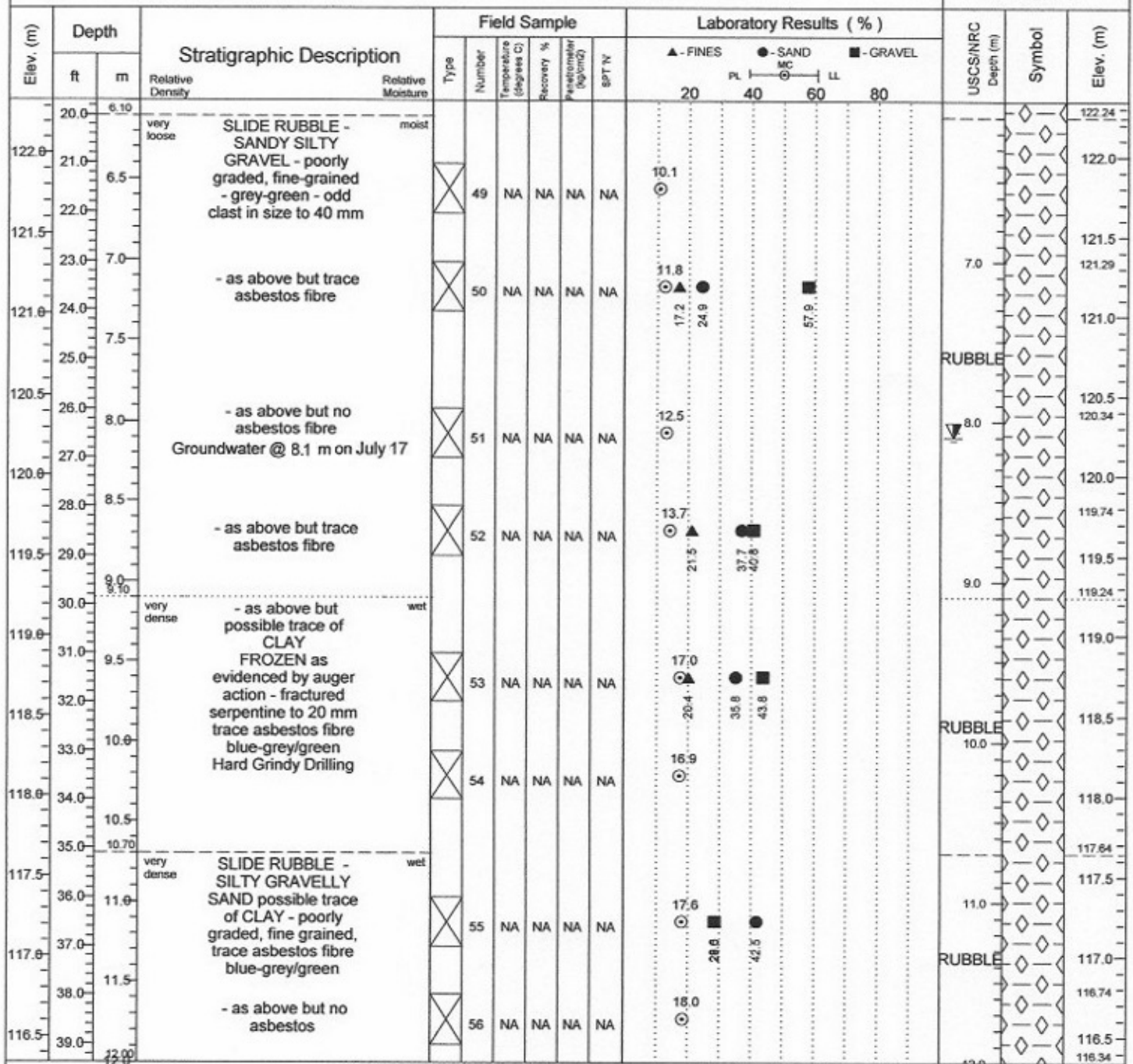
Client : Yukon Government - Energy, Mines & Resources
Location : Moosehide Slide - Dawson, Yukon
Project : Geotechnical Evaluation - Geohazards Assessment
Date Drilled: May 25 & 26, 2017

