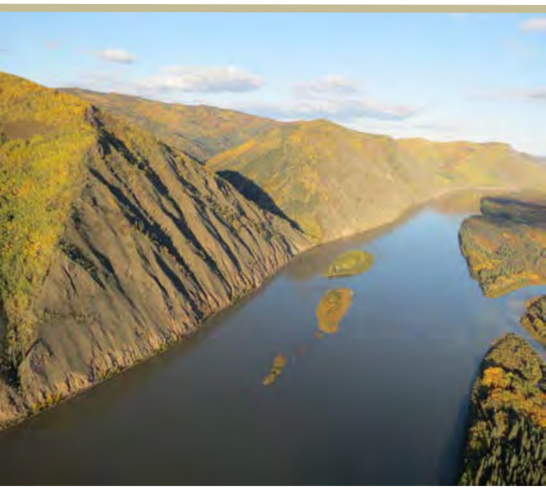
APPENDIX 11-A

Surficial Geology, Permafrost, and Terrain Stability

COFFEE GOLD PROJECT
Environmental Baseline Report, Mine Site Study Area: Surficial Geology, Permafrost, and Terrain Stability



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MAY 2, 2016
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Tetra Tech EBA Inc.
14940 - 123 Avenue
Edmonton, AB T5V 1B4 CANADA
Tel 780.451.2121 Fax 780.454.5688

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EXECUTIVE SUMMARY

Tetra Tech EBA Inc. (Tetra Tech EBA) was retained by Kaminak Gold Corporation (Kaminak) to provide surficial geology, permafrost, terrain, and soils baseline information for the Coffee Gold Project, in preparation for submission of an Environmental Assessment to the Yukon Environmental and Socio-Economic Assessment Board (YESAB).

This report presents summary background information, methods, and results for baseline conditions for the purposes of an environmental assessment. The baseline conditions covered include surficial geology, physiography, permafrost, and terrain stability studies conducted for the Coffee Gold Project from 2011 to 2016. These baseline studies provide important input for the Effects Assessment portion of the Environmental Assessment. The soils portion of the report will be submitted under separate cover.

The study area for this baseline report encompasses the conceptual Coffee mine development area (the mine site study area), as it was proposed at the time of writing. The mine site study area is situated on the divide between the headwaters of Latte Creek and Halfway Creek, in the northern Dawson Range.

First, a literature review was completed to summarize the known conditions at site to date. It shows that the area has not been glaciated, resulting in a landscape consisting of rounded ridges separated by deep, V-shaped valleys. Climate is characterized by warm, short summers and long, cold winters. Weathered bedrock, colluvium derived from weathered bedrock and loess, and fluvial deposits are found in the mine site study area, but colluvial deposits are by far the most common. These deposits are affected by gullying, cryoturbation, solifluction, permafrost processes, periglacial processes, landslides, and snow avalanches. The mine site study area is located within the zone of extensive discontinuous permafrost. Permafrost is most common on north-facing slopes with thick organic cover and in colluvial apron/muck deposits located on lower slopes and at valley bottoms. South-facing slopes are typically permafrost-free. Permafrost-related processes include cryoturbation, solifluction, active layer detachments, slope creep, frost heave, and thermal erosion. Open-system pingos are present locally.

Since 2011, ten field investigation programs have been completed for the baseline studies. These include soils, hydrogeology, permafrost, and geotechnical studies. Drilling, instrument installation in boreholes, testpitting, ground investigations on foot, and helicopter flyovers were all included in these studies.

Evaluations of surficial geology, permafrost, and terrain stability were undertaken for this report. The first two used PurVIEW software for the analysis, while the latter used PurVIEW and DAT/EM Summit Lite software. The desktop mapping draws heavily on the data supplied by the many field investigations; these were used as ground-truthing points for the mapping.

Various permafrost maps, a map of the surficial geology of the mine site, terrain maps, and terrain stability/hazard maps were generated from these studies; these are included at the end of this report. Geohazards and organic soil surface layers were also described.

Results from this study conclude that colluvium is indeed pervasive, and that ridge tops may have exposed weathered bedrock, some of which form tors. Colluvium is dominated by silt and sand, but also contains angular pebbles, cobbles, and boulders. Organic material interbedded with the colluvium at a few sites shows that downslope creep or possibly sliding of some colluvial deposits may be fairly recent (Holocene in age). Thin fluvial deposits consisting of gravelly silt are found in the narrow valley bottoms and a few fluvial fans are present at the mouths of small tributary valleys. Organic deposits are rare; they are found in the Latte Creek valley and overlying colluvial apron/muck deposits at the base of some slopes.

The only rare landforms in the mine site study area are tors and one collapsed open-system pingo.

Permafrost distribution determined from the mapping shows that approximately 62% of the mine site study area is underlain by permafrost. Permafrost thicknesses range from approximately 30 m to 165 m. The active layer is highly variable: it is usually thin (approximately 0.3 m to 0.6 m), but it can be several metres thick in bedrock areas or where coarse surficial sediments are present. Ground temperatures range from close to 0ºC to approximately -2ºC, indicating warm permafrost conditions. Ground containing permafrost is therefore sensitive to disturbance. Ground ice has been classified as non-visible, visible, or forming significant accumulations, such as massive ice bodies, although the latter is rare. The spatial distribution of these across the mine site was determined to be 34% for ice-poor permafrost with non-visible ice; 27% for permafrost with visible excess ice; and 1% for very ice-rich permafrost, which is mainly found at the bottom of the Latte Creek valley.

Five terrain stability classes (stable; generally stable; generally stable with minor instability; potentially unstable; and unstable) were mapped by Palmer Environmental Consulting Group (PECG) within the mine site. These classes were differentiated for both the existing and disturbed condition because of the complexity of the permafrost terrain in the mine site study area. The “existing terrain stability” class represents current conditions, in the absence of any project-related activity; whereas the “disturbed terrain stability” class represents conditions following disturbance to ground conditions from exploration activities and road/mine facility construction without mitigation. This format of mapping, in PECG’s opinion (Appendix B), distinguishes natural hazards, which may be triggered by occurrences such as wildfire, from those potentially exacerbated or initiated by project-related disturbance.

Calculations of the areas occupied by each of the five terrain stability classes using ArcGIS technology show that prior to the proposed construction activities (existing undisturbed terrain) the majority (approximately 78%) of the mine site study area has an existing terrain stability class of “generally stable” (Class II). Approximately 15% is considered “generally stable with isolated minor instability” (Class III). Approximately 1% of the mine site study area is considered “potentially unstable” (Class IV) and approximately 6% - “unstable” (Class V).

According to the disturbed terrain stability class, the proportion of terrain stability polygons in the mine site study area with a “generally stable” (Class II) rating drops from 78% to 27% (disturbed). The majority (approximately 42%) becomes “generally stable with isolated minor instability” (Class III). Approximately 24% of the mine site study area becomes “potentially unstable” (Class IV) and approximately 7% - “unstable” (Class V).

Various hazards were identified and described by magnitude, frequency, and considerations for mitigation of each. These include rockfall, debris slides, rock creep, gullying, solifluction, thermokarst, and slopewash. The various geohazards within each proposed infrastructure footprint were also described.

Finally, the organic surface soil was described. It is generally 0.2 m thick, but is slightly thinner on ridge tops, and is thicker in areas of non-visible ground ice or areas of very ice-rich permafrost. Organic silt is most common on north-facing slopes and is found only in areas of visible or non-visible ground ice. The presence of silt within the organics may be caused by a combination of more active slope creep in permafrost areas, cryoturbation or loess capture by permafrost-bearing units, which are wetter in summer.

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GLOSSARY OF TERMS

Term	Definition
Active Layer	The top layer of ground above the permafrost table that is subject to annual thawing and freezing.
Active Layer Detachment	Shallow slope failure in which the thawed or thawing active layer and vegetation mat detach from the underlying frozen material. Common on colluvial slopes in areas of fine-grained, ice-rich deposits.
Apron	Coalesced fans which occur at foot of bluffs, escarpments, or steep slopes. They are formed by materials transported from the steeper slope and form wedge-shaped deposits with concave to planar surfaces. Deposition of materials typically occurs during extreme storm or runoff events.
Blanket	A mantle of surficial materials thicker than about 1 metre, which reflects the topography of the bedrock or older surficial materials upon which it rests, although minor details of the topography may be masked.
Colluvial Deposits/Colluvium	Materials deposited as a result of downslope movements due to gravity, such as rockfall, soil creep, and debris flows, including talus slopes and mantles of weathered bedrock. Colluvial deposits are composed of rock fragments of all sizes derived from the local bedrock and reworked loess, as well as finer textured material derived from in place weathering of the rock fragments. These deposits are generally poorly sorted and poorly consolidated.
Creep	The imperceptibly slow downward movement of soil or rock on slopes or slow deformation of frozen ground; caused by gravity or long-term application of a stress too small to produce failure in the frozen material.
Cryoplanation	Alteration by intense frost action that effectively reduces slope steepness and lowers mountain and hill peaks, modifying landscapes into cryoplanation terraces, i.e. step-like benches cut in bedrock.
Cryoturbation	Heaving, churning, and sorting of soil and surficial materials due to repeated freezing and thawing; results in the development of convoluted and flame-like structures in the soil and patterned ground.
Debris Flow	A sudden and destructive landslide where loose material on a slope, with more than 50% of particles larger than sand size, is mobilized by saturation and flows down a channel or canyon. The flow contains a combination of or all of the following: soil, surficial materials, bedrock, and plant material. Whether saturated or dry, a debris flow behaves much like a viscous fluid when moving.
Debris Slide	A shallow slide consisting of a mass of soil, vegetation, and surficial material; initial displacement is along one or several surfaces of rupture. Composed of comparatively dry and largely unconsolidated surficial material and results in an irregular, hummocky deposit.
Dendritic	Surface drainage pattern where streams branch out in an irregular tree-like fashion.
Depth of Zero Annual Amplitude	The distance from the ground surface downward to the level beneath which there is practically no annual fluctuation in ground temperature.

Eolian	Well sorted materials, predominantly silt and fine to medium sand, which have been eroded, transported, and deposited by wind.
Excess Ice	The volume of ice in the ground, which exceeds the total pore volume that the ground would have under natural unfrozen conditions.
Felsenmeer	An accumulation of angular boulders on a level or gently sloping surface, comprising local rocks broken up by frost action, generally located in high altitude or high latitude regions.
Fluvial Deposits	Sediments transported and deposited by streams and rivers, including floodplain deposits, river terraces, and fluvial fans. “Alluvial” is an older term meaning the same.
Fluvial Fan	A fan-shaped deposit built by streams, usually located at the mouth of a tributary valley. The sediment flows start at the apex of the fan, and over time move to occupy many positions on the fan surface. Sediments generally consist of sand and gravel, and are formed by a combination of stream flood and debris flow activity. Fluvial fans typically have gradients of less than 10%.
Friable Permafrost	Permafrost in which the soil particles are not held together by ice; the material is easily broken up under light to moderate finger pressure.
Frost Action	The process of alternate freezing and thawing of moisture in soil, rock, and other materials, and the resulting effects on materials, and on structures placed on, or in, the ground.
Frost Heave	The upward or outward movement of the ground surface (or objects on, or in, the ground) caused by the formation of ice in the soil.
Glaciofluvial Deposits	Sediments formed by meltwater issuing from, or within, a glacier. The deposits are stratified and may form outwash plains, or terraces.
Ground Ice	Ice in pores, cracks, and other openings in surface sediments or rock, which forms in permafrost terrain. A general term referring to all types of ice formed in freezing or frozen ground.
Ice Wedge	A massive, generally wedge-shaped body of ground ice with its apex pointing downward, composed of foliated or vertically banded, commonly white, ice; forms in permafrost environments.
Loess	A homogeneous massive deposit formed by wind consisting mainly of silt. Loess sediment sources include glaciofluvial and glaciolacustrine deposits or fine-grained colluvium.
Muskeg	A North American term frequently used for peatlands. The word is of Algonquin Indian origin and is applied in ordinary speech to natural and undisturbed areas covered more or less with *Sphagnum* mosses, tussocky sedges, and an open growth of scrubby trees. (The terms peatland and muskeg are commonly used interchangeably).
Peat	Unconsolidated compressible material consisting largely of undecomposed, or slightly decomposed, organic matter accumulated under water-saturated conditions. Peat is commonly formed by the slow decay of successive layers of aquatic and semi-aquatic plants in swampy or water-logged areas, where oxygen is absent.

Periglacial	Pertaining to cold climates, in proximity to the margin of a continental ice sheet, such as in arctic and alpine areas, where frost action is an important feature.
Permafrost	Ground (soil or rock) that remains at or below 0ºC for at least two years.
Pingo	A large perennial frost mound consisting of a core of massive ice, formed primarily by injection of water, and covered with soil and vegetation. Pingos occur in the zones of continuous and discontinuous permafrost. There are two varieties of pingos: closed-system and open-system.
Pingo, Closed-System	A pingo formed by doming of frozen ground due to freezing of injected water supplied by expulsion of pore water during permafrost growth. Found mainly in the zone of continuous permafrost, in flat, poorly-drained terrain.
Pingo, Collapsed	A pingo remnant represented by a low or arcuate ridge of material resulting from the slumping of the sides of the pingo during thawing. The former centre is marked by a depression which may be filled with water.
Pingo, Open-System	A pingo formed by doming of frozen ground due to freezing of injected water supplied by groundwater moving downslope through taliks to the site of the pingo, where it moves towards the surface. Found mainly in the zone of discontinuous permafrost, in areas of marked relief.
Rockfall	The process, associated sediments or resultant landform characterized by very rapid downslope movement of newly detached pieces of bedrock that fall freely from a cliff or cascade down a steep slope.
Rotational Slide	The process, associated sediments or resultant landforms characterized by an extremely slow to moderately rapid landslide, in which movement occurs along a well-defined, spoon-shaped shear surface; produces a backward rotation of the displaced block or blocks; sometimes referred to as a slump.
Segregated Ice	Ice in discrete layers or ice lenses, formed by ice segregation; commonly occurs in alternating layers of ice and soil. Segregated ice layers can range from hairline to more than 10 m in thickness.
Solifluction	Slow downslope movement of saturated unfrozen (in non-permafrost regions) or thawed (associated with frozen ground) earth materials across a frozen (in permafrost regions) or otherwise impermeable substrate.
Talik	A layer or body of unfrozen ground in a permafrost area.
Thermal Erosion	The general process whereby frozen soils thaw and then are removed by moving water or remain in place in waterlogged conditions.
Tor	A high, isolated pinnacle, or rocky peak; or a pile of rocks, heavily jointed and usually granitic, exposed to intense weathering, and often assuming peculiar shapes.
Veneer	A cover of surficial material with a thickness less than 1 metre.
Well-Bonded	A condition in which soil particles are strongly held together by ice, so that the frozen soil possesses relatively high resistance to chipping or breaking.

ACRONYMS & ABBREVIATIONS

HLF	Heap Leach Facility
PECG	Palmer Environmental Consulting Group
TK	Traditional Knowledge
VWP	Vibrating Wire Piezometer
WRSF	Waste Rock Storage Facility
YESAB	Yukon Environmental and Socio-Economic Assessment Board
YG	Yukon Government
YGS	Yukon Geological Survey

CONFIDENTIALITY STATEMENT

LIMITATIONS OF REPORT

This report and its contents are intended for the sole use of Kaminak Gold Corporation and their agents. Tetra Tech EBA Inc. (Tetra Tech EBA) does not accept any responsibility for the accuracy of any of the data, the analysis, or the recommendations contained or referenced in the report when the report is used or relied upon by any Party other than Kaminak Gold Corporation, or for any Project other than the proposed development at the subject site. Any such unauthorized use of this report is at the sole risk of the user. Use of this report is subject to the terms and conditions stated in Tetra Tech EBA's Services Agreement. Tetra Tech EBA's General Conditions are provided in Appendix A of this report.

1.0 INTRODUCTION

Tetra Tech EBA Inc. (Tetra Tech EBA) was retained by Kaminak Gold Corporation (Kaminak) to provide surficial geology, permafrost, terrain, and soils baseline information for the Coffee Gold Project, in preparation for submission of an Environmental Assessment to the Yukon Environmental and Socio-Economic Assessment Board (YESAB).

This report presents summary background information, methods, and results for the baseline physiography, surficial geology, permafrost, and terrain stability studies conducted for the Coffee Gold Project from 2011 to 2016. The soils portion of the report will be submitted under separate cover.

The baseline study provides important input for the Effects Assessment portion of the Environmental Assessment. The study area for this baseline report encompasses the proposed Coffee mine development area (the mine site study area), and is shown in Figure 1. The mine site study area is situated on the divide between the headwaters of the Latte Creek and the Halfway Creek, in the northern Dawson Range, and has a slightly different extent than the study area used for the terrain stability study by Palmer Environmental Consulting Group Inc. (PECG Appendix B).

Work completed for the baseline report for the proposed access road is outside the scope of this study.

2.0 METHODS

2.1 Literature Review

A literature review was undertaken to summarize existing information on surficial geology, permafrost, physiography, and terrain stability for the mine site study area. Surficial geology maps, unpublished reports, and published journal articles were reviewed to determine general information for the area, as it was known at the time of this study. Maps and other documents are referenced accordingly within the Literature Review section.

2.2 Previous Field Programs

Ten field investigation programs have been completed for the baseline study since 2011. These are described below.

Ground Truthing Program (AECOM, August 2011)

Results of the soils field investigations conducted within the mine site study area in August 2011 (AECOM 2012) were used to confirm surficial geology and permafrost mapping, where possible.

Hydrogeological Field Program (Tetra Tech EBA, Fall 2013)

This first hydrogeological field program (Tetra Tech EBA 2014) consisted of installing four single-point vibrating wire piezometers (VWPs) in NQ2-sized boreholes to collect hydraulic testing and ground temperature data. This information was referred to while compiling the permafrost map of the mine site study area.

Hydrogeological Drilling Program (Lorax, August-September 2014)

The 2014 hydrogeological drilling program was implemented within upland areas in and around proposed pits and the formerly proposed valley-fill Heap Leach Facility (HLF) footprint. This data was mainly used to confirm surficial geology mapping, permafrost mapping, and soil texture.

Geotechnical Field Program (Knight Piesold, August-September 2014)

This geotechnical field investigation (Knight Piesold 2015) was conducted in the formerly proposed valley-fill HLF footprint area. The investigation comprised a combination of test pits and borings to assess shallow and deeper subsurface conditions. This information aided with the compilation of the permafrost map of the mine site study area.

Hydrogeological Drilling Program (Lorax, March 2015)

This hydrogeological field investigation consisted of drilling vertical boreholes and installing thermistor and VWP strings downgradient of the proposed North and South Waste Rock Storage Facilities (WRSF). This information aided with the compilation of the permafrost map.

Geotechnical Field Investigation Sonic Drilling Program (SRK, April 2015)

The April 2015 geotechnical investigation included field and laboratory tests to characterize the proposed waste rock dump, HLF pad, and plant site footprints. This data was mainly used to confirm surficial geology, permafrost mapping, and soil texture.

Hydrogeological Drilling Program (Lorax, April-June 2015)

The hydrogeological investigation consisted of drilling vertical and angled boreholes and installing thermistor and VWP strings. This information aided with the compilation of the permafrost map.

Geotechnical Field Investigation Supplementary Test Pitting Program (SRK, June-July 2015)

The June 2015 supplementary test pitting program confirmed findings of the sonic drilling program and provided additional bulk samples for laboratory testing and analyses. This data was mainly used to confirm surficial geology, permafrost mapping, and soil texture.

Terrain Stability Field Investigation (PECG, August 2015)

The August 2015 field investigation focused on the terrain stability of the mine site study area, albeit with slightly different study area boundaries. The investigation included documenting terrain characteristics, permafrost, and drainage conditions. Observations regarding permafrost conditions and terrain hazards were also recorded.

Geotechnical Site Reconnaissance Program (Tetra Tech EBA, September 2015)

The Tetra Tech EBA field program is described in detail in Section 2.4.

2.3 Data Analysis

2.3.1 Surficial Geology Mapping

Mapping of surficial geology was completed using PurVIEW software, which is an add-on to ArcGIS. PurVIEW is a 3D mapping tool that allows stereo pair air photos to be viewed on a computer screen with 3D glasses. High-resolution digital images provided by Kaminak were loaded into PurVIEW and analyzed. Polygons, lines, and point symbols were mapped in ArcGIS/PurVIEW and map figures were created in ArcGIS.

Surficial geology was mapped (Figures 2a to 2f) according to the Yukon Digital Surficial Geology Compilation and Terrain Classification System (YG 2016). However, only the surficial units and expressions (e.g. colluvial veneer) were mapped for simplicity, as requested by Kaminak. Textures of the materials were recorded only for mapped polygons in which ground data describing soil texture was available.

A number of additional data sources were used to confirm mapping for this study and to determine sediment texture for applicable portions of the mapped area. These include:

- Borehole data (KP 2015), (Lorax 2016), and (SRK 2016a);
- Terrain field data supplied by PECG;
- Soils field data supplied by AECOM (2012); and
- Terrain field data collected by Tetra Tech EBA during field reconnaissance for permafrost studies.

The above field site and borehole locations were loaded into ArcGIS and were referred to while mapping.

2.4 Permafrost Mapping

Reconnaissance of permafrost conditions in the mine site study area was completed between September 5 and September 8, 2015, by Vladislav E. Roujanski, Ph.D., P. Geol., of Tetra Tech EBA and Chalsie Warren of Kaminak. Fieldwork involved measurement of active layer thickness with a permafrost probe, hand-dug testpit excavation, and acquisition of georeferenced field photographs of terrain features indicative of various permafrost conditions. Some areas were accessed by pickup truck, while others were accessed by helicopter or on foot. Several helicopter overview flights were also completed.

Permafrost and related geohazard mapping within the mine site study area was carried out by Vladislav E. Roujanski and Shirley McCuaig, Ph.D., P. Geol. in November-December 2015, and was subsequently updated in February 2016 as new data became available. Digital colour air photos covering the mine site study area were acquired by Kaminak in August 2011 at a nominal scale of 1:20,000. These were provided to Tetra Tech EBA in November 2015 and were used to generate 3D digital models of the landscape in PurVIEW. Permafrost mapping was initially carried out at 1:20,000 scale, based on stereoscopic interpretation (using a Sokkia MS27 stereoscope) of the colour air photo printouts. The permafrost distribution linework was then refined using the PurVIEW system. This software allowed the mappers to zoom in and out of the 3D air photos, which increased mapping accuracy. The PurVIEW-based mapping was done at 1:5,000 to 1:20,000 scale, but is presented in this report at a scale of 1:20,000.

Permafrost terrain units (map polygons) were delineated according to geobotanical indicators, e.g. stunted black spruce stands on shallow permafrost vs. deciduous (dominantly aspen) stands on unfrozen soils, slope aspect (north-facing vs. south-facing slopes), and extrapolated surface appearance (texture, colour, hue etc.). Where possible, mapped permafrost conditions were confirmed by ground temperature measurements acquired from thermistor-instrumented boreholes. In addition, intrusive exploration data and detailed ground/soil/terrain/permafrost observation site logs were used to inform the mapping, as described in Section 2.3.1. Limited ground temperature data, frozen soil condition information, and other relevant data contained therein were useful data points for the permafrost mapping effort.

Hazardous permafrost-related geomorphic processes and landforms that may pose a challenge to mine site construction and operations were mapped as point and line symbols.

Two versions of the permafrost map were compiled (Figures 3a to 3d): one with permafrost polygons colour-coded according to ground ice occurrence in perennially frozen ground (Figure 3a) and one with transparent labelled polygons overlaid on the orthophotographs (Figure 3b). Figure 3c shows the mine facility layout plan overlaid on

Figure 3b. Figure 3d shows the as-drilled borehole locations along with the mine facility footprints and permafrost distribution.

2.5 Terrain, Terrain Stability and Hazard Mapping

The terrain, terrain stability, and hazard mapping was completed by PECG and the results are summarized in a report dated March 19, 2016. This work is included as Appendix B of this report; the map figures have been edited to include only those that pertain to the mine site study area.

The work completed by PECG included the following tasks:

- Background review and consultation;
- Field investigation;
- Terrain and terrain stability mapping;
- Hazard identification; and
- Assessment of soil erosion potential[1].

Terrain, terrain stability, and geohazard methods described by PECG are summarized below.

2.5.1 Background review and consultation

PECG reviewed aerial photography, LiDAR-derived elevation data, satellite imagery, surficial and geomorphological mapping, previous investigations, and peer-reviewed literature. They also consulted with senior members of the Yukon Geological Survey (YGS) regarding their field experience with the paleo-landslides in the area and members of Yukon Highways to discuss mass movement and icing hazards in the mine site study area.

2.5.2 Field Investigation

A field investigation was completed in August 2015. There were at least 15 sites investigated within the PECG mine site study area, including both helicopter reconnaissance and detailed ground investigations. Site characteristics, terrain characteristics and hazards, drainage conditions, permafrost conditions, and vegetation were recorded at each site. Hand-dug soil pits were used to examine subsurface materials and the active layer thickness was determined by making a minimum of five frost-probing measurements at each ground investigation site.

2.5.3 Terrain and Terrain Stability Mapping

The terrain and terrain stability mapping was completed in accordance with YESAB's mapping requirements (Guthrie and Cuervo 2015). However, the terrain stability classes were modified to include disturbances that may result from thermokarst processes and have been tailored to consider the presence or absence of warm permafrost with variable ground ice content (not to be confused with "existing" and "disturbed" terrain stability classes).

Terrain mapping was completed by dividing the terrain into polygons according to surficial materials, landform characteristics, and geomorphological processes. Each polygon was assessed to be stable, potentially unstable, or unstable. The terrain maps of the mine site study area are provided in Appendix B (Map 1).

[1] Soil erosion potential will be discussed in the Soils portion of this Environmental Assessment.

The delineation of the polygons was completed using either PurVIEW or DAT/EM Summit Lite software with digital air photos having a scale of 1:10,000. Photos having a scale of 1:2,500 were used when additional details were required. The polygons were delineated based on eight attributes: surficial material, surface expression, texture, geomorphological process, and drainage class, depth to permafrost, ice content, and slope class.

Additional point or linear features, such as thermokarst ponds or slope failures that are too small to be mapped as polygons are identified with point and line symbols.

The terrain stability maps were compiled with the aid of AECOM's (2012) geomorphological maps.

PECG assessed terrain stability both before and after disturbance ("existing" and "disturbed" classes) to provide design engineers with all potential hazard information in the area of development, particularly as the mine site study area is characterized by extensive discontinuous permafrost.

2.5.4 Hazard Identification

Terrain polygons were categorized by the dominant hazard type to depict the nature of the hazard governing the terrain stability class of each polygon. Three categories were used to classify the stability class of each polygon:

i. Slope failure potential is dominant;

ii. Thermokarst potential is dominant; or

iii. Slope failure and thermokarst potential are co-dominant.

2.6 Organic Soils Analysis

The organic surface layer analysis was completed by reviewing borehole logs recorded in Lorax (2016) and SRK (2016a). The thickness and composition of organic cover at each borehole was summarized and uploaded to an ArcGIS database. A topographic map was created in ArcGIS and the organic thicknesses labelled for each borehole, but it was not necessary to present this map as a figure in this report.

The organic thickness map was reviewed to determine if elevation or aspect had any effect on the amount or type of organic material present on the ground surface within the mine site study area. The surficial geology/permafrost map was also reviewed in the context of the organic soil thicknesses to check for relationships to sediment type and ground ice content.

3.0 RESULTS

The following sections begin with the literature review, and then present results for surficial geology and permafrost mapping completed by Tetra Tech EBA, followed by a summary of the terrain and terrain stability mapping completed by PECG (full report is provided in Appendix B).

3.1 Literature Review

3.1.1 Physiography and Climate

The mine site study area is located within the Klondike Plateau physiographic region. The Klondike Plateau is a Tertiary-age upland that has undergone variable uplift and stream dissection, resulting in rounded summits and ridges, and deep V-shaped valleys hosting **dendritic** streams (Mathews 1986; Huscroft 2002). Most valley sides exhibit convex profiles (Photo 1), with concave profiles restricted to localized bench or gully features and valley bottoms filled with material derived from upslope erosion (PECG Appendix B). The mine site study area, which is situated within the Coffee Creek and Yukon River watershed, was not glaciated during the last Wisconsin glaciation (Duk-Rodkin 1999) and has since been modified by frost action and permafrost-related processes.

Photo 1: Latte Creek valley exhibiting convex valley slopes, looking east. Sparse stunted black spruce on the north-facing slope (on right side of photo) is indicative of shallow ice-rich permafrost; whereas the south-facing slope (left side), covered with moderately dense aspen and aspen/white spruce mixed forest, is predominantly permafrost-free.

There is little traditional knowledge related to terrain in the region: most traditional uses pertain only to topography. Trails used by First Nation groups tend to be located on gently sloping or flat “easy passage” areas, such as ridge tops and valley bottoms. Some high elevation areas are used as lookouts.

The climate of the Klondike Plateau is continental: it is characterized by warm, short summers and long, cold winters. Mean annual air temperature is near -5ºC, mean January temperatures range from -23ºC to -32ºC and mean July temperatures from 10ºC to 15ºC (Yukon Ecoregions Working Group 2004). Strong thermal inversions are common from December to February, in association with prolonged atmospheric stability (Williams 1995). During this period, air temperatures on valley bottoms can be tens of degrees lower than surrounding higher-elevation areas (PECG Appendix B). Mean annual precipitation ranges from about 300 mm to 500 mm, giving the region a semi-arid classification (Yukon Ecoregions Working Group 2004). The wettest period occurs in summer, when most precipitation falls as rain during convective rain showers and thunderstorms (PECG Appendix B).

3.1.2 Surficial Geology

Although the mine site and most of its access road fall within the unglaciated portion of the Yukon, glaciers occupied the Stewart River valley to the north and a few small glaciers were present east and west of the mine site study area in Pliocene to early Pleistocene time (3 million to 1.8 million years ago) (Duk-Rodkin 1999). Glacial Lake Yukon was dammed by this ice sheet (Duk-Rodkin 1996).

The lack of glaciation in the mine site study area means that the area has experienced a significant period of weathering. Surficial deposits comprise weathered bedrock, **colluvium** derived from weathered bedrock and **loess**, and **fluvial** deposits (Huscroft 2002; AECOM 2012). Colluvium is expected to be coarser grained on steeper slopes, while colluvial aprons on lower slopes commonly include ice-rich resedimented loess and **peat** (informally called "muck" when taken together) (Huscroft 2002; McKenna and Lipovsky 2014). Colluvial deposits dominate high elevation areas and valley slopes, while fluvial deposits are found in valley bottoms. These deposits may be affected by gullying, **cryoturbation**, **solifluction**, permafrost processes, **periglacial** processes, landslides, and snow avalanches (AECOM 2012; McKenna and Lipovsky 2014; KP 2015).

Weathered bedrock is exposed on several ridge tops in the mine site study area; it locally exhibits **cryoplanation** terraces or granitic **tors** (Huscroft 2002; AECOM 2012). Weathered bedrock consists of fractured and jointed bedrock exposures covered with less than 1 m of **felsenmeer** or residual soil, which commonly forms a yellowish sand consisting of quartz, feldspar, plagioclase, biotite, and hornblende derived from the disintegration of the Coffee Creek granite (AECOM 2012; KP 2015). Bedrock terraces are present in some valley bottoms and bedrock is exposed in a few valleys where it has been cut by stream erosion (AECOM 2012).

Most of the area is covered with colluvium. **Creep, debris slides, rockfall**, and one **rotational slide** have been identified within the mine site study area (AECOM 2012). Colluvial deposits comprise loose, poorly sorted angular gravel, and boulders with a sandy silt to silty sand matrix (KP 2015; SRK 2016a, b). Colluvial apron/muck deposits consist of **eolian** fine sand and silt reworked with organic silt, organic deposits, colluvium, and locally, fluvial fan gravel and sand. The colluvial apron/muck deposits are most common on north-facing lower valley slopes and commonly contain **segregated ice** bodies and buried **ice wedges** (Huscroft 2002). Colluvium thickness is estimated at less than 1 m on ridge tops, less than 1 m to 2 m on valley slopes and up to 10 m on valley bottoms and lower slopes (Huscroft 2002; AECOM 2012; KP 2015; SRK 2016b). Organic soils 0.2 m to 0.3 m thick typically cover the colluvial deposits (SRK 2016b).

Fluvial deposits consist of beds of sand, silt, and organic layers in slow-moving reaches, or gravel and cobbles in faster-moving reaches or underlying the finer-grained units (AECOM 2012; KP 2015). Fluvial deposits may also contain reworked eolian silt and sand (McKenna and Lipovsky 2014).

Eolian deposits formed when parts of the surrounding region were vegetation-free, shortly after the Pliocene-Pleistocene deglaciation and other younger, less extensive glaciations. Fine sand and silt (loess), derived from **glaciofluvial** deposits in the Donjek and White River valleys, has coated the surficial deposits within the mine site area, but has since been eroded, redeposited and reworked (Huscroft 2002; AECOM 2012).

Organic deposits are typically poorly drained due to the presence of permafrost and consist mainly of moss (AECOM 2012).

Numerous boreholes and testpits have been completed within the mine site study area (Lorax 2016; SRK 2016a). These were referenced while mapping and rather than summarizing them here, individual areas of interest are highlighted in the surficial geology descriptions.

3.1.3 Permafrost

The mine site study area is located within the zone of extensive discontinuous permafrost, where 50% to 90% of the area is expected to be perennially frozen (Heginbottom et al. 1995). Locally, permafrost distribution is related to slope aspect, angle and shape, soil texture and moisture, and the presence, thickness, and type of organic cover (Williams 1995; Williams and Burn 1996; PECG Appendix B). Permafrost is most common on north-facing slopes with thick organic cover and within the colluvial apron/muck deposits (Bond and Lipovsky 2011). Steep, well drained, south-facing slopes are invariably permafrost-free (PECG Appendix B).

Although initially permafrost was thought to be thickest on lower slope aprons with northerly aspects and to thin toward ridge tops (AECOM 2012), recent data suggests that permafrost extends to its greatest depths in ridge areas and appears to thin towards areas of lower elevation (Lorax 2016) (with the notable exception of colluvial apron/muck units). Permafrost was found to be 135 m to 165 m thick on Supremo Ridge, with temperatures of approximately -1.1°C at those depths (SRK 2016b). Permafrost depths were 75 m to 83 m below the West WRSF and the toe of the North WRSF (SRK 2016b). Permafrost was absent at two boreholes within the South WRSF (SRK 2016b).

Active layer thickness primarily depends on elevation, aspect, soil texture, drainage, snow pack, vegetation cover, and wildfire history (Williams and Burn 1996; McKillop et al. 2013). The active layer is generally 1 m to 2 m thick within the region encompassing the mine site study area (Yukon Ecoregions Working Group 2004; Bond and Lipovsky 2011), except in areas where vegetation has been stripped, i.e. in road cuts (Lorax 2016). Well drained, coarse-grained soils tend to have a thicker active layer than poorly drained, fine-grained ones (PECG Appendix B). The active layer is suggested to be about 1 m thick in the HLF area (KP 2015). Permafrost temperatures within the mine site study area are measured with thermistor strings installed by Lorax (2016) and SRK (2016a). While most thermistor installations indicate sub-zero temperatures in bedrock, observations of ice in bedrock are limited (Lorax 2016).

The ice content of permafrost across the mine site study area is highly variable. Areas of perennially frozen intact or weathered bedrock and well drained, coarse-grained colluvial mantles generally contain little to no visible ice. Such ice-poor permafrost is common in upland settings, on summits, along ridges and spurs, and on moderate to moderately steep valley sides with convex or straight slopes (PECG Appendix B). Permafrost more commonly contains excess ice in the form of thin seams and lenses in silt-rich colluvial blankets, on solifluction slopes and in inactive portions of fluvial plains. Ice-rich permafrost containing massive ice bodies is most commonly encountered in organic terrain and silt-rich colluvial complexes in fluvial valley bottoms (PECG Appendix B). Lorax (2016) reports on three large bodies of ground ice intercepted between 8 m and 13 m below ground surface in Borehole MW15-01T (Figure 3d, this report). The drill pad was located on a slope classified as poorly drained colluvial veneer modified by solifluction (AECOM 2012). In general, perennially frozen deposits contain visible and non-visible ice, largely in the form of ice crystals, inclusions and/or coatings on soil particles (KP 2015).

Permafrost-related processes and landforms within the mine site study area include cryoturbation, solifluction, **active layer detachments**, slope creep, **frost heave**, and **thermal erosion** (AECOM 2012; McKillop et al. 2013; KP 2015). Open-system **pingos** are present locally, commonly in slope-toe settings of small drainages where groundwater discharges to surface through discontinuities in the permafrost table (Hughes 1969; Bond and Lipovsky 2011; Huscroft 2002; AECOM 2012; McKillop et al. 2013). Saturation of fine-grained colluvial soils in summer is caused by the underlying permafrost; these soils are referred to as “thaw unstable” (SRK 2016b).

3.2 Surficial Geology

The mapping done for this report is given in Figures 2a to 2f. The maps show that the mine site study area is dominated by the colluvium described in Section 3.1.2. Colluvial blanket and veneer (thick and thin deposits) are dominant. The colluvial apron/muck deposits cannot be identified definitively from air photo interpretation alone. As a result, at slope breaks near valley bottoms, units mapped as Ca (colluvial apron), may in fact contain some amount of eolian material. Colluvial aprons are generally poorly to very poorly-drained due to the presence of permafrost. It is also possible that silt-dominated colluvial deposits also contain some component of wind-blown silt.

Although colluvium dominates the mine site area, a few other units are present as well. Weathered bedrock is exposed in places, mainly on the ridge tops, while limited areas of fluvial and organic deposits are found in valley bottoms. In some tributary valleys, thin fluvial deposits are present, but are too small to map.

3.2.1 Weathered Bedrock

In the borehole and testpit logs, bedrock exposed at surface is described as coarse-grained granite or felsic gneiss with clay alteration and fracture-controlled hematite and limonite (Lorax 2016). Weathered bedrock consists of coarse angular gravel with silt and sand or heavily fractured bedrock. The angular gravel fragments are weak and can be broken apart by hand (SRK 2016a). Areas mapped as weathered bedrock may contain local patches of fresher-looking rock. They are mainly found on ridge tops and include the tors, which are mapped with point symbols (Figures 2a to 2f). Bedrock exposed on slopes in valley bottoms appears to be less weathered on the air photos.

3.2.2 Colluvial Deposits

Colluvium is pervasive across the mine site area. It is described in the borehole/testpit data as comprising nonplastic, non-cohesive deposits of angular pebbles, cobbles and boulders (rubble), silt and/or sand. Silt and sand are generally the main components, but some areas are dominated by cobbles (Lorax 2016; SRK 2016a). Rubble lithologies in the areas covered by the boreholes are local: felsic or mafic gneiss, granite and schist (Lorax 2016). Beds of silt, sand, or both may be interspersed with otherwise non-bedded material. Less commonly, organic soil layers may be interbedded with colluvium near the surface (SRK 2016a). Tetra Tech EBA interprets this surface layering as recording previous downslope movement of the upper portions of the colluvium.

Boreholes SRK-15S-07 and -09 and testpit SRK-15TP-38 all contain organic material within the colluvium that can be dated to determine the timing of slope activity in these locations. The material at Boreholes SRK-15S-07 and SRK-15TP-38 consists of organic gravelly silt with large woody pieces at 1.4 m depth and organic woody material at 0.2 m depth, respectively. Borehole SRK-15S-07 records a piece of wood at about 0.2 m depth, as well as organic layers at 1.22 m and 3.96 m. This site could potentially give an approximate return frequency for slope movement at this location. These organic pieces are suspected to be Holocene in age.

3.2.3 Fluvial Deposits

Fluvial deposits are generally thin and are found in narrow valley bottoms. The Latte Creek valley is an exception – here fluvial sediments are thicker and are overlain by organic deposits.

At the confluence of two small streams in the northern part of the mine site area, Borehole SRK-15S-02 describes the fluvial deposit as silty sand with subangular pebbles and cobbles, while nearby Testpit SRK-15TP-36A describes the unit as gravelly silt with cobbles, overlying cobbles. This testpit may be located within thin fluvial sediments overlying colluvium. Further south at the bottom of another tributary valley, Boreholes SRK-15S-12 and SRK-15S-35 identified thin deposits of sandy silt with gravel, containing angular to subangular clasts.

A few fluvial fans are present in the Latte creek valley. One fan has a borehole within it (MW15-02T), which describes the deposit as colluvium ranging from silty sand to boulders. Rounding is not described so it is possible the deposit represents the debris flow portion of the fan; however, the tributary valley is short, so fluvial deposits are unlikely to be well sorted or well-rounded and thus would likely resemble colluvium.

3.2.4 Organic Deposits

Organic deposits are the primary unit in only four locations within the mine site study area; three of these are in the Latte Creek valley and one is in an unnamed valley in the northeast. Organics make up the second or third component of mapped surficial geology units in the bottom of Latte Creek valley, where the primary units are either valley floor fluvial deposits or colluvial aprons.

Unfortunately, there is no field data for organic deposits. Tetra Tech EBA assumes that they consist of peat and/or organic silt as described in Huscroft (2002).

3.2.5 Landforms

The geomorphic processes and landforms within the mine site study area include mass-wasting features (landslide failure scars and headscarps; retrogressive thaw flow scars and headscarps; active layer detachment scars and headscarps; solifluction); thermal erosion, gullying, a collapsed open-system pingo, cryoplanation terraces, and tors (Figures 2a to 2f; 3a and 3b). Two of these landform types are considered rare landforms: the pingo and the tors.

The collapsed pingo is located in the central portion of the mine site study area, in a small creek valley that is a tributary of Latte Creek (Photo 2). It indicates the former presence of massive ground ice and ice-rich permafrost underlying the lower slope of northwesterly aspect at that location.

Photo 2: Collapsed open-system pingo in in a small tributary valley of Latte Creek, looking south.

The tors, erosional remnants of a higher plateau level, are found on ridge tops in the western, southwestern, and central parts of the mine site study area (Figures 2a to 2f; Photos 3 and 4), towering over otherwise smooth rounded ridges underlain by granitic bedrock. Tors are surrounded by either a thick colluvial halo or weathered bedrock. Some of the tors are located within the HLF footprint and there are quad trails visible on the air and field photos in this area on the ridge top (Photo 4).

Photo 3: Ground view of a tor located within the HLF footprint in the western part of the mine site study area.

Photo 4: Aerial photograph of the same tor. Note quad tracks to left of the tor.

Although pingos and tors are not specifically mentioned in the Traditional Knowledge (TK) data collected to date for the Coffee Project, the importance of these features is inferred through views that expressed traditional ways of life being tied to "healthy and intact ecosystems" (Bates et al 2014). The importance of terrain features, possibly including tors and pingos, has been identified with respect to the use of elevated landforms as lookouts (Dobrowolsky 2014; Tr'ondëk Hwëch'in 2012).

There are no trails leading to the collapsed pingo; it is therefore not suspected to be used by First Nations peoples. The quad tracks on the ridge tops may or may not be of First Nations origin.

3.3 Permafrost

3.3.1 Permafrost Distribution

Our calculations of spatial distribution of permafrost within the mine site study area using ArcGIS technology show that approximately 62% of the mapped area is underlain by permafrost (Tetra Tech EBA 2016; Figures 3a and 3b), which is in agreement with Heginbottom et al. (1995). Approximately 38% of the mine site study area is therefore estimated to be permafrost-free. However, permafrost-free areas may contain patches of permafrost in locations where conditions are favourable for its formation.

Relationships between permafrost distribution, slope aspect, and vegetation in the mine site study area are illustrated in Photo 5. In the South WRSF area located within the small creek valley, shallow permafrost underlies the northeast-facing slope, which is vegetated with sparse, stunted black spruce and thick moss; whereas the southwest-facing slope is permafrost-free and covered by almost pure stands of trembling aspen. Aspen requires warmer air temperatures and deeper root penetration; it is therefore unable to grow in shallow permafrost conditions.

Photo 5: South WRSF, Perennially frozen northeast-facing slope (right) and permafrost-free southwest-facing slope (left), looking south towards the Latte Creek valley.

3.3.2 Permafrost Thickness

Permafrost thicknesses within the mine site study area are highly variable, ranging from approximately 30 m (MW15-04T and MW14-02B) to approximately 165 m near the north end of the proposed Supremo open pit (MW14-04T, Figures 3c and 3d). Permafrost thickness measurements are shown in Figures 3a and 3b (borehole locations shown in Figure 3d).

3.3.3 Active Layer

Active layer thickness in the mine site study area varies spatially and temporally. In areas with thicker insulating organic cover, it is usually thin (approximately 0.3 m to 0.6 m), whereas it can be several metres thick within partially exposed bedrock or within coarse surficial material with a high clast content.

3.3.4 Ground Temperatures

Ground temperatures within the mine site study area have been monitored since 2013 by the companies listed in Section 2.2. Permafrost temperatures measured at the **depth of zero annual amplitude** range from temperatures near the freezing point to approximately -2ºC. These temperatures are indicative of warm permafrost conditions; the ground is therefore sensitive to disturbance. The spatial distribution of permafrost temperatures and the measurement locations are shown in Figures 3a and 3b.

The depth of zero annual amplitude within the permafrost interval was estimated from the ground temperature profiles plotted by Lorax (2016). It varies across the mine site study area, but generally lies between approximately 10 m (MW15-07T) and 15 m (MW14-04T) below the ground surface.

3.3.5 Ground Ice

Ground ice content in the perennially frozen surficial materials is highly variable and was mapped accordingly based on the limited information on volumetric ice content (percent by volume) currently available. The mine site study area was found to be underlain by perennially frozen ground with ground ice that is predominantly:

- Non-visible (Nf, Nbn, Nbe) labeled as "**Fn**";
- Visible (Vx, Vc, Vr, Vs) labeled as "**Fv**"; or
- Forms significant accumulations, such as massive ice bodies, labeled as "**Fi**".

The following describes each of the three permafrost types mapped in Figures 3a to 3d (**Fn**, **Fv**, and **Fi**) in detail:

- Areas labelled as **"Fn"** are generally ice-poor (Frozen, Non-Visible Ice). These consist of perennially frozen ground that is **well-bonded** to **friable** and typically does not contain visible excess ice. However, these areas may include patches of permafrost with visible ground ice (Fv), having ice contents ranging from 1% to 5% by volume, as well as patches of unfrozen ground.
- Areas labelled as **"Fv"** contain visible excess ground ice (Frozen, Visible Ice). This ice-rich permafrost is well-bonded but rarely includes large ground ice bodies. The ice-rich areas may include patches of ice-poor permafrost with ground ice that is not visible to the unaided eye (**Fn**) and patches of permafrost-free ground. Ice content is estimated to range from 1% to 30% by volume (SRK, 2016a). The visible excess ice content (percent by volume) within areas designated as "**Fv**" may exceed 30% (e.g. Borehole SRK-15S-08, West WRSF (SRK, 2016a)).
- Areas labelled as **"Fi"** (Frozen, Ice-Rich) are generally very ice-rich and may include large accumulations of ground ice, such as ice wedges and other massive ice bodies.

In the mine site study area, distribution of these three permafrost types characterized by ground ice content can be broken down as follows:

- 34% is underlain by predominantly ice-poor permafrost with predominantly non-visible ice (**Fn**);
- 27% is underlain by permafrost with visible excess ice (**Fv**); and
- Approximately 1% is underlain by very ice-rich permafrost (**Fi**), which is located at the bottom of some of the creek valleys, e.g. the Latte Creek and the May Lady Creek.

3.4 Terrain Stability

The terrain stability mapping of a mine site study area with slightly different boundaries conducted by PECG is given in Appendix B and is summarized in this section.

PECG's mapping was based on delineating five standard terrain stability classes which are as follows:

- I – stable;
- II – generally stable;
- III – generally stable with isolated minor instability;
- IV – potentially unstable; and
- V – Unstable.

However, because of the complexity of the landscape, which is within the zone of widespread discontinuous permafrost with variable ground ice content and warm permafrost temperatures, PECG differentiated the terrain stability classes in both the existing and disturbed condition. The "existing terrain stability" class represents current conditions, in the absence of any project-related activity; whereas, the "disturbed terrain stability" class represents conditions following disturbance to ground conditions during exploration and from road/mine facility construction without mitigation. This format of mapping, in PECG's opinion, distinguishes natural hazards, which may be triggered by occurrences such as wildfire, from those potentially exacerbated or initiated by project-related disturbance.

Calculations of the areas occupied by each of the five terrain stability classes using ArcGIS technology show that prior to the proposed construction activities (the existing undisturbed terrain), the majority (approximately 78%) of the mine site study area has an existing terrain stability class of "generally stable" (Class II). Approximately 15% of the mine site study area is considered "generally stable with isolated minor instability" (Class III). Approximately 1% of the mine site study area is considered "potentially unstable" (Class IV) and approximately 6% - "unstable" (Class V).

According to the disturbed terrain stability class, the proportion of terrain stability polygons in the mine site study area with a "generally stable" (Class II) rating drops from 78% to 27% (disturbed). The majority (approximately 42%) of the mine site study area becomes "generally stable with isolated minor instability" (Class III). Approximately 24% of the mine site study area becomes "potentially unstable" (Class IV) and approximately 7% - "unstable" (Class V).

PECG's mapping of terrain and terrain stability and hazards, together, identify various geohazards through the assignment of geomorphic process codes (polygon-scale) and discrete geomorphologic processes (point or linear features) in addition to the terrain stability classes (Appendix B, Maps 1 and 2). Table 3-1 outlines the likelihood and potential magnitude of hazard occurrence over the mine life, generalized according to each of the identified hazards with the potential to affect proposed mine infrastructure footprints. The hazards identified and shown in Table 3-1 vary in likelihood and magnitude, and carry with them different project concerns for avoidance and/or mitigation.

Table 3-1. Hazards with the Potential to Affect the Proposed Mine Site Study Area (Summarized from Tables 5-1 and 5-2, PECG Appendix B)

Hazard	Likelihood (over mine life)	Magnitude	Project Considerations
Rockfall	High – typically recurrent and frequent, where present, freshness of talus at base of bluff indicate recent activity	Moderate – generally small in volume, but rapid and dense	Plan for rockfall below bluffs, especially in areas of fresh deposits (avoid or mitigate) and on steep slopes with small bedrock outcrops
Debris slide	Moderate – most likely to occur on steep slopes with a history of debris sliding, especially within areas adjacent to scars	High – generally small to moderate in volume, but rapid and moderately dense	Avoid debris slide slopes and runout zones
Rock creep	High – periodic movement expected; freshness of patches of rock debris indicate recent activity	Low – small volume, short distance, slow movements of angular rock debris	Expect increased maintenance and allow for minor settlement and shifting of rock debris
Gullying	High – periodic and localized gully erosion processes (e.g. fluvial incision, side wall mass-wasting)	Low – generally incremental and localized incision, minor surface sloughing	Minimize crossings of gullied slopes, especially where underlain by permafrost, and expect increased maintenance

Table 3-1. Hazards with the Potential to Affect the Proposed Mine Site Study Area (Summarized from Tables 5-1 and 5-2, PECG Appendix B)

Hazard	Likelihood (over mine life)	Magnitude	Project Considerations
Solifluction	High – near-continuous, incremental movement	Low – small volume, short distance, slow movements of silt-rich debris	Expect increased maintenance and allow for minor settlement and shifting of surficial material
Thermokarst	Moderate – gradual or periodic settlement, especially in areas of ice-rich permafrost	Low – isolated, slow deepening of ground surface depressions, formation and expansion of tension cracks, possible slow, inward slumping	Minimize disturbance to surface organics and drainage in areas of ice-moderate to ice-rich permafrost through use of appropriate gravel embankments/pads and water management. Expect increased maintenance that could involve localized road reconstruction; consider monitoring settlement
Slopewash	High – seasonal slopewash and transport of fine sediments within runnels; near continuous seepage	Low – localized, slow transport of fine sediments; seepage and icing, especially in runnels	Accommodate seepage-induced icing accumulation especially within intercepted runnels, expect increased maintenance due to fine sediment delivery adjacent to road, manage downslope drainage

3.4.1 Geohazards by Footprint

The hazards identified by PECG include those that have the potential to affect the various infrastructure footprints of the mine site. These are detailed in this section.

3.4.1.1 Open Pits

Deep, ice-poor permafrost is present in the vicinity of most of the proposed open pit areas. There are a few slopes with active rock creep, some ice-moderate permafrost on the west side of the Latte pit, and gullied terrain on the south side of the Supremo pit.

Surface runoff should be managed around the rim of the pits to prevent retrogressive gullying and settlement of the overburden cap.

3.4.1.2 West WRSF

The West WRSF footprint is on a laterally-convex hillside that is covered with thin colluvium. Here, continuous, ice-poor permafrost is shallow to deep. There is an area of potentially ice-rich permafrost and a fringing colluvial blanket in the southwest portion of the WRSF.

In September 2015, Tetra Tech EBA observed human-induced **thermal erosion** developing along the recent access trail within the area of potentially ice-rich permafrost mentioned above (Figures 3a and 3b; Photos 6 and 7).

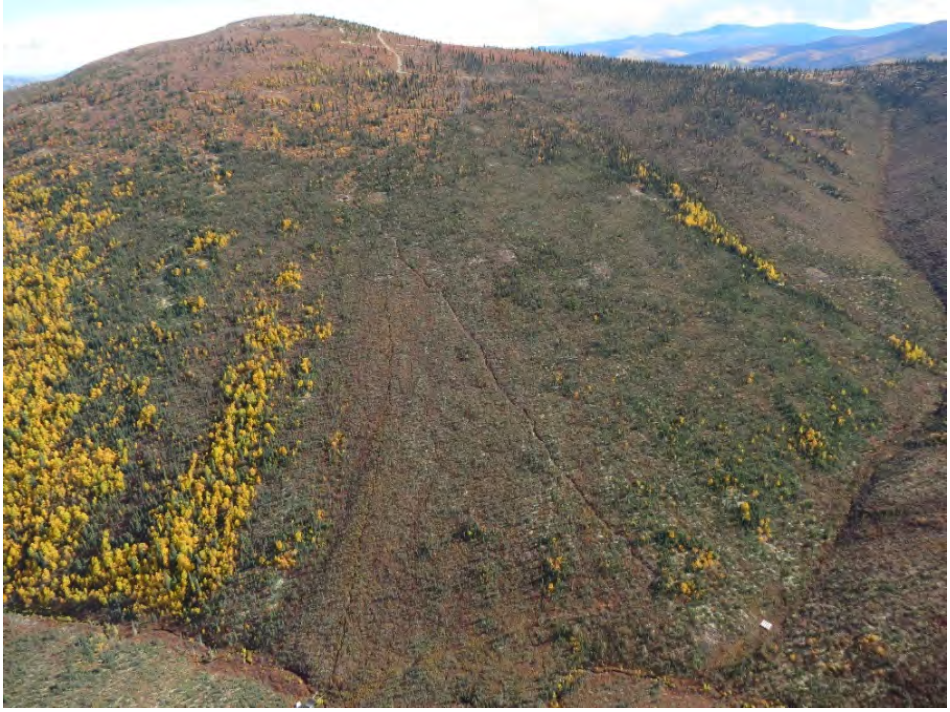


Photo 6: West WRSF, Recent access trail along west-northwest-facing perennially frozen slope, looking southeast. Drillers' access trail crosses photo from the hill top in the upper left to the base of the slope on the lower right.

Photo 7: West WRSF, west-northwest-facing slope. Thermal erosion along recent access trail, looking west.

3.4.1.3 South WRSF

This WRSF is located in a small, first order tributary valley. The west side of the valley contains shallow, ice-moderate permafrost. Slopewash was the only geomorphological process mapped. There are a few subdued gullies on the east side of the valley and permafrost is suspected at lower elevations.

3.4.1.4 North WRSF

The North WRSF partially fills a headwater basin mostly covered with colluvial veneer, but areas of thicker colluvium are also present. All of the colluvium contains permafrost; it is ice-moderate[2] in places. There is potential for thermokarst, rock creep, and slopewash.

3.4.1.5 Unnamed WRSF

This WRSF is located in an area of weathered bedrock and colluvial veneer with shallow to deep, ice-poor permafrost. There is an area of infilled colluvial and fluvial material at the valley bottom that may contain ground ice at depth.

3.4.1.6 HLF Area

A gentle ridge of weathered bedrock with colluvial veneer hosts the proposed HLF. Shallow to deep, ice-poor permafrost is present throughout the footprint. An area of colluvial blanket in the northwest corner may contain ice-moderate permafrost. There is a small active layer detachment on the slope in this area, which indicates permafrost thaw. Solifluction and related rock creep are also evident within the footprint.

3.4.1.7 Plant Site Area

The plant site footprint is located on a broad, near level section of a ridge. It is covered with a veneer of weathered bedrock and colluvium and ice-poor permafrost is shallow to deep. There are no stability concerns in this area.

3.5 Organic Soils

No organic cover was observed at boreholes SRK-15S-05 (disturbed), 15S-26 to 15S-28, 15TP-68, 15TP-69, 15TP-75A, and 15TP-82A (SRK 2016a). Organic deposits were not described in the Lorax boreholes (Lorax 2016), with the exception of MW15-04WB, MW15-01AZ, and MW15-01T. At the latter site, 2 m of muddy brown organics and colluvium were observed, but the thickness of the organics is not given.

The organic surface soil layer typically ranges from 0.1 m to 0.3 m thick, but is most commonly 0.2 m in thickness. Thicknesses of 0.1 m are more common on, but are not limited to, the ridge tops, and thicknesses of 0.3 m or greater tend to be found in areas of non-visible ground ice (Fn). The greatest organic layer thickness recorded (0.6 m) is located in an area of very ice-rich permafrost (Fi).

The organic soils were generally described as moist, dark brown organics containing moss and fibrous lichens (SRK 2016a) or simply as moss with root inclusions (KP 2015). However, a few were described as organic silt or organic silt with sand, gravel, and/or cobbles (Lorax 2016; SRK 2016a), one was described as topsoil/**muskeg** (Lorax 2016), and two were described as green moss (SRK 2016a).

[2] See Appendix B for definition

Organic silt is most common on north-facing slopes and is found only in areas of visible or non-visible ground ice. The presence of silt within the organics may be caused by a combination of more active slope creep in permafrost areas, cryoturbation, or loess capture by permafrost-bearing units, which are wetter in summer.

Very few holes were drilled in valley bottoms, so the wet fluvial units are under-represented in the borehole and testpit data. The topsoil/muskeg site is found adjacent to one of the fluvial units (MW15-05T, Lorax 2016) in an area of very ice-rich permafrost.

4.0 SUMMARY AND CONCLUSIONS

This report elucidates the Coffee Gold Project mine site study area's surficial geology, physiography, permafrost, and terrain stability baseline conditions for the purposes of an environmental assessment.

First, a literature review was completed to summarize the conditions at site to date. It shows that the area has not been glaciated, resulting in a landscape consisting of rounded ridges separated by deep, V-shaped valleys. Climate is characterized by warm, short summers and long, cold winters. Weathered bedrock, colluvium derived from weathered bedrock and loess, and fluvial deposits are found within the mine site study area, but colluvial deposits are by far the most common. These deposits are affected by gullying, cryoturbation, solifluction, permafrost processes, periglacial processes, landslides, and snow avalanches. The mine site study area is located within the zone of extensive discontinuous permafrost. Permafrost is most common on north-facing slopes with thick organic cover and in colluvial apron/muck deposits on lower slopes and on creek bottoms. South-facing slopes are permafrost-free. Permafrost-related processes include cryoturbation, solifluction, active layer detachments, slope creep, frost heave, and thermal erosion. Open-system pingos are present locally.

Since 2011, ten field investigation programs have been completed, each of which provides useful information for this baseline study. These field programs include soils, hydrogeology, permafrost, and geotechnical studies. Drilling, instrument installation in boreholes, testpitting, ground investigations on foot, and helicopter flyovers were all included in these studies.

Surficial geology, permafrost, and terrain stability mapping were undertaken for this report. The first two were completed by Tetra Tech EBA and the third by PECG. The desktop mapping draws heavily on data supplied by the many field investigations; these were used as ground truthing points for three types of mapping.

Various permafrost maps, a map of the general surficial geology of the mine site, and terrain stability/hazard maps were generated for this baseline study; these are included at the end of this report. Geohazards and organic surface soils were also described.

Results from this baseline study conclude that colluvium is indeed pervasive, and that ridge tops may have exposed weathered bedrock, some of which forms tors. Colluvium is dominated by silt and sand, but also contains angular pebbles, cobbles, and boulders. Organic material interbedded with the colluvium at a few sites shows that downslope creep or possibly sliding of some colluvial deposits may be fairly recent. Thin fluvial deposits consisting of gravelly silt are found in the narrow valley bottoms and a few fluvial fans are present at the mouths of small tributary valleys. Thick organic deposits are rare; they are found in the Latte Creek valley and overlying colluvial apron/muck deposits at the base of some slopes.

The only rare landforms in the mine site study area are the tors and one collapsed open-system pingo.

Permafrost distribution determined from the mapping shows that approximately 62% of the mine site study area is underlain by permafrost. Permafrost thicknesses range from approximately 30 m to 165 m. The active layer is highly variable: it is usually thin (approximately 0.3 m to 0.6 m), but it can be several metres thick in bedrock areas or where coarse surficial sediments are present. Ground temperatures range from close to 0ºC to approximately -2ºC, indicating warm permafrost conditions. Ground containing permafrost is therefore sensitive to disturbance. Ground ice has been classified as non-visible, visible, or forming significant accumulations, such as massive ice bodies, although the latter is rare. The spatial distribution of these across the mine site was determined to be 34% for ice-poor permafrost with non-visible ice; 27% for permafrost with visible excess ice; and 1% for very ice-rich permafrost, which is mainly located at the bottom of the Latte Creek valley.

Five terrain stability classes (stable; generally stable; generally stable with minor instability; potentially unstable; and unstable) were mapped within the mine site. These classes were differentiated in both the existing and disturbed condition because of the complexity of the mine site study area permafrost terrain. The "existing terrain stability" class represents current conditions, in the absence of any project-related activity; whereas, the "disturbed terrain stability" class represents conditions following disturbance to ground conditions from road/mine facility construction without mitigation.

Calculations of the areas occupied by each of the five terrain stability classes using ArcGIS technology show that prior to the proposed construction activities (the existing undisturbed terrain) the majority (approximately 78%) of the mine site study area has an existing terrain stability class of "generally stable" (Class II). Approximately 15% of is considered "generally stable with isolated minor instability" (Class III). Approximately 1% of the mine site study area is considered "potentially unstable" (Class IV) and approximately 6% - "unstable" (Class V).

According to the disturbed terrain stability class, the proportion of terrain stability polygons in the mine site study area with a "generally stable" (Class II) rating drops from 78% to 27%. The majority (approximately 42%) of the mine site study area becomes "generally stable with isolated minor instability" (Class III). Approximately 24% becomes "potentially unstable" (Class IV) and approximately 7% - "unstable" (Class V).

Various hazards were identified and described by magnitude, frequency, and considerations for mitigation of each. These include rockfall, debris slides, rock creep, gullying, solifluction, thermokarst, and slopewash. The various geohazards within each proposed infrastructure footprint were also described.

Finally, the organic surface soil was described. It is generally 0.2 m thick, but is slightly thinner on ridge tops, and is thicker in areas of non-visible ground ice or where very ice-rich permafrost is found. Organic silt is most common on north-facing slopes and is found only in areas of visible or non-visible ground ice. The presence of silt within the organics may be caused by a combination of more active slope creep in permafrost areas, cryoturbation, or loess capture by permafrost-bearing units, which are wetter in summer.

5.0 CLOSURE

We trust this report meets your present requirements. If you have any questions or comments, please contact the undersigned.

Respectfully submitted,
Tetra Tech EBA Inc.

Signature REDACTED

Signature REDACTED

Prepared by:
Shirley McCuaig, Ph.D., P.Geo. (NWT/NU/AB)
Senior Terrain Geologist, Geotechnical Engineering
Email Address REDACTED

Prepared by:
Vladislav Roujanski, Ph.D., P.Geol. (NWT/NU/AB)
Senior Geologist-Geocryologist, Arctic Group
Email Address REDACTED

Signature REDACTED

KEVIN W. JONES
TERRITORY
May 2, 2016
ENGINEER

Signature REDACTED

Date May 4/16
PERMIT NUMBER PP003
Association of Professional
Engineers of Yukon

Reviewed by:
Kevin Jones, P.Eng.
Vice President, Arctic Development
Email Address REDACTED

/jf

REFERENCES

AECOM Canada Ltd. 2012. Geomorphological Mapping and Landscape Model Development for Strategic Soil Geochemical Sampling at the Coffee Gold Project, Yukon Territory. Report prepared for Kaminak Gold Corporation, dated March 30, 2012.

Bates, P., S. DeRoy, The Firelight Group, with White River First Nation. 2014. White River First Nation Knowledge and Use Study (For Kaminak Gold Corporation).

Bond, J.D. and Lipovsky, P.S. 2011. Surficial geology, soils and permafrost of the northern Dawson Range. In: Yukon Exploration and Geology, 2010, K.E. MacFarlane, L.H. Weston, and C. Relf (eds.), Yukon Geological Survey, 19-32.

Dobrowolsky, D. 2014. Compilation of Information relating to Coffee Creek/White River Areas (January 2014). Prepared for Kaminak Gold Corporation, Tr'ondëk Hwëchin First Nation, White River First Nation.

Duk-Rodkin, A. 1996. Surficial geology, Dawson, Yukon Territory. Geological Survey of Canada Open File 3288, scale 1:250,000.

Duk-Rodkin, A. 1999. Glacial limits map of Yukon Territory. Geological Survey of Canada Open File 3694, Indian and Northern Affairs Canada Geoscience Map 1999-2, scale 1:1,000,000.

Guthrie, R.H., and Cuervo, V. 2015. Geohazards and Risk: A Proponent’s Guide to Linear Infrastructure. Yukon Environmental and Socio-economic Assessment Board, Whitehorse, YT.

Heginbottom, J.A., Dubreuil, M.A., and Harker, P.T. 1995. Canada Permafrost. *In:* The National Atlas of Canada, 5th Edition, Sheet MCR 4177, Plate 2.1, Scale: 1:7,500,000. National Atlas Information Service, Canada Centre for Mapping, Geomatics Canada, Terrain Sciences Division, Geological Survey of Canada, Natural Resources Canada, Ottawa.

Hughes, O.L., 1969. Distribution of Open-System Pingos in Central Yukon Territory with Respect to Glacial Limits. Geological Survey of Canada, Paper 69.

Huscroft, C.A. 2002. Surficial Geology, Coffee Creek, Yukon Territory (115J/14). Geological Survey of Canada, Open File 4344, scale 1:50,000.

Knight Piesold (KP). 2015. Kaminak Gold Corporation, Coffee Gold Project, Report on Feasibility Study Level Geotechnical Investigations. Report prepared for Kaminak Gold Corporation, dated March 12, 2015.

Lorax Environmental Services Ltd. (Lorax). 2016. Coffee Gold Baseline Hydrogeological Assessment. Report prepared for Kaminak Gold Corporation, dated March 14, 2016.

Mathews, W.H. 1986. Physiography of the Canadian Cordillera. Geological Survey of Canada, Map 1701A, scale 1:5,000,000.

McKenna, K.M and Lipovsky, P.S. 2014. Surficial geology, Dawson Region, Yukon: Parts of NTS 115O14 & 15 and 116B/1, 2, 3 & 4. Yukon Geological Survey Open File 2014-12, scale 1:25,000.

McKillop, R., Turner, D., Johnston, K., and Bond, J. 2013. Property-Scale Classification of Surficial Geology for Soil Geochemical Sampling in the Unglaciated Klondike Plateau, West-Central Yukon. Yukon Geological Survey Open File 2013-15.

SRK Consulting Inc. (SRK). 2016a. 2015 Geotechnical Field Investigation, Coffee Gold Project, Yukon Territory, Canada. Report prepared for Kaminak Gold Corporation, dated January 4, 2016.

SRK Consulting Inc. (SRK). 2016b. Feasibility Slope Stability Evaluation: Waste Rock Storage Facilities, Coffee Gold Project, Yukon Territory, Canada. Report prepared for Kaminak Gold Corporation, dated February 29, 2016.

Tetra Tech EBA. 2014. Hydrogeological Data Collection, Coffee Gold Project, Yukon. Report submitted to Kaminak Cold Corporation, dated March 2014.

Tetra Tech EBA. 2016. Permafrost and Related Geohazard Mapping within the Coffee Mine Site Study Area. Technical memorandum prepared for Kaminak Gold Corporation, dated February 25, 2016.

Tr'ondëk Hwëch'in. 2012. Tr'ondëk Hwëch'in Resource Report, Submitted to the Dawson Regional Land Use Planning Commission (May 2012). In: 'Appendix C' of the Dawson Planning Region Resource Assessment Report (DRAFT), November 2012. http://dawson.planyukon.ca/index.php/the-dawson-region/resource-assessment-report/appendices/186-appendix-c-tr-ondek-hwechin-in-resource-report/file (accessed February 1, 2016)

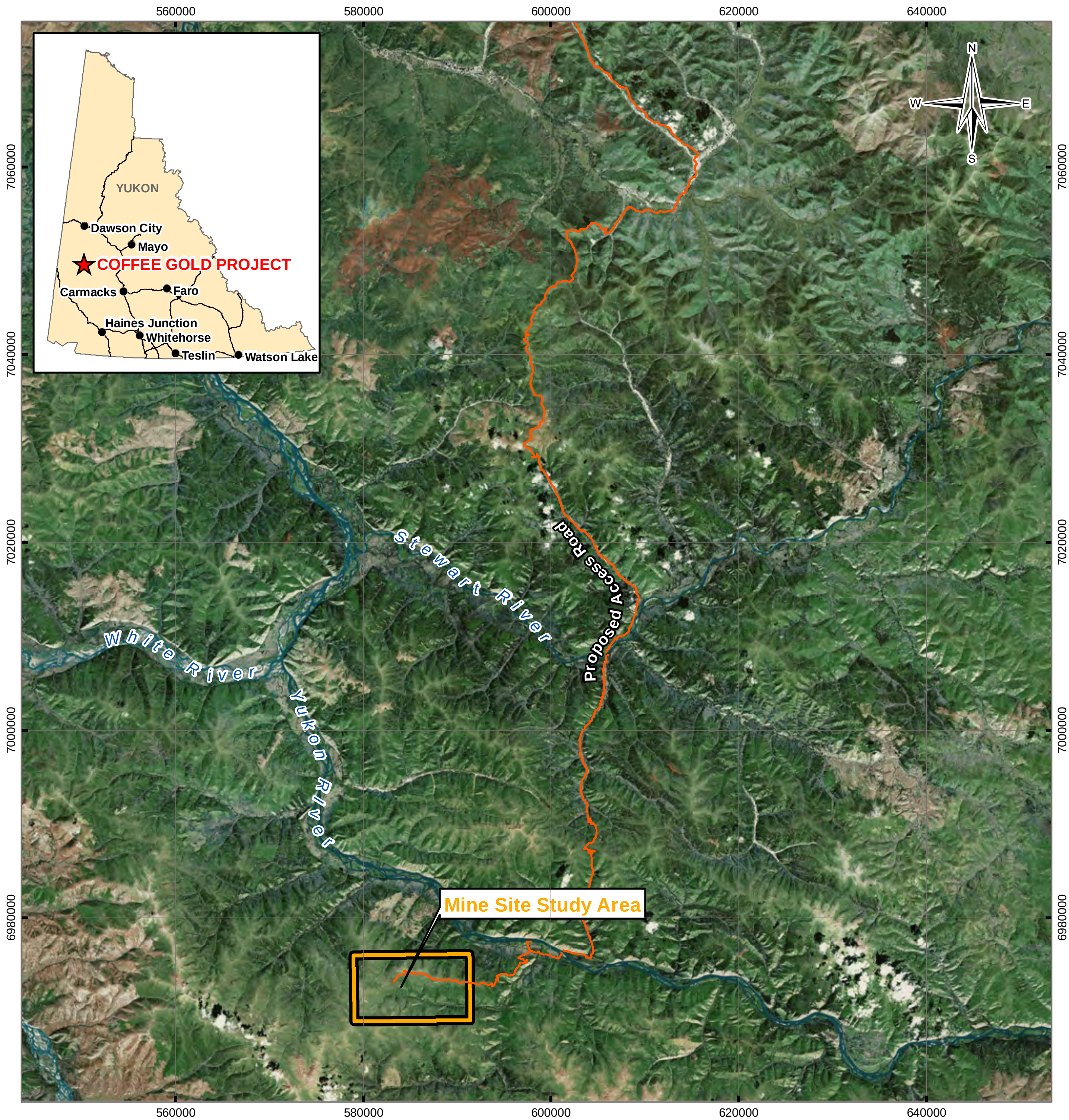
Williams, D.J. 1995. Predicting the Location of Permafrost in Central Yukon Territory. Unpublished MA Thesis, Carleton University, Ottawa, Canada.

Williams, D.J. and Burn, C.R. 1996. Surficial characteristics associated with the occurrence of permafrost near Mayo, central Yukon Territory, Canada. Permafrost and Periglacial Processes Vol. 7, 193-206.

Yukon Government (YG). 2016. Website accessed March 1, 2016: http://www.geology.gov.yk.ca/digital_surficial_data.html

Yukon Ecoregions Working Group. 2004. Klondike Plateau. In: Ecoregions of the Yukon Territory: Biophysical Properties of Yukon Landscapes, C.A.S. Smith, J.C. Meikle, and C.F. Roots (eds.), Agriculture and Agri-Food Canada, PARC Technical Bulletin No 04-01, Summerland, B.C., 159-168.

FIGURES



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LEGEND

Mine Site Study Area

Proposed Access Road

NOTES

Base data source:
Imagery from ESRI;
Earthstar Geographics (1999)
Road data from Kaminak (February 2016)

STATUS
ISSUED FOR USE

COFFEE GOLD PROJECT ENVIRONMENTAL BASELINE REPORT

Site Location

PROJECTION	DATUM	CLIENT
UTM Zone 7	NAD83	KAMINAK GOLD CORPORATION

Scale: 1:600,000

10 5 0 10

Kilometres

TETRA TECH EBA

FILE NO.
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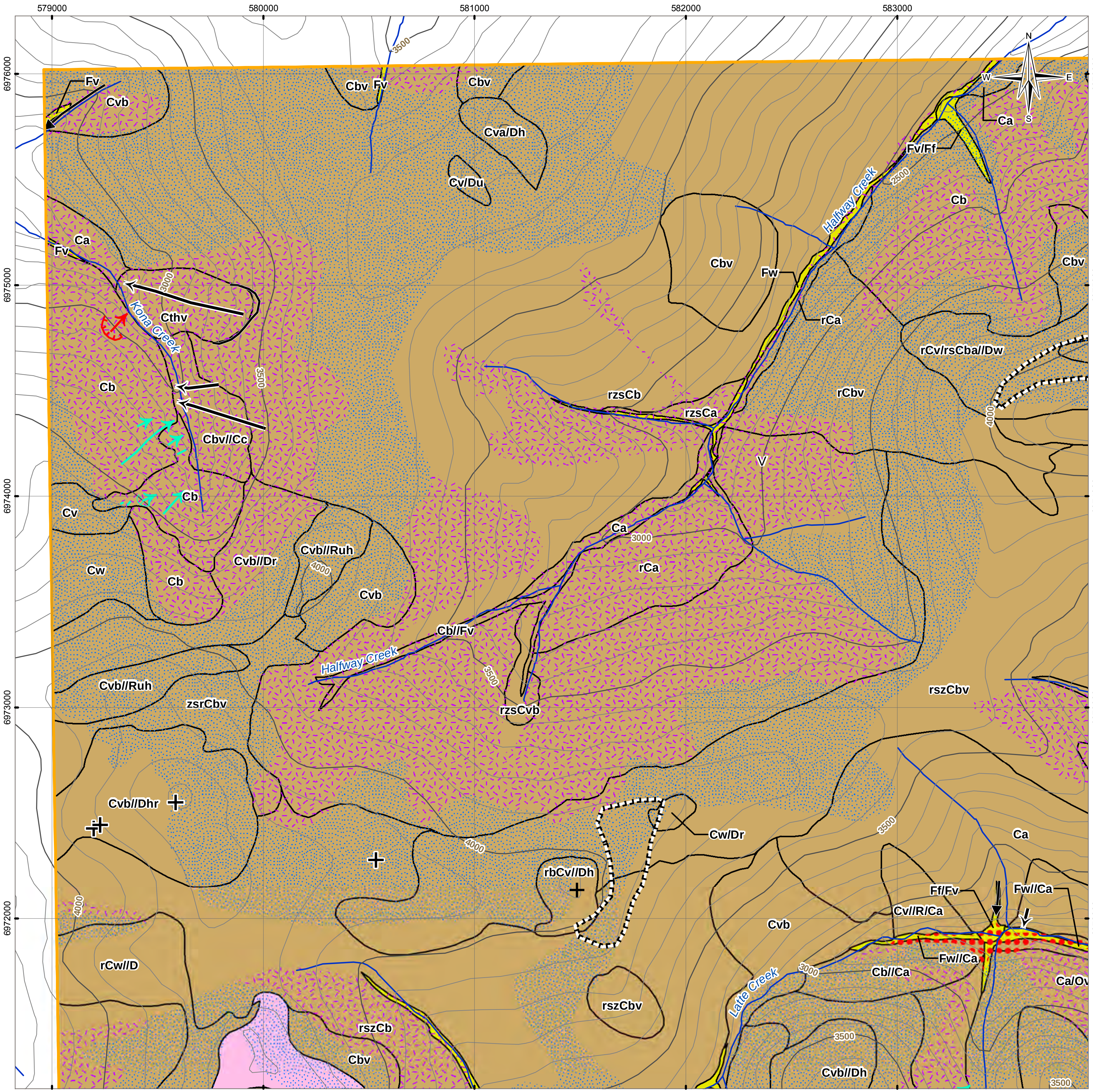
PROJECT NO.	DWN	CKD	APVD	REV
ENG.EARC03004-01	MEZ	SL	SMC	0

OFFICE	DATE
Tt EBA-VANC	May 2, 2016

Figure 1



LEGEND

- Mine Site Study Area
- Collapsed Pingo
- Solifluction Feature
- Thermal Erosion Feature
- Tor
- Cryoplanation Terrace
- Gully
- Landslide Failure Scar
- Landslide Headscarp
- Recent Landslide Failure Scar
- Recent Landslide Headscarp
- Retrogressive Thaw Flow Scar
- Retrogressive Thaw Flow Headscarp
- Active Layer Detachment Scar
- Active Layer Detachment Headscarp

Permafrost Characterization by Ground Ice Content

- Perennially Frozen Ground – very ice-rich
- Perennially Frozen Ground – visible excess ice
- Perennially Frozen Ground – ice not visible
- Unfrozen
- Intermediate Contour (100 ft)
- Index Contour (500 ft)
- Watercourse

NOTES
Base data source: CanVec 1:50,000
PECG (2016)

TERRAIN CODE

TEXTURE(S)
SURFICIAL MATERIAL
SURFACE EXPRESSION(S)

rszCbv

TEXTURE

- b boulders (>256 mm, rounded)
- k cobble (64-256 mm, rounded)
- s sand (0.062 - 2 mm)
- z silt (0.002 - 0.062 mm)
- g gravel (rounded; 2 to > 256 mm)
- x angular fragments (2 to > 256 mm)
- r rubble (2-256 mm, angular particles)

SURFICIAL MATERIAL

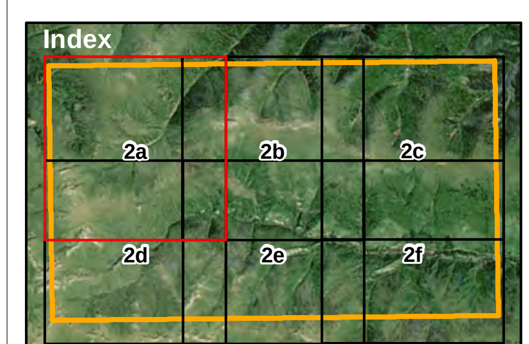
- C Colluvium
- D Weathered Bedrock
- E Eolian
- F Fluvial
- FA Active Fluvial
- O Organic
- R Bedrock

SURFICIAL EXPRESSION

- a apron
- b blanket (>1 m thick)
- c cone(s)
- f fan(s)
- h hummock(s)
- p plain
- r ridge(s)
- t terrace(s)
- u undulating
- v veneer (0.1 - 1 m thick)
- w mantle of variable thickness

DELIMITERS

- . components on either side of the "." symbol are of approximately equal proportion
- / the component in front of the "/" symbol is more extensive than the one that follows
- // the component in front of the "//" symbol is considerably more extensive than the one that follows
- \ the component(s) in front of the "\" symbol stratigraphically overlies the component(s) that follows



COFFEE GOLD PROJECT ENVIRONMENTAL BASELINE REPORT

Surficial Geology and Permafrost

PROJECTION	DATUM	CLIENT
UTM Zone 7	NAD83	KAMINAK GOLD CORPORATION

Scale: 1:20,000
400 200 0 400
Metres

TETRA TECH EBA

FILE NO.
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ENG.EARC03004-01	MEZ	SL	SMC	0

OFFICE	DATE
Tt EBA-VANC	May 2, 2016

STATUS
ISSUED FOR USE

Figure 2a

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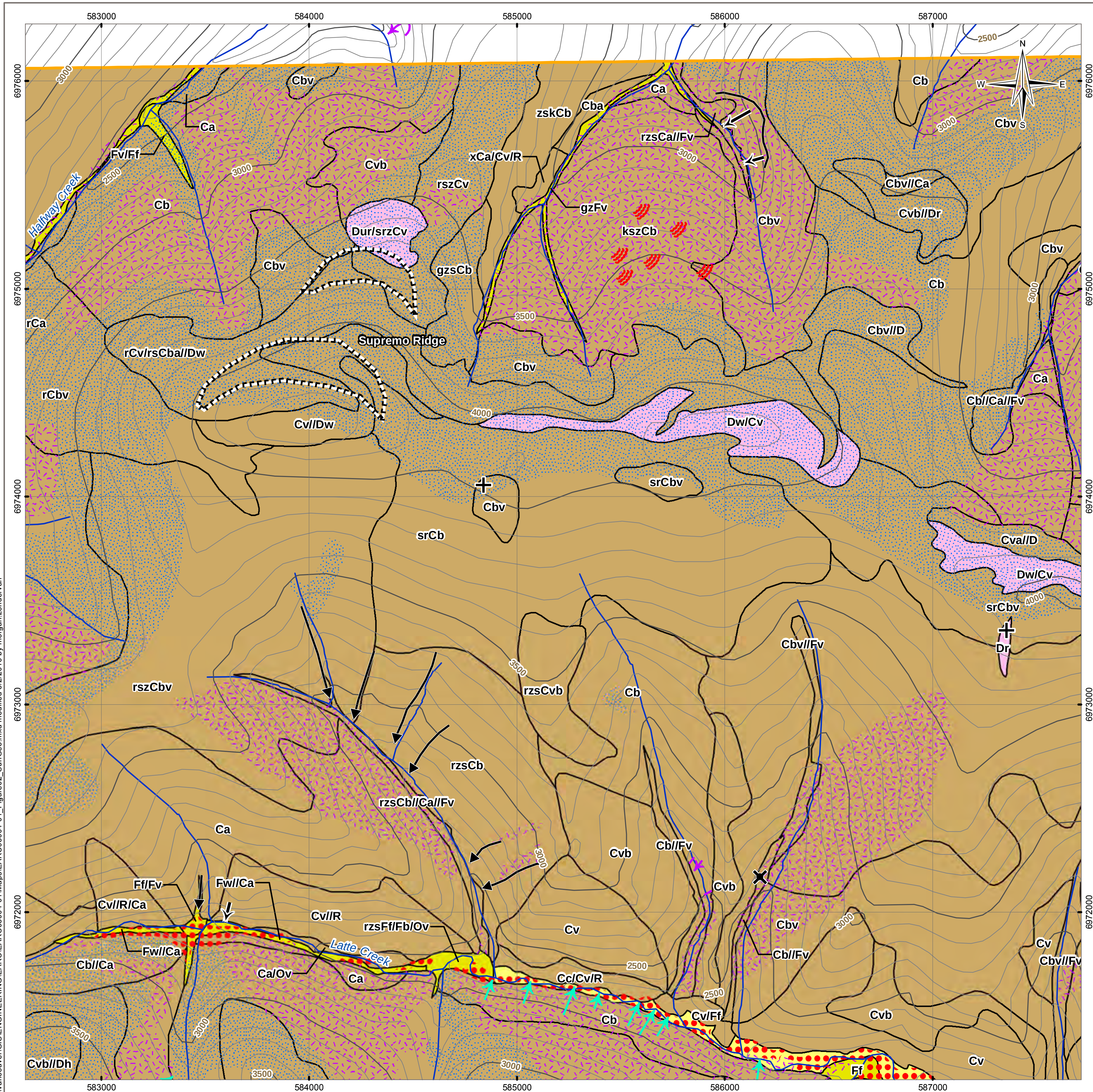

LEGEND

- Mine Site Study Area
- Collapsed Pingo
- Solifluction Feature
- V Thermal Erosion Feature
- Tor
- Cryoplanation Terrace
- Gully
- Landslide Failure Scar
- Landslide Headscarp
- Recent Landslide Failure Scar
- Recent Landslide Headscarp
- Retrogressive Thaw Flow Scar
- Retrogressive Thaw Flow Headscarp
- Active Layer Detachment Scar
- Active Layer Detachment Headscarp

Permafrost Characterization by Ground Ice Content

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- Perennially Frozen Ground – visible excess ice
- Perennially Frozen Ground – ice not visible
- Unfrozen
- Intermediate Contour (100 ft)
- Index Contour (500 ft)
- Watercourse

NOTES
Base data source: CanVec 1:50,000
PECG (2016)

TERRAIN CODE

TEXTURE(S)
SURFICIAL MATERIAL
SURFACE EXPRESSION(S)

rszCbv

TEXTURE

- **b** boulders (>256 mm, rounded)
- **k** cobble (64-256 mm, rounded)
- **s** sand (0.062 - 2 mm)
- **z** silt (0.002 - 0.062 mm)
- **g** gravel (rounded; 2 to > 256 mm)
- **x** angular fragments (2 to > 256 mm)
- **r** rubble (2-256 mm, angular particles)

SURFICIAL MATERIAL

- C Colluvium
- D Weathered Bedrock
- E Eolian
- F Fluvial
- FA Active Fluvial
- O Organic
- R Bedrock

SURFICIAL EXPRESSION

- **a** apron
- **b** blanket (>1 m thick)
- **c** cone(s)
- **f** fan(s)
- **h** hummock(s)
- **p** plain
- **r** ridge(s)
- **t** terrace(s)
- **u** undulating
- **v** veneer (0.1 - 1 m thick)
- **w** mantle of variable thickness

DELIMITERS

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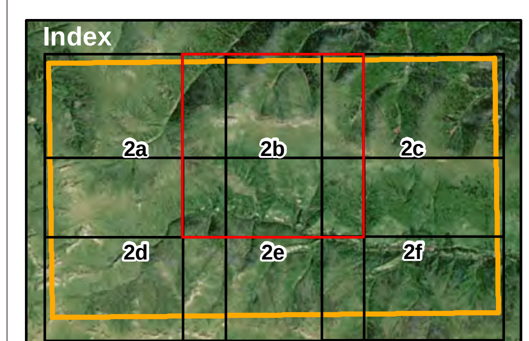

COFFEE GOLD PROJECT
ENVIRONMENTAL BASELINE REPORT

Surficial Geology and Permafrost

PROJECTION	DATUM	CLIENT
UTM Zone 7	NAD83	KAMINAK GOLD CORPORATION

Scale: 1:20,000
400 200 0 400
Metres

TETRA TECH EBA

FILE NO.
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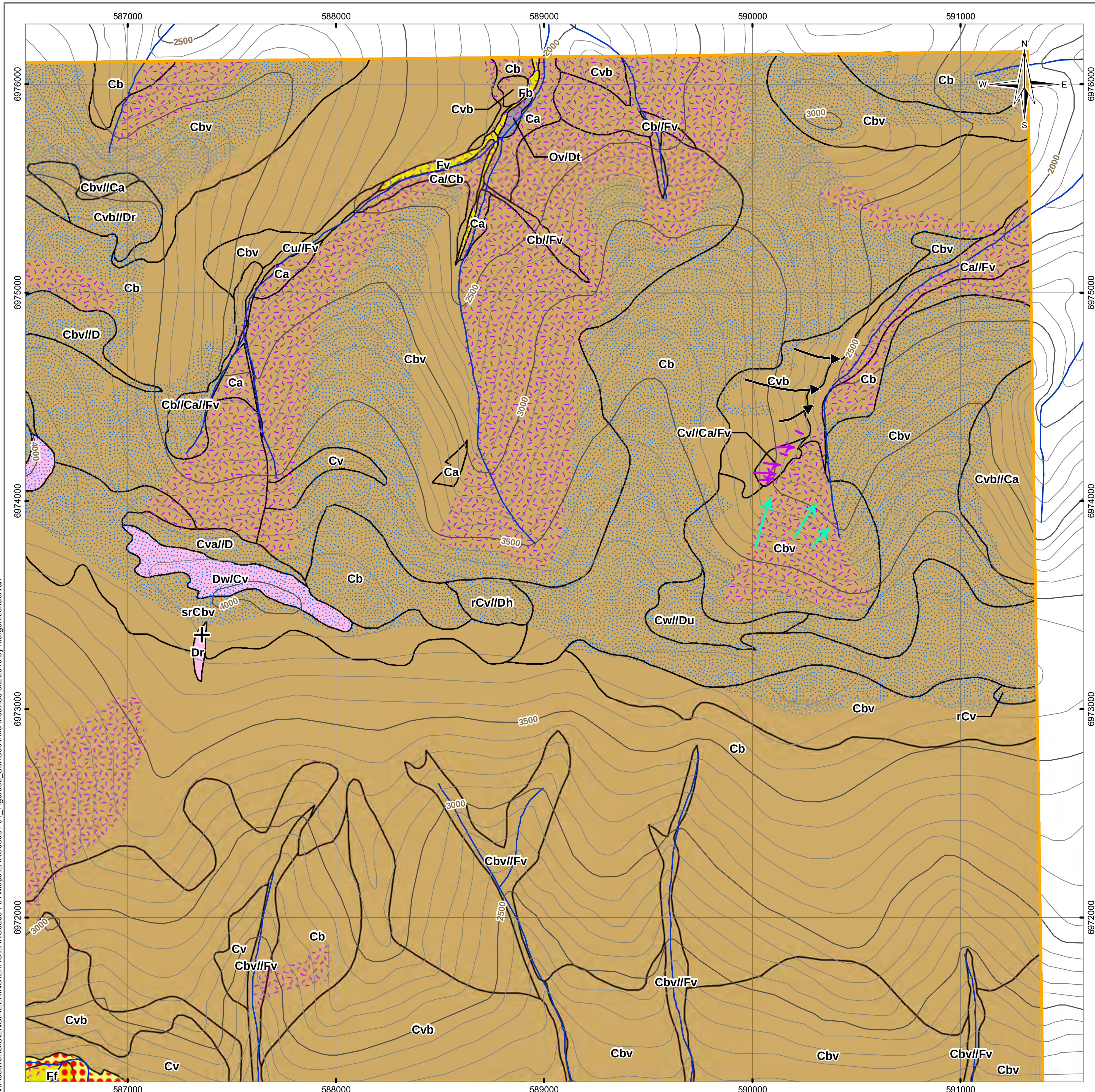
PROJECT NO.	DWN	CKD	APVD	REV
ENG.EARC03004-01	MEZ	SL	SMC	0

OFFICE	DATE
Tt EBA-VANC	May 2, 2016

STATUS
ISSUED FOR USE

Figure 2b



LEGEND

- Mine Site Study Area
- Collapsed Pingo
- Solifluction Feature
- Thermal Erosion Feature
- Tor
- Cryoplanation Terrace
- Gully
- Landslide Failure Scar
- Landslide Headscarp
- Recent Landslide Failure Scar
- Recent Landslide Headscarp
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- Retrogressive Thaw Flow Headscarp
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- Active Layer Detachment Headscarp

Permafrost Characterization by Ground Ice Content

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- Perennially Frozen Ground – visible excess ice
- Perennially Frozen Ground – ice not visible
- Unfrozen
- Intermediate Contour (100 ft)
- Index Contour (500 ft)
- Watercourse

NOTES
Base data source: CanVec 1:50,000
PECG (2016)

TERRAIN CODE

TEXTURE(S)
SURFICIAL MATERIAL
SURFACE EXPRESSION(S)

rszCbv

TEXTURE

- **b** boulders (>256 mm, rounded)
- **k** cobble (64-256 mm, rounded)
- **s** sand (0.062 - 2 mm)
- **z** silt (0.002 - 0.062 mm)
- **g** gravel (rounded; 2 to > 256 mm)
- **x** angular fragments (2 to > 256 mm)
- **r** rubble (2-256 mm, angular particles)

SURFICIAL MATERIAL

- C Colluvium
- D Weathered Bedrock
- E Eolian
- F Fluvial
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SURFICIAL EXPRESSION

- **a** apron
- **b** blanket (>1 m thick)
- **c** cone(s)
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- **t** terrace(s)
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- **v** veneer (0.1 - 1 m thick)
- **w** mantle of variable thickness

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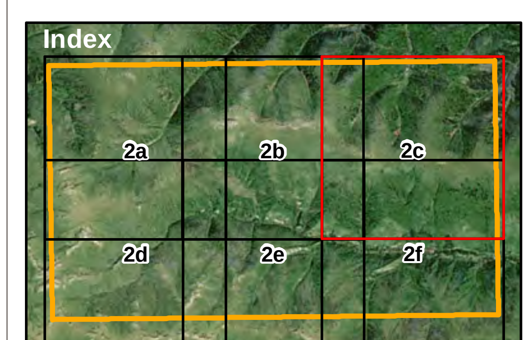

COFFEE GOLD PROJECT
ENVIRONMENTAL BASELINE REPORT

Surficial Geology and Permafrost

PROJECTION	DATUM	CLIENT
UTM Zone 7	NAD83	KAMINAK GOLD CORPORATION

Scale: 1:20,000
400 200 0 400
Metres

TETRA TECH EBA

FILE NO.
EARC03004-01_Figure02_SurfGeo.mxd

PROJECT NO.	DWN	CKD	APVD	REV
ENG.EARC03004-01	MEZ	SL	SMC	0

OFFICE	DATE
Tt EBA-VANC	May 2, 2016

STATUS
ISSUED FOR USE

Figure 2c

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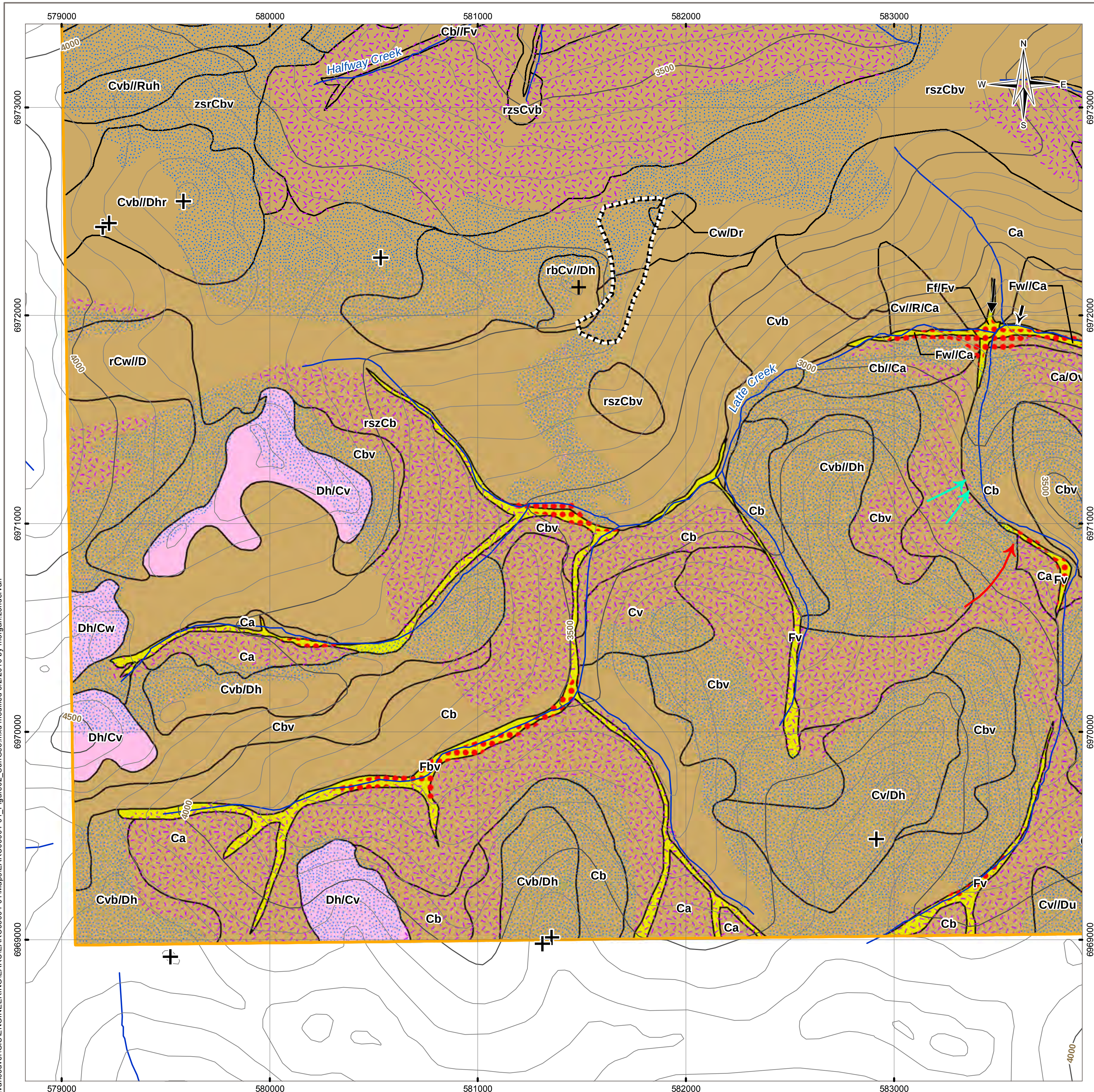

LEGEND

- Mine Site Study Area
- Collapsed Pingo
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PECG (2016)

TERRAIN CODE

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rszCbv

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Index
2a 2b 2c
2d 2e 2f

STATUS
ISSUED FOR USE

COFFEE GOLD PROJECT
ENVIRONMENTAL BASELINE REPORT

Surficial Geology and Permafrost

PROJECTION	DATUM	CLIENT
UTM Zone 7	NAD83	KAMINAK GOLD CORPORATION

Scale: 1:20,000
400 200 0 400
Metres

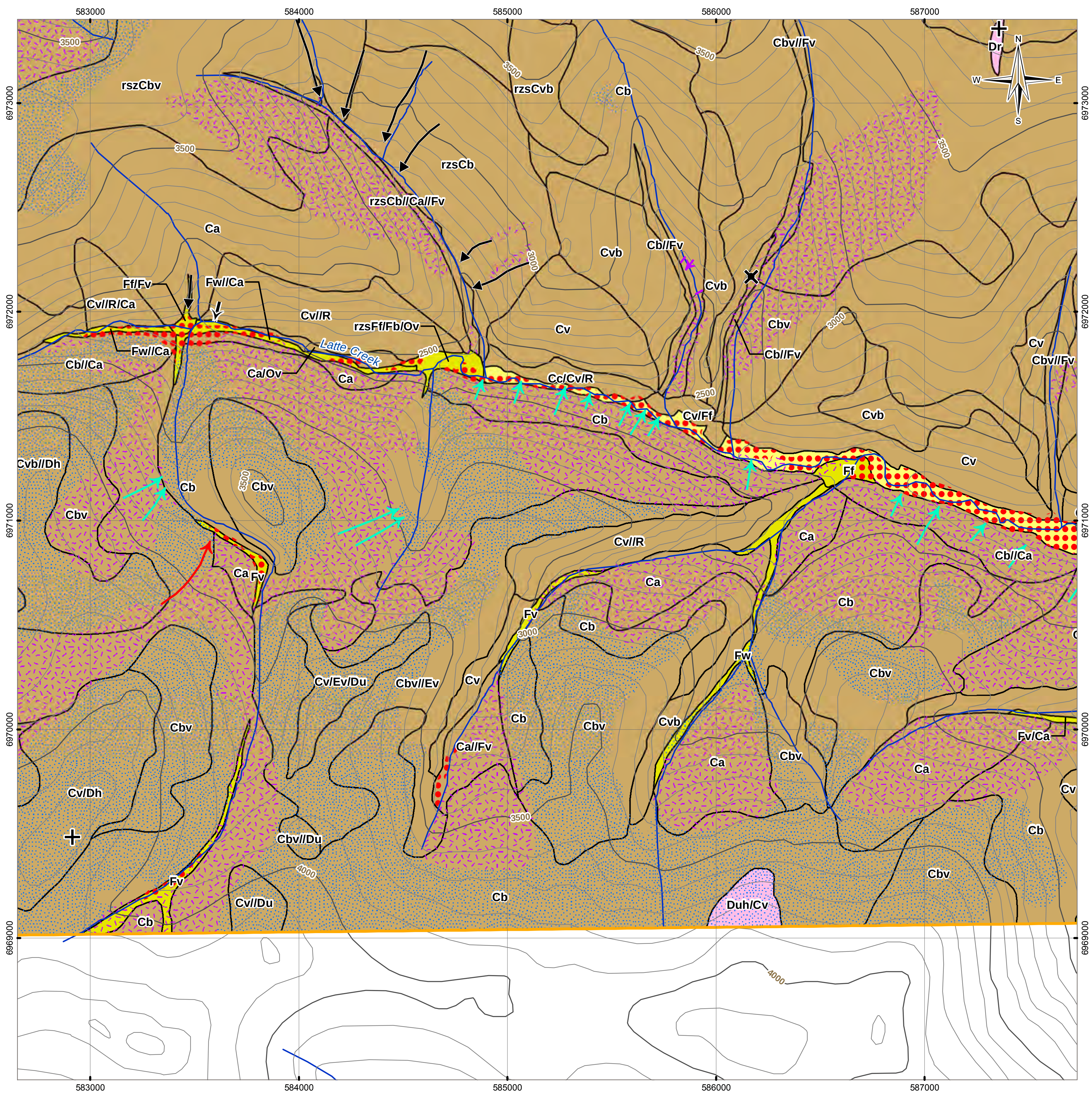
FILE NO.
EARC03004-01_Figure02_SurfGeo.mxd

PROJECT NO.	DWN	CKD	APVD	REV
ENG.EARC03004-01	MEZ	SL	SMC	0

OFFICE	DATE
Tt EBA-VANC	May 2, 2016

TETRA TECH EBA

Figure 2d



LEGEND

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NOTES
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PECG (2016)

TERRAIN CODE

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SURFACE EXPRESSION(S)

rszCbv

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FA	Active Fluvial
O	Organic
R	Bedrock

SURFICIAL EXPRESSION

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h	hummock(s)
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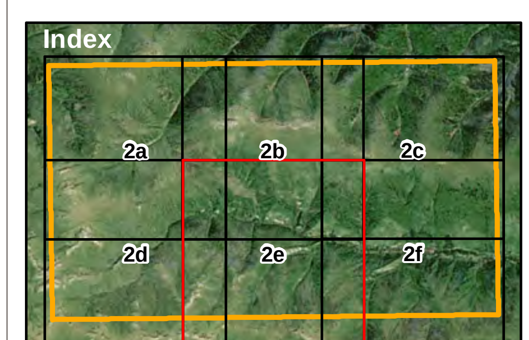
//	the component in front of the "//" symbol is considerably more extensive than the one that follows
\	the component(s) in front of the "\" symbol stratigraphically overlies the component(s) that follows



COFFEE GOLD PROJECT
ENVIRONMENTAL BASELINE REPORT

Surficial Geology and Permafrost

PROJECTION	DATUM	CLIENT
UTM Zone 7	NAD83	KAMINAK GOLD CORPORATION

Scale: 1:20,000
400 200 0 400
Metres

TETRA TECH EBA

FILE NO.
EARC03004-01_Figure02_SurfGeo.mxd

PROJECT NO.	DWN	CKD	APVD	REV
ENG.EARC03004-01	MEZ	SL	SMC	0

OFFICE	DATE
Tt EBA-VANC	May 2, 2016

STATUS
ISSUED FOR USE

Figure 2e

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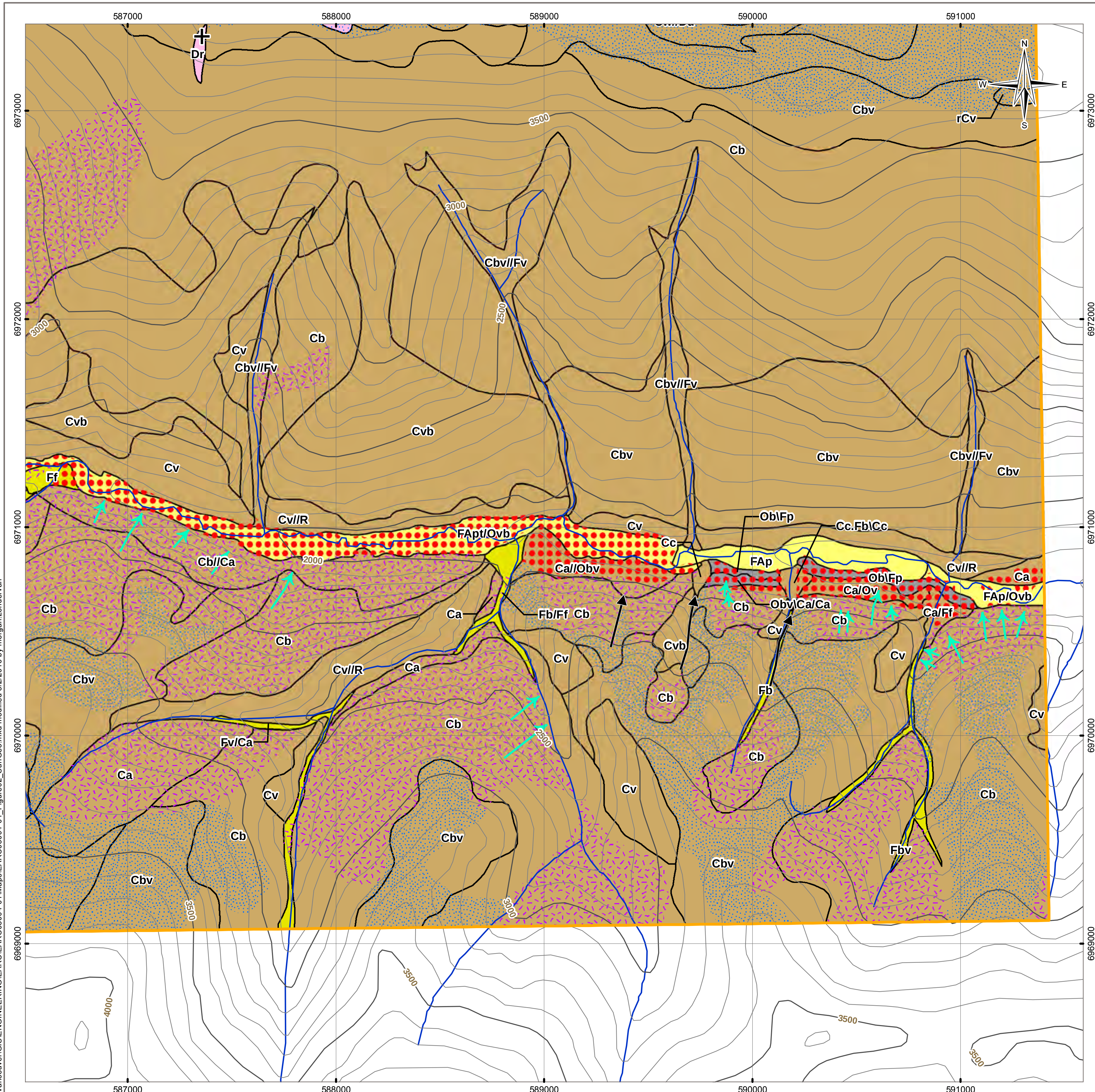


LEGEND

- Mine Site Study Area
- Collapsed Pingo
- Solifluction Feature
- V Thermal Erosion Feature
- Tor
- Cryoplanation Terrace
- Gully
- Landslide Failure Scar
- Landslide Headscarp
- Recent Landslide Failure Scar
- Recent Landslide Headscarp
- Retrogressive Thaw Flow Scar
- Retrogressive Thaw Flow Headscarp
- Active Layer Detachment Scar
- Active Layer Detachment Headscarp

Permafrost Characterization by Ground Ice Content

- Perennially Frozen Ground – very ice-rich
- Perennially Frozen Ground – visible excess ice
- Perennially Frozen Ground – ice not visible
- Unfrozen
- Intermediate Contour (100 ft)
- Index Contour (500 ft)
- Watercourse

NOTES
Base data source: CanVec 1:50,000
PECG (2016)

TERRAIN CODE

TEXTURE(S)
SURFICIAL MATERIAL
SURFACE EXPRESSION(S)

rszCbv

TEXTURE

b	boulders (>256 mm, rounded)
k	cobble (64-256 mm, rounded)
s	sand (0.062 - 2 mm)
z	silt (0.002 - 0.062 mm)
g	gravel (rounded; 2 to > 256 mm)
x	angular fragments (2 to > 256 mm)
r	rubble (2-256 mm, angular particles)

SURFICIAL MATERIAL

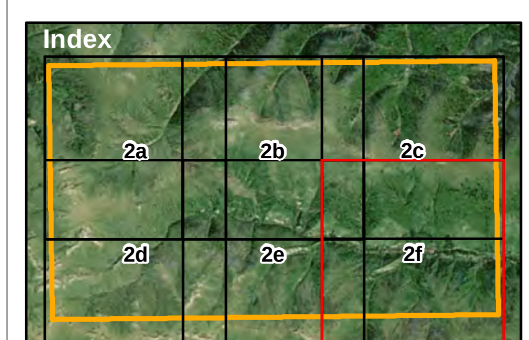
C	Colluvium
D	Weathered Bedrock
E	Eolian
F	Fluvial
FA	Active Fluvial
O	Organic
R	Bedrock

SURFICIAL EXPRESSION

a	apron
b	blanket (>1 m thick)
c	cone(s)
f	fan(s)
h	hummock(s)
p	plain
r	ridge(s)
t	terrace(s)
u	undulating
v	veneer (0.1 - 1 m thick)
w	mantle of variable thickness

DELIMITERS

.	components on either side of the "." symbol are of approximately equal proportion
/	the component in front of the "/" symbol is more extensive than the one that follows
//	the component in front of the "//" symbol is considerably more extensive than the one that follows
\	the component(s) in front of the "\" symbol stratigraphically overlies the component(s) that follows



COFFEE GOLD PROJECT ENVIRONMENTAL BASELINE REPORT

Surficial Geology and Permafrost

PROJECTION: UTM Zone 7
DATUM: NAD83
CLIENT: KAMINAK GOLD CORPORATION

Scale: 1:20,000
400 200 0 400
Metres

TETRA TECH EBA

FILE NO.: EARC03004-01_Figure02_SurfGeo.mxd

PROJECT NO.	DWN	CKD	APVD	REV
ENG.EARC03004-01	MEZ	SL	SMC	0

OFFICE: Tt EBA-VANC
DATE: May 2, 2016

STATUS: ISSUED FOR USE

Figure 2f

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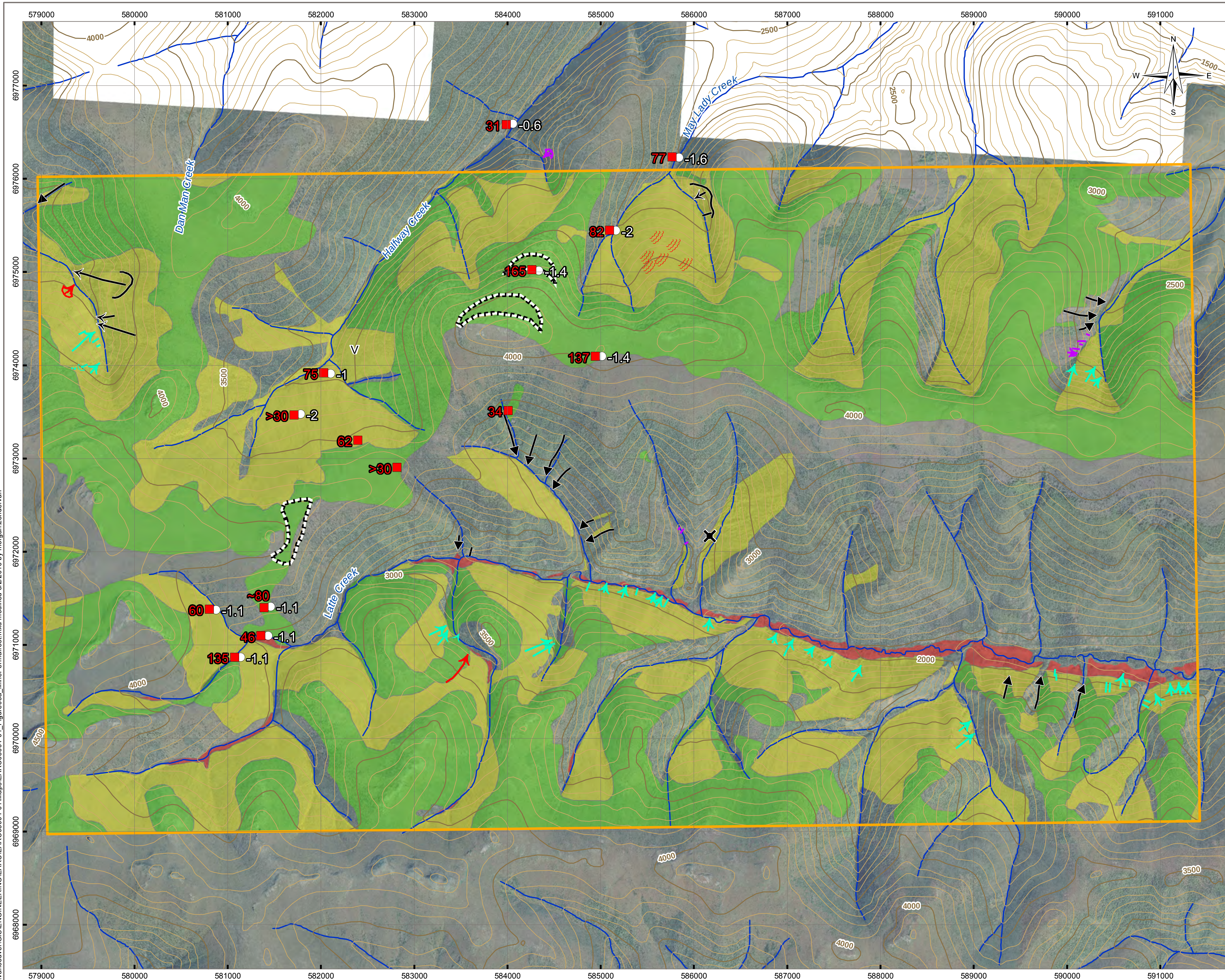


Q:\Vancouver\GIS\ENGINEERING\EARC\EARC03004-01\Maps\EARC03004-01_Figure03a_MinePermafrost.mxd modified 5/2/2016 by morgan.zondervan

LEGEND

Permafrost Characterization by Ground Ice Content

- Perennially Frozen Ground – very ice-rich (Fi)
- Perennially Frozen Ground – visible excess ice (Fv)
- Perennially Frozen Ground – ice not visible (Fn)
- Unfrozen
- Mine Site Study
- Permafrost Temperature (°C)
- Permafrost Thickness (m)
- Collapsed Pingo
- Solifluction Feature
- Thermal Erosion Feature
- Cryoplanation Terrace
- Gully
- Landslide Failure Scar
- Landslide Headscarp
- Recent Landslide Failure Scar
- Recent Landslide Headscarp
- Retrogressive Thaw Flow Scar
- Retrogressive Thaw Flow Headscarp
- Active Layer Detachment Scar
- Active Layer Detachment Headscarp
- Intermediate Contour (100 ft)
- Index Contour (500 ft)
- Watercourse

NOTES
Base data source:
Imagery provided by Kaminak (2011)
CanVec 1:50,000

STATUS
ISSUED FOR USE

COFFEE GOLD PROJECT ENVIRONMENTAL BASELINE REPORT

Permafrost Distribution and Related Geohazards

PROJECTION	DATUM	CLIENT
UTM Zone 7	NAD83	KAMINAK GOLD CORPORATION

Scale: 1:40,000
500 250 0 500
Metres

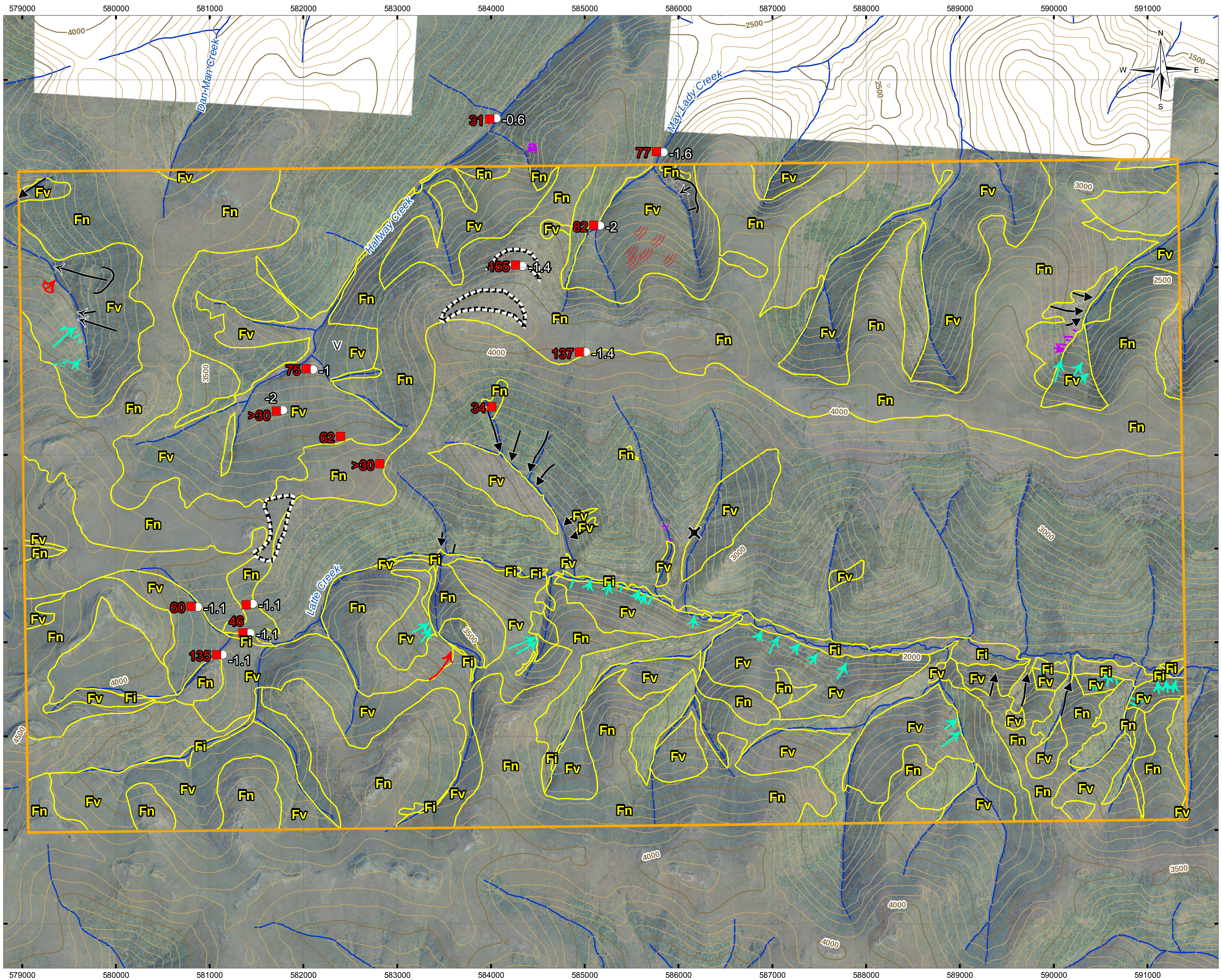
TETRA TECH EBA

FILE NO.
EARC03004-01_Figure03a_MinePermafrost.mxd

PROJECT NO.	DWN	CKD	APVD	REV
ENG.EARC03004-01	MEZ	SL	VR/SMC	0

OFFICE	DATE
Tt EBA-VANC	May 2, 2016

Figure 3a



LEGEND

- Fi — Perennially Frozen Ground – very ice-rich
- Fv — Perennially Frozen Ground – visible excess ice
- Fn — Perennially Frozen Ground – ice not visible
- Unfrozen
- Mine Site Study
- Permafrost Temperature (°C)
- Permafrost Thickness (m)
- Collapsed Pingo
- Solifluction Feature
- V Thermal Erosion Feature
- Cryoplanation Terrace
- Gully
- Landslide Failure Scar
- Landslide Headscarp
- Recent Landslide Failure Scar
- Recent Landslide Headscarp
- Retrogressive Thaw Flow Scar
- Retrogressive Thaw Flow Headscarp
- Active Layer Detachment Scar
- Active Layer Detachment Headscarp
- Intermediate Contour (100 ft)
- Index Contour (500 ft)
- Watercourse

NOTES
Base data source:
Imagery provided by Kaminak (2011)
CanVec 1:50,000

STATUS
ISSUED FOR USE

COFFEE GOLD PROJECT ENVIRONMENTAL BASELINE REPORT

Permafrost Distribution and Related Geohazards

PROJECTION	DATUM	CLIENT
UTM Zone 7	NAD83	KAMINAK GOLD CORPORATION

Scale: 1:40,000
500 250 0 500
Metres

TETRA TECH EBA

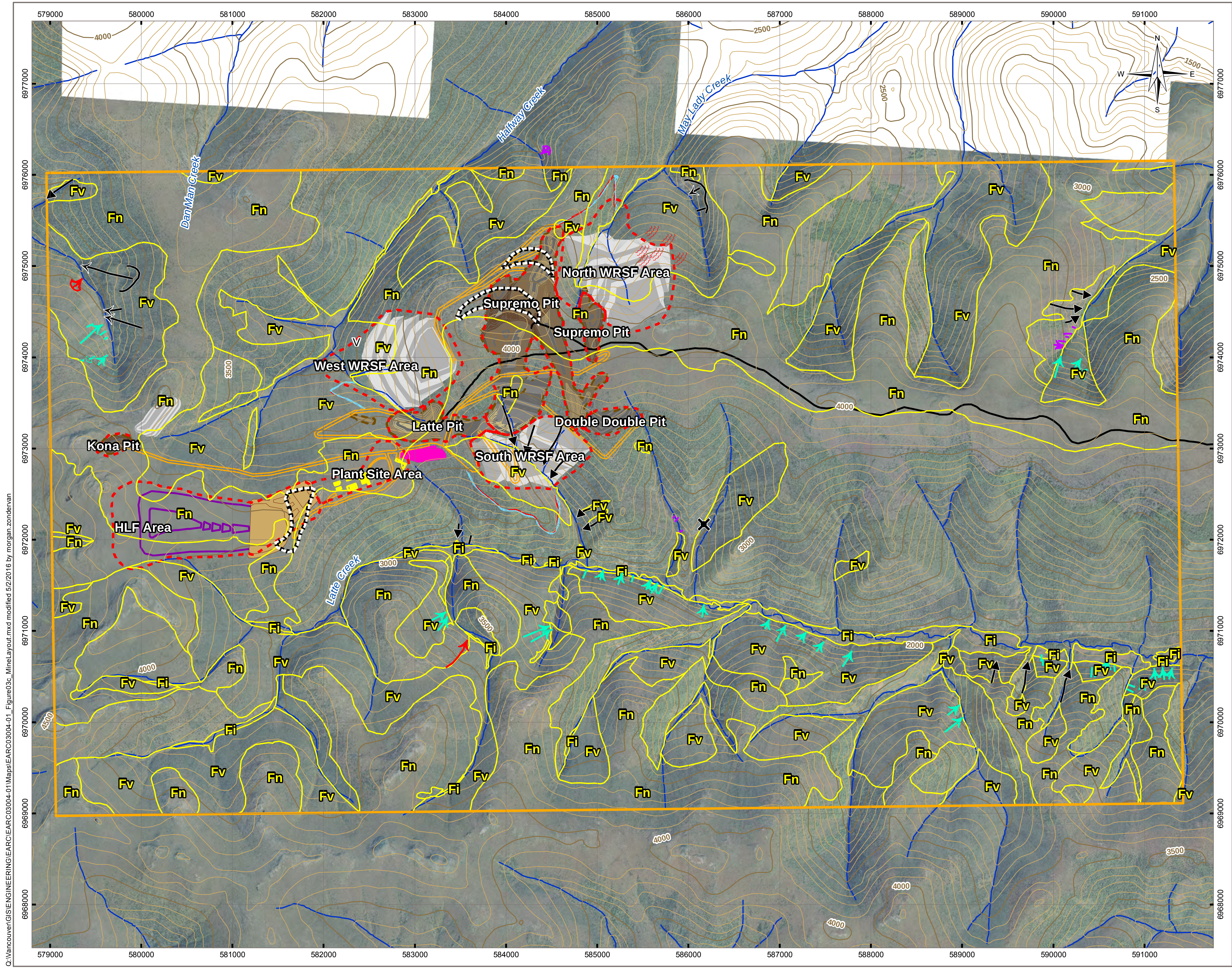
FILE NO.
EARC03004-01_Figure03b_MinePF_Image.mxd

PROJECT NO.	DWN	CKD	APVD	REV
ENG.EARC03004-01	MEZ	SL	VR/SMC	0

OFFICE	DATE
Tt EBA-VANC	May 2, 2016

Figure 3b

Q:\Vancouver\GIS\ENGINEERING\EARC\EARC03004-01\Maps\EARC03004-01_Figure03b_MinePF_Image.mxd modified 5/2/2016 by morgan.zondervan



LEGEND

- Fi Perennially Frozen Ground – very ice-rich
- Fv Perennially Frozen Ground – visible excess ice
- Fn Perennially Frozen Ground – ice not visible
- Unfrozen
- Mine Site Study Area
- Mine Site Facility Areas
- Collapsed Pingo
- Solifluction Feature
- V Thermal Erosion Feature
- Cryoplanation Terrace
- Gully
- Landslide Failure Scar
- Landslide Headscarp
- Recent Landslide Failure Scar
- Recent Landslide Headscarp
- Retrogressive Thaw Flow Scar
- Retrogressive Thaw Flow Headscarp
- Active Layer Detachment Scar
- Active Layer Detachment Headscarp

Proposed Mine Site Layout

- Plant
- Leach Pad
- Stockpile
- Event Pond
- Pit Outline

Pit Backfill

- 0 m
- 1 m - 1250 m

Pit Surface

- 0 m
- 1 m - 1000 m
- 1000 m - 1100 m
- 1100 m - 1200 m
- 1200 m - 1300 m

Waste Dumps

- 0 m
- 1 m - 1250 m
- WRSF Access Road (cut)
- WRSF Access Road (fill)
- Access to Coffee Deposits from Barge Landing
- Haul Road
- Intermediate Contour (100 ft)
- Index Contour (500 ft)
- Watercourse

NOTES

Base Data Source:
Access road provided by Kaminak (August 2015).
WRSF roads from JDS Mining (March 2016)
Project Footprint provided by Hemerra (December 14, 2015).
Imagery provided by Kaminak (2011).
CanVec 1:50,000

STATUS
ISSUED FOR USE

COFFEE GOLD PROJECT ENVIRONMENTAL BASELINE REPORT

Permafrost Distribution and Proposed Mine Site Layout

PROJECTION	DATUM	CLIENT
UTM Zone 7	NAD83	KAMINAK GOLD CORPORATION

Scale: 1:40,000
500 250 0 500
Metres

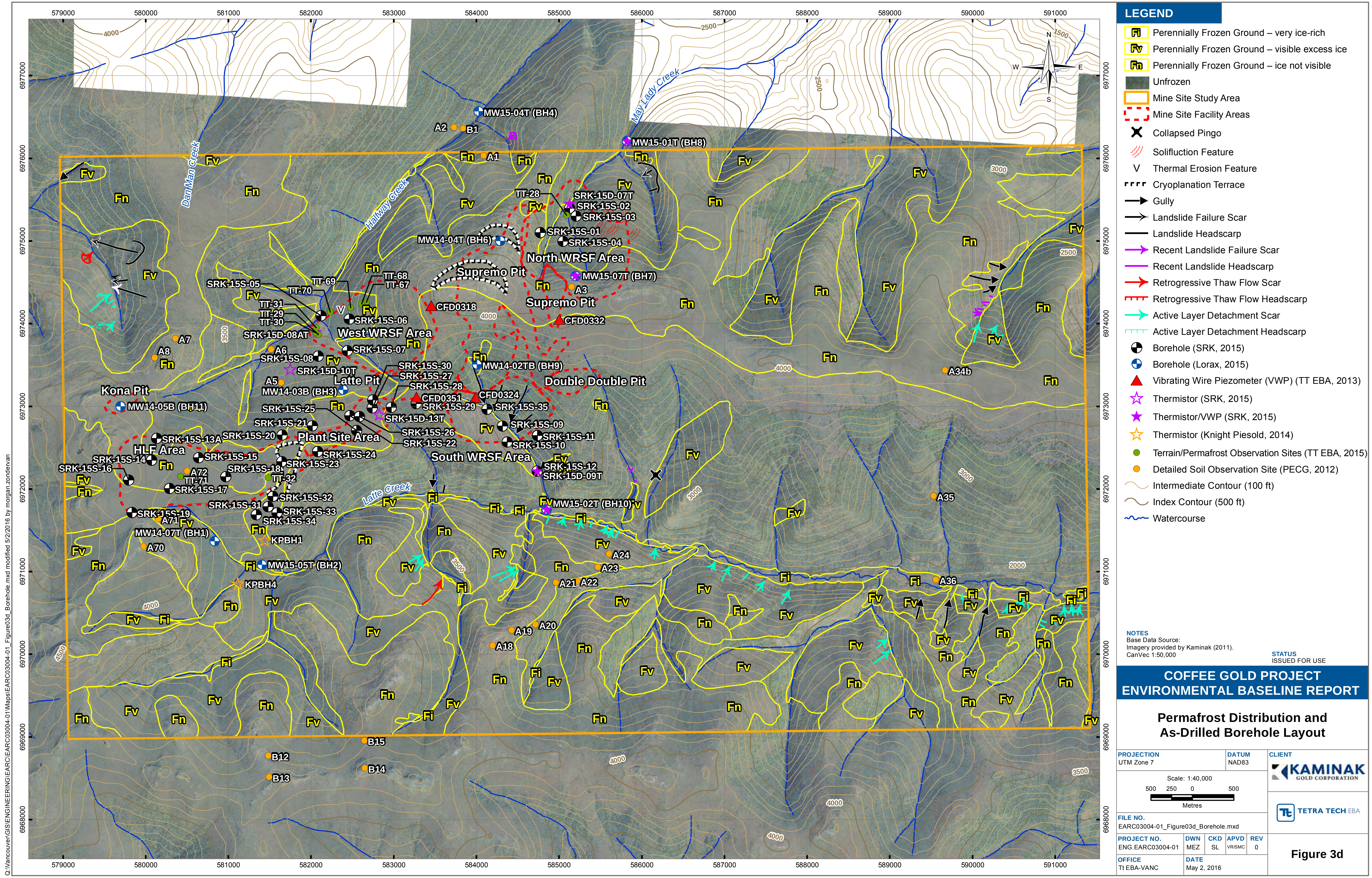
TETRA TECH EBA

FILE NO.
EARC03004-01_Figure03c_MineLayout.mxd

PROJECT NO.	DWN	CKD	APVD	REV
ENG.EARC03004-01	MEZ	SL	VR/SMC	0

OFFICE	DATE
Tt EBA-VANC	May 2, 2016

Figure 3c


LEGEND
Fi Perennially Frozen Ground – very ice-rich
Fv Perennially Frozen Ground – visible excess ice
Fn Perennially Frozen Ground – ice not visible
Unfrozen
Mine Site Study Area
Mine Site Facility Areas
Collapsed Pingo
Solifluction Feature
Thermal Erosion Feature
Cryoplanation Terrace
Gully
Landslide Failure Scar
Landslide Headscarp
Recent Landslide Failure Scar
Recent Landslide Headscarp
Retrogressive Thaw Flow Scar
Retrogressive Thaw Flow Headscarp
Active Layer Detachment Scar
Active Layer Detachment Headscarp
Borehole (SRK, 2015)
Borehole (Lorax, 2015)
Vibrating Wire Piezometer (VWP) (TT EBA, 2013)
Thermistor (SRK, 2015)
Thermistor/VWP (SRK, 2015)
Thermistor (Knight Piesold, 2014)
Terrain/Permafrost Observation Sites (TT EBA, 2015)
Detailed Soil Observation Site (PECG, 2012)
Intermediate Contour (100 ft)
Index Contour (500 ft)
Watercourse
NOTES
Base Data Source:
Imagery provided by Kaminak (2011).
CanVec 1:50,000
STATUS
ISSUED FOR USE
COFFEE GOLD PROJECT
ENVIRONMENTAL BASELINE REPORT
Permafrost Distribution and
As-Drilled Borehole Layout
PROJECTION
UTM Zone 7
DATUM
NAD83
CLIENT
KAMINAK GOLD CORPORATION
Scale: 1:40,000
500 250 0 500
Metres
TETRA TECH EBA
FILE NO.
EARC03004-01_Figure03d_Borehole.mxd
PROJECT NO.
ENG.EARC03004-01
DWN
MEZ
CKD
SL
APVD
VR/SMC
REV
0
OFFICE
Tt EBA-VANC
DATE
May 2, 2016
Figure 3d
North WRSF Area
Supremo Pit
West WRSF Area
Latte Pit
Double Double Pit
Kona Pit
Plant Site Area
HLF Area
South WRSF Area
Dan Man Creek
Halfway Creek
Latte Creek
May Lady Creek
Q:\Vancouver\GIS\ENGINEERING\EARC\EARC03004-01\Maps\EARC03004-01_Figure03d_Borehole.mxd modified 5/2/2016 by morgan.zondervan

APPENDIX A

TETRA TECH'S GENERAL CONDITIONS

GENERAL CONDITIONS

GEOTECHNICAL REPORT

This report incorporates and is subject to these "General Conditions".

1.0 USE OF REPORT AND OWNERSHIP

This geotechnical report pertains to a specific site, a specific development and a specific scope of work. It is not applicable to any other sites nor should it be relied upon for types of development other than that to which it refers. Any variation from the site or development would necessitate a supplementary geotechnical assessment.

This report and the recommendations contained in it are intended for the sole use of Tetra Tech EBA's Client. Tetra Tech EBA does not accept any responsibility for the accuracy of any of the data, the analyses or the recommendations contained or referenced in the report when the report is used or relied upon by any party other than Tetra Tech EBA's Client unless otherwise authorized in writing by Tetra Tech EBA. Any unauthorized use of the report is at the sole risk of the user.

This report is subject to copyright and shall not be reproduced either wholly or in part without the prior, written permission of Tetra Tech EBA. Additional copies of the report, if required, may be obtained upon request.

2.0 ALTERNATE REPORT FORMAT

Where Tetra Tech EBA submits both electronic file and hard copy versions of reports, drawings and other project-related documents and deliverables (collectively termed Tetra Tech EBA's instruments of professional service), only the signed and/or sealed versions shall be considered final and legally binding. The original signed and/or sealed version archived by Tetra Tech EBA shall be deemed to be the original for the Project.

Both electronic file and hard copy versions of Tetra Tech EBA's instruments of professional service shall not, under any circumstances, no matter who owns or uses them, be altered by any party except Tetra Tech EBA. Tetra Tech EBA's instruments of professional service will be used only and exactly as submitted by Tetra Tech EBA.

Electronic files submitted by Tetra Tech EBA have been prepared and submitted using specific software and hardware systems. Tetra Tech EBA makes no representation about the compatibility of these files with the Client's current or future software and hardware systems.

3.0 ENVIRONMENTAL AND REGULATORY ISSUES

Unless stipulated in the report, Tetra Tech EBA has not been retained to investigate, address or consider and has not investigated, addressed or considered any environmental or regulatory issues associated with development on the subject site.

4.0 NATURE AND EXACTNESS OF SOIL AND ROCK DESCRIPTIONS

Classification and identification of soils and rocks are based upon commonly accepted systems and methods employed in professional geotechnical practice. This report contains descriptions of the systems and methods used. Where deviations from the system or method prevail, they are specifically mentioned.

Classification and identification of geological units are judgmental in nature as to both type and condition. Tetra Tech EBA does not warrant conditions represented herein as exact, but infers accuracy only to the extent that is common in practice.

Where subsurface conditions encountered during development are different from those described in this report, qualified geotechnical personnel should revisit the site and review recommendations in light of the actual conditions encountered.

5.0 LOGS OF TESTHOLES

The testhole logs are a compilation of conditions and classification of soils and rocks as obtained from field observations and laboratory testing of selected samples. Soil and rock zones have been interpreted. Change from one geological zone to the other, indicated on the logs as a distinct line, can be, in fact, transitional. The extent of transition is interpretive. Any circumstance which requires precise definition of soil or rock zone transition elevations may require further investigation and review.

6.0 STRATIGRAPHIC AND GEOLOGICAL INFORMATION

The stratigraphic and geological information indicated on drawings contained in this report are inferred from logs of testholes and/or soil/rock exposures. Stratigraphy is known only at the locations of the testhole or exposure. Actual geology and stratigraphy between testholes and/or exposures may vary from that shown on these drawings. Natural variations in geological conditions are inherent and are a function of the historic environment. Tetra Tech EBA does not represent the conditions illustrated as exact but recognizes that variations will exist. Where knowledge of more precise locations of geological units is necessary, additional investigation and review may be necessary.

7.0 PROTECTION OF EXPOSED GROUND

Excavation and construction operations expose geological materials to climatic elements (freeze/thaw, wet/dry) and/or mechanical disturbance which can cause severe deterioration. Unless otherwise specifically indicated in this report, the walls and floors of excavations must be protected from the elements, particularly moisture, desiccation, frost action and construction traffic.

8.0 SUPPORT OF ADJACENT GROUND AND STRUCTURES

Unless otherwise specifically advised, support of ground and structures adjacent to the anticipated construction and preservation of adjacent ground and structures from the adverse impact of construction activity is required.

9.0 INFLUENCE OF CONSTRUCTION ACTIVITY

There is a direct correlation between construction activity and structural performance of adjacent buildings and other installations. The influence of all anticipated construction activities should be considered by the contractor, owner, architect and prime engineer in consultation with a geotechnical engineer when the final design and construction techniques are known.

10.0 OBSERVATIONS DURING CONSTRUCTION

Because of the nature of geological deposits, the judgmental nature of geotechnical engineering, as well as the potential of adverse circumstances arising from construction activity, observations during site preparation, excavation and construction should be carried out by a geotechnical engineer. These observations may then serve as the basis for confirmation and/or alteration of geotechnical recommendations or design guidelines presented herein.

11.0 DRAINAGE SYSTEMS

Where temporary or permanent drainage systems are installed within or around a structure, the systems which will be installed must protect the structure from loss of ground due to internal erosion and must be designed so as to assure continued performance of the drains. Specific design detail of such systems should be developed or reviewed by the geotechnical engineer. Unless otherwise specified, it is a condition of this report that effective temporary and permanent drainage systems are required and that they must be considered in relation to project purpose and function.

12.0 BEARING CAPACITY

Design bearing capacities, loads and allowable stresses quoted in this report relate to a specific soil or rock type and condition. Construction activity and environmental circumstances can materially change the condition of soil or rock. The elevation at which a soil or rock type occurs is variable. It is a requirement of this report that structural elements be founded in and/or upon geological materials of the type and in the condition assumed. Sufficient observations should be made by qualified geotechnical personnel during construction to assure that the soil and/or rock conditions assumed in this report in fact exist at the site.

13.0 SAMPLES

Tetra Tech EBA will retain all soil and rock samples for 30 days after this report is issued. Further storage or transfer of samples can be made at the Client's expense upon written request, otherwise samples will be discarded.

14.0 INFORMATION PROVIDED TO TETRA TECH EBA BY OTHERS

During the performance of the work and the preparation of the report, Tetra Tech EBA may rely on information provided by persons other than the Client. While Tetra Tech EBA endeavours to verify the accuracy of such information when instructed to do so by the Client, Tetra Tech EBA accepts no responsibility for the accuracy or the reliability of such information which may affect the report.

APPENDIX B

PECG'S 2016 REPORT "TERRAIN STABILITY AND HAZARD MAPPING FOR THE COFFEE GOLD PROJECT"

PALMER ENVIRONMENTAL CONSULTING GROUP INC.

Terrain Stability and Hazard Mapping for the Coffee Gold Project

PN 13103

Prepared for

Kaminak Gold Corporation

March 19, 2016

PALMER
ENVIRONMENTAL
CONSULTING
GROUP INC.

*470 Granville Street, Suite 630, Vancouver, BC V6C 1V5 **t** 604-629-9075*

March 19, 2016

Tim Smith, P.Geo.
Vice President Exploration
Kaminak Gold Corporation
1020 – 800 West Pender Street
Vancouver, BC V6C 2V6

Dear Mr. Smith,

Re: Terrain Stability and Hazard Mapping for the Coffee Gold Project

Palmer Environmental Consulting Group Inc. is pleased to provide Kaminak Gold Corporation with the results of the terrain stability and hazard mapping we completed for the Coffee Gold Project in west-central Yukon.

This report, in combination with the appended mapping of terrain (Map 1), terrain stability and hazards (Map 2) and soil erosion potential (Map 3), provides the information necessary to inform engineering and environmental studies being completed in support of project proposal submission to the Yukon Environmental and Socio-economic Assessment Board. It characterizes the types and distribution of terrain hazards in the vicinity of proposed project infrastructure, as a basis for evaluating risks and prioritizing opportunities for avoidance and mitigation.

Should you or technical reviewers have any questions or require additional information, please feel free to contact Robin McKillop at 604-629-9075 (ext. 106) or via email at robin@pecg.ca.

Yours truly,

Palmer Environmental Consulting Group Inc.

Signature REDACTED

Robin McKillop, M.Sc., P.Geo.
Partner, Geomorphologist

PALMER ENVIRONMENTAL CONSULTING GROUP INC.

Distribution List

# of Hard Copies	PDF Required	Association / Company Name
1	Yes	Kaminak Gold Corporation
	Yes	Onsite Engineering Ltd.
	Yes	Tetra Tech EBA

Revision Log

Revision #	Revised By	Date	Issue / Revision Description

Signatures

Signature REDACTED

Robin McKillop, M.Sc., P.Geo.
Partner, Geomorphologist
Palmer Environmental Consulting Group Inc.

David Sacco, M.Sc.
Surficial Mapping and Exploration Specialist
Palmer Environmental Consulting Group Inc.

Signature REDACTED

Signature REDACTED

Signature REDACTED

Courtenay Brown, M.Sc., G.I.T.
Terrain Mapping Specialist
Palmer Environmental Consulting Group Inc.

Jim Coates, M.Sc.
Permafrost Specialist
Kryotek Arctic Innovation Inc.

Executive Summary

Kaminak Gold Corporation is proposing to develop its Coffee Gold Project, located approximately 130 km south of Dawson, in Yukon's White Gold District. A service road, approximately 215 km in length and comprising existing and new sections, is proposed to provide access from Dawson. Kaminak retained PECG to complete terrain stability and hazard mapping within a 526 km^2 study area that encompasses the proposed mine facilities and access road corridor. The objective of the mapping is to inform engineering and environmental studies advancing in support of project proposal submission to the Yukon Environmental and Socio-economic Assessment Board.

The study area is within the zone of discontinuous permafrost in an unglaciated region of rolling mountains in Yukon's Klondike Plateau. The proposed mine area straddles a broad subalpine ridge south of Yukon River. The proposed access road from Dawson traverses several large valleys, gently undulating ridge systems, rounded mountain passes, and crosses the Stewart and Yukon rivers. Ten main terrain units occur within the study area, the majority of which are colluvial mantles of varying thicknesses on slopes with (45%) and without (24%) permafrost. Comparatively small portions of the study area are dominated by intact or weathered bedrock (3%), mixed weathered bedrock and colluvium (14%), fluvial (6%) or glaciofluvial (<1%) deposits, or organic terrain (1%). Anthropogenic disturbance from placer mining is common (6%) within most of the valleys along which the road is proposed. Mass movement and slope erosion processes that contribute to the geomorphology of the landscape include rockfall, debris slides, rock slumps, rock creep, gullying, solifluction, active layer detachments, thermokarst subsidence, thermal erosion, slopewash and pingos. The fluvial processes with the greatest potential to affect the project are meander migration and icing.

The study area was divided into areas (polygons) based on their terrain stability class prior to (existing state) and following (disturbed state) conventional facility/road construction without mitigation. In its existing state, approximately 85% of the study area is considered stable (Class I), generally stable (Class II) or generally stable with minor potential for instability (Class III), with approximately 8% considered potentially unstable (Class IV) or unstable (Class V). The remaining approximately 7% is unclassified anthropogenic disturbances or open water. In a disturbed state, the proportion of Class I to III polygons would decrease to 64% and correspondingly increase the proportion of Class IV and V polygons to 29%. This elevation in terrain stability class mainly reflects increased potential for permafrost-related slope failures or thermokarst activity if facility/road construction proceeded without regard for the sensitivity of ground underlain by permafrost. The distinction between existing and disturbed terrain stability classes facilitates accurate recognition of upslope or downslope hazards unaffected by project activities.

The primary hazards requiring consideration in the final siting and design of the mine facilities and access road include rockfall, debris slides, active layer detachments and thermokarst activity. Careful site preparation, construction and mitigation will minimize exposure to these hazards, where unavoidable. Erosion protection, such as riprap, will be required along sections of the access road near migrating meanders and river crossings. Special consideration will need to be given to the design and maintenance of drainage crossings prone to icing.

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1 Introduction

Palmer Environmental Consulting Group Inc. (PECG) is pleased to provide Kaminak Gold Corporation (Kaminak) with the results of our terrain stability and hazard mapping for the Coffee Gold Project (the Project). Our work aligns with the hazard mapping expectations of Yukon Environmental and Socio-economic Assessment Board (YESAB). The landscape encompassing the proposed mine area and access route was mapped to support engineering planning, including risk assessment, and environmental studies such as terrestrial ecosystem mapping, aquatic risk assessment and acid rock drainage potential evaluations. This report and its appended maps inform the routing and design of the access road, and the footprint and site preparation for mine facilities. We provide a comprehensive description of the distribution, characteristics and implications of different terrain units and geomorphological processes, as a basis for minimizing construction and maintenance costs, and avoiding and mitigating risks to infrastructure and the natural environment.

Following provision of important background information (Section 1), the physical setting of the region encompassing the study area is described (Section 2). The methods used for field work, mapping and hazard identification are outlined in Section 3. Dominant terrain units and geomorphological processes encountered within the study area are characterized in Section 4. Section 5 presents the results of the terrain stability and hazard mapping, and summarizes the distribution, characteristics and implications of potential hazards to project infrastructure footprints. Considerations for hazard avoidance and mitigation and highlighted in Section 6. Key conclusions are stated in Section 7, followed by acknowledgment of study limitations in Section 8. References cited throughout the report are provided in Section 9.

Mapping of terrain (Map 1), terrain stability and hazards (Map 2), and soil erosion potential (Map 3) is provided in **Appendices A**, **B** and **C**, respectively. **Appendix D**, submitted digitally, includes data collected by PECG at detailed field sites throughout the study area. A technical memorandum prepared by Tetra Tech EBA (TT-EBA) on geotechnical considerations for road design in areas underlain by permafrost is included in **Appendix E**.

1.1 Background

Kaminak is proposing to develop a gold mine, comprising four open pits known as Latte, Double Double, Supremo and Kona, using conventional shovel and truck methods at an average rate of 5 million tonnes per year of heap leach feed (JDS Energy & Mining Inc., 2016). The ore will be crushed and placed in a heap leach facility for nine months of the year. During the coldest winter months, run-of-mine ore will be stockpiled. Gold will be extracted from pregnant leach solution by a 5 tonnes per day Adsorption-Desorption Recovery carbon plant with mercury retorting to produce a final gold doré product. A total of 1.9 million ounces of gold is planned to be recovered over a ten-year mine life. The mine is proposed to be accessed from Dawson along a 215 km-long, upgraded and extended existing road. Stewart and Yukon Rivers are proposed to be crossed by barge in summer and ice road in winter.

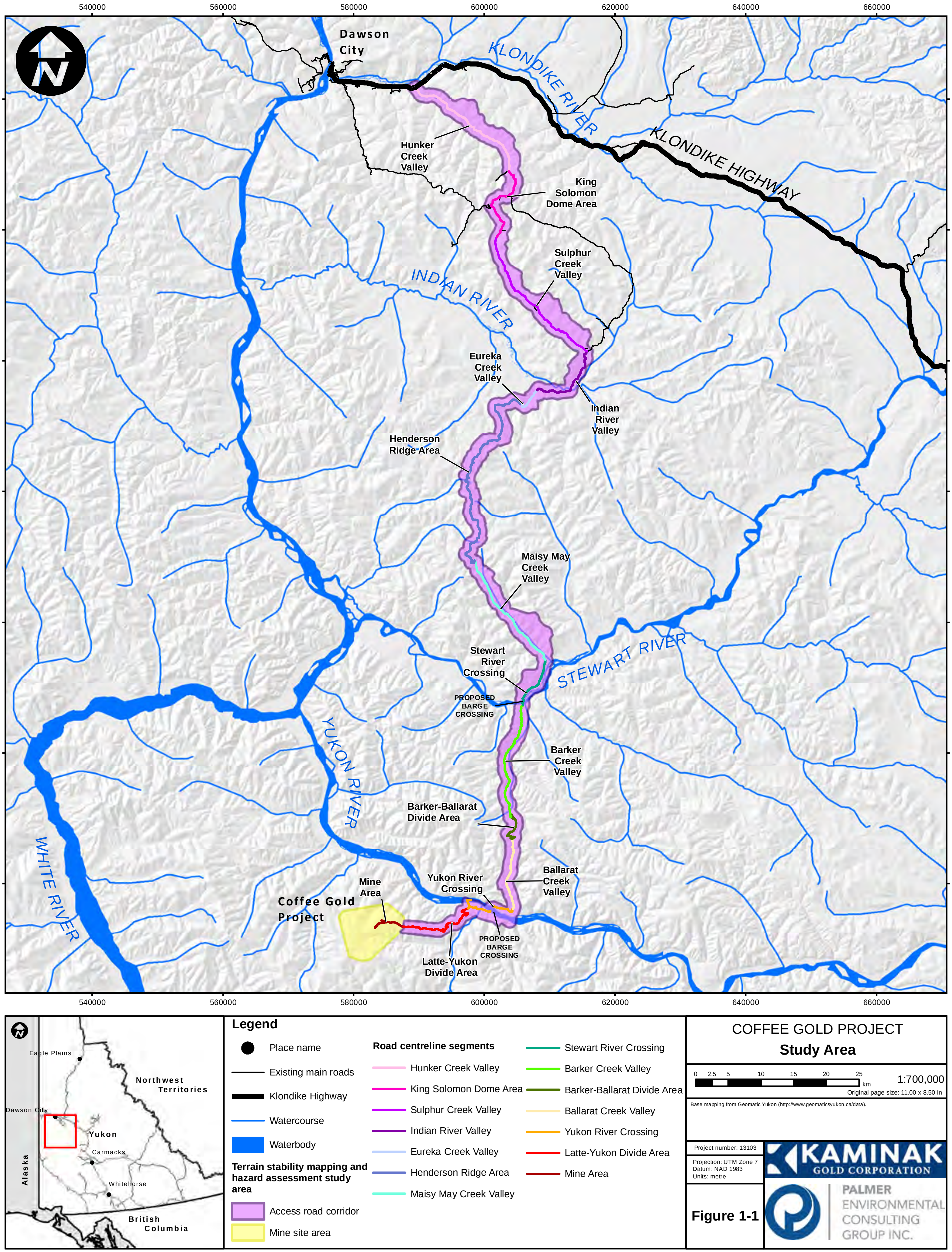
In order to inform mine facility and access road planning, Kaminak retained PECG, working in association with Kryotek Arctic Innovation Inc. (Kryotek), to complete terrain stability mapping and hazard mapping for the Project area. PECG's recognized experts in terrain and terrain stability mapping led all aspects of the mapping assignment, applying knowledge of permafrost conditions and associated hazards specific to the valleys south of Dawson gained through extensive drilling and geophysical surveys by Kryotek. PECG's mapping also benefited from collaboration with TT-EBA, which concurrently mapped permafrost distribution and related geohazards along a 200 m-wide corridor along the proposed access road centreline (TT-EBA, 2016b) and within the mine site area (TT-EBA, 2016c).

PECG recognized that accurate terrain stability mapping in the unglaciated region south of Dawson requires an understanding of the distribution and implications of permafrost, in addition to mass movement processes. Permafrost is extensive, occurring on all aspects and underlying approximately two-thirds of the ground (Hegginbottom et al., 1995; Bonnaventure et al., 2012; McKillop et al., 2013). Permafrost terrain exhibits unique challenges for road construction and maintenance, particularly where it contains significant ground ice, due to its sensitivity to changes in ground thermal regime. The potential for permafrost-related mass movements, whether on slopes or in valley bottoms rich in ice, must be considered. Other hazards that warrant attention in the valleys south of Dawson relate to icing, mostly at stream crossings, and meander migration, alongside sections of road traversing valley bottoms.

1.2 Study Area

The Project is located in the White Gold District of west-central Yukon, approximately 130 km south of Dawson. Detailed terrain stability and hazard mapping were completed to encompass all proposed mine site facilities and the access route from Dawson (**Figure 1-1**). The 526 km^2 study area consists of two main sections:

1. **Access Road Corridor** – The proposed access road corridor extends from KP 700 of the North Klondike Highway, 16 km east of Dawson, southward to the proposed mine site. It has a minimum width of 2 km, roughly centred along the proposed road alignment, with local widenings up to 5 km to encompass heights of land where processes upslope could potentially affect infrastructure (**Figure 1-1)**. From north to south, the route initially follows existing government-maintained roads ascending Hunker Creek, over the divide near King Solomon Dome and descending Sulphur Creek. Along and south of the Indian River valley, the route generally follows existing roads used by placer miners, with some upgrades, realignments and extensions required to meet design criteria and make the road suitable for year-round access. After crossing Indian River, the route ascends Eureka Creek, follows a ridge system at the headwaters of Henderson Creek, and then descends Maisy May Creek to Stewart River, which is proposed to be crossed by barge in summer and ice road in winter. Crossing will not be possible during spring break-up and fall freeze-up each year. South of Stewart River, the route ascends Barker Creek, climbs over a divide and descends lower Ballarat Creek to its confluence with Yukon River, which is also only proposed to be crossed by barge in summer and ice road in winter. The route follows the south side of Yukon River until it crosses Coffee Creek to Coffee Camp, after which it ascends a ridge above "Latte Creek" to the proposed mine site.



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2. **Mine Site Area** – The proposed mine site is situated on the divide between the headwaters of “Latte Creek” and Halfway Creek, in the northern Dawson Range. The mine site study area encompasses the footprints of all proposed mine infrastructure, with a surrounding buffer of at least about 1 km. Key infrastructure within the overall mine footprint includes four open pits, waste rock storage facilities, a heap leach facility, ore stockpiles and processing facilities.

Mapping and assessment of the buffer around the overall Project footprint was completed such that any upslope instabilities or hazards were identified, minor adjustments in site or route selection were accommodated, and environmental studies had a foundation on which their potential effects assessments could be based. A geographic division of the study area into 14 contiguous sections is depicted on **Figure 1-1** as a basis for reference throughout the report.

The Black Hills Creek and upper Ballarat Creek valleys were investigated as possible route options (as described further in Section 3.2). Both route options, however, were excluded from further mapping and consideration due to the extent and distribution of less favourable conditions for road construction and maintenance.

1.3 Objective

PECG completed project-specific terrain stability and hazard mapping to inform the siting and design of mine site facilities and the access road, in general accordance with YESAB’s hazard mapping expectations for Project proposal submission. Three supporting objectives facilitated this ultimate goal: (1) delineate and characterize distinct terrain units and geomorphological processes within the study area; (2) identify potential hazards posed by the environment on the Project, and by the Project on the environment; and (3) provide a basis for project engineers to evaluate and mitigate risks to project infrastructure.

2 Physical Setting

Understanding the regional setting is critical to accurate representation of terrain stability and hazards within the Project area. The following sections describe the physical setting, largely drawing on summaries from McKillop et al. (2013) that were prepared for the same Klondike Plateau study region.

2.1 Physiography

The Project is entirely within the Klondike Plateau physiographic region (Mathews, 1986) and ecoregion (Smith et al., 2004). The Klondike Plateau is a Tertiary-age upland that has undergone variable uplift and stream dissection, resulting in rounded summits and ridges, and deep, V-shaped valleys (Mathews, 1986). Accordant hill crests represent an approximation of the former plateau surface. Most valley sides exhibit convex profiles, with concave terrain restricted to localized bench or gully features and valley bottoms filled with material derived from upslope erosion. Elevations within the study area range from just under 370 m above sea level at the Stewart River to about 1,250 m along “Henderson Ridge” (**Figure 1-1**). Local relief is typically between 300 and 450 m.

The proposed access road crosses the Indian, Stewart and Yukon rivers, which have incised deeply into the plateau surface. The Indian and Stewart rivers are both major tributaries to Yukon River; all three rivers meander westward across the access road corridor. Valley reaches of the rivers and major tributaries become more deeply incised with increased proximity to the Yukon River (Bond and Lipovsky, 2011). Reaches in close proximity to the Yukon River commonly contain stream-cut bedrock terraces, along one or both sides of the valley, which are typically capped by fluvial sand and gravel. Bedrock terraces are thought to be formed by accelerated down-cutting initiated by the reversal of the Yukon River from a south to north-flowing drainage during the late Pliocene to early Pleistocene (Tempelman-Kluit, 1980; Jackson et al., 2008). Some headwater tributaries also exhibit anomalously steep toe slopes that may correspond to this base level change.

The climate of the Klondike Plateau is continental; summers are warm and short, and winters are long and cold. Mean annual temperature is near -5ºC, with mean January temperatures of -23 to -32ºC and mean July temperatures of 10 to 15ºC (Yukon Ecoregions Working Group, 2004). Strong thermal inversions are common from December to February, in association with prolonged atmospheric stability (Williams, 1995). During this period, valley bottom temperatures can be tens of degrees Celsius lower than surrounding higher-elevation areas. Mean annual precipitation ranges from about 300 to 500 mm, giving the region a semi-arid classification (Yukon Ecoregions Working Group, 2004). The wettest period is in the summer, when most precipitation falls as rain during convective rainshowers and thunderstorms.

Thunderstorms trigger wildfires throughout the region, which exhibits the highest frequency of lightning strikes in Yukon (Yukon Ecoregions Working Group, 2004). Yoshikawa et al. (2003) estimate natural wildfire recurrence of 50 to 300 years in the similar boreal forest of interior Alaska. **Figure 2-1** depicts the fire history within the region encompassing the study area. As described below in Section 2.4, fire has important implications for ground stability in areas of permafrost, such as observed in a recently burned area along Barker Creek that post-dates the fire inventory depicted on this figure.

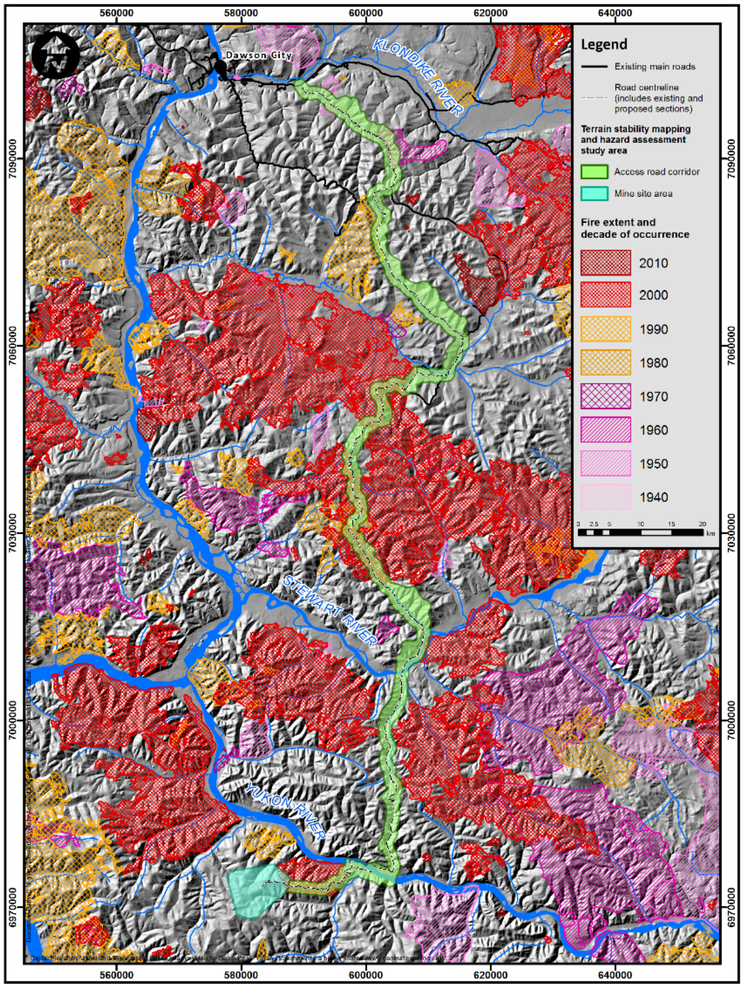