Elevation : 128.34 meters
BH Termination Depth: 15.15 meters
Instrumentation: 1.5" ABS Well & Casing
Weather: 16 C - Showers

BOREHOLE

5-17

Sheet 2 of 3



Drilled By : Donjek Drilling
Drill Type : CME 750

Auger Type : 150 mm Solid-Stem and 200 mm Hollow-Stem
Bit Type : Fish Tail / Carbide Button

Water Level(s)

During Drilling After Drilling
At End of Drilling

Logged By : T.Dhara, P.Eng.
Date : May 25 & 26, 2017

Data Entry By : T.Dhara, P.Eng.
Date : July 5-8, 2017

Reviewed By :
Date : July 11, 2017

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BOREHOLE LOG

Client : Yukon Government - Energy, Mines & Resources
Location : Moosehide Slide - Dawson, Yukon
Project : Geotechnical Evaluation - Geohazards Assessment
Date Drilled : May 25 & 26, 2017

Elevation : 128.34 meters
BH Termination Depth: 15.15 meters
Instrumentation: 1.5" ABS Well & Casing
Weather: 16 C - Showers

BOREHOLE

5-17

Sheet 3 of 3

Elev. (m)	Depth		Stratigraphic Description	Relative Density	Relative Moisture	Field Sample					Laboratory Results (%)				USCS/NRC Depth (m)	Symbol	Elev. (m)
	ft	m				Type	Number	Temperature (degrees C)	Recovery %	Penetrometer (kg/cm2)	SPT N	▲ - FINES	● - SAND	■ - GRAVEL			
												PL	MC	LL			
												20	40	60	80		
116.0			Possible 0.5 meter thick ice lens noticed during Hollow-Stem Auger advancement	soft	wet											ICE	116.0
41.0	12.50																115.84
115.5			SLIDE RUBBLE - GRAVELLY SILTY SAND possible trace of CLAY - poorly grade, fine grained, trace asbestos fibre blue-grey/green	very dense	wet	X	57	NA	NA	NA	NA	18.1	26.8	31.4	42.0	RUBBLE	115.5
43.0	12.95																115.39
115.0			SLIDE RUBBLE - SANDY SILTY GRAVEL possible trace of CLAY - poorly grade, fine grained, blue-grey/green	very dense	wet	X	58	NA	NA	NA	NA	20.0	25.0	31.2	43.3	RUBBLE	115.04
44.0	13.41																114.99
114.5			SLIDE RUBBLE - SANDY SILTY GRAVEL possible trace of CLAY - poorly grade, fine grained, blue-grey/green	very dense	wet	■	59	NA	NA	NA	105/6	22.1	25.0	31.2	46.7	ICE & RUBBLE	114.78
45.0	13.56																
46.0	14.0		- Withdrew Solid-Stems at 13.4 m - BH collapsed to 12.2 m - Advanced Hollow-Stems to 13.4 m														114.5
47.0	14.5		SLIDE RUBBLE - SILTY SANDY GRAVEL possible trace of CLAY - blue-grey/green														114.0
48.0			Estimate 40% volume of ice by visual estimate - See Geotech Report for details														
49.0	15.0		SLIDE RUBBLE - SILTY SANDY GRAVEL possible trace of CLAY - blue-grey/green	very dense	wet	■	60	NA	NA	NA	107/7	18.1	22.4	31.2	46.7	RUBBLE (Vr & Vc)	113.5
113.5	15.15		Estimate 25% volume of ice by visual estimate - See Geotech Report for details														113.4
113.0			No Groundwater Encountered - 1.5" ABS Casing installed to 15.09 m														113.0
112.5			1.5" ABS Well installed to 15.03 m														112.5
112.0			Borehole terminated at 15.15 m. below the existing ground surface.														112.0
111.5																	111.5
111.0																	111.0
110.5																	110.5

Drilled By : Donjek Drilling
Drill Type : CME 750

Auger Type : 150 mm Solid-Stem and 200 mm Hollow-Stem
Bit Type : Fish Tail / Carbide Button

Water Level(s)
 During Drilling
 After Drilling
 At End of Drilling

Logged By : T.Dhara, P.Eng.
Date : May 25 & 26, 2017

Data Entry By : T.Dhara, P.Eng.
Date : July 5-8, 2017

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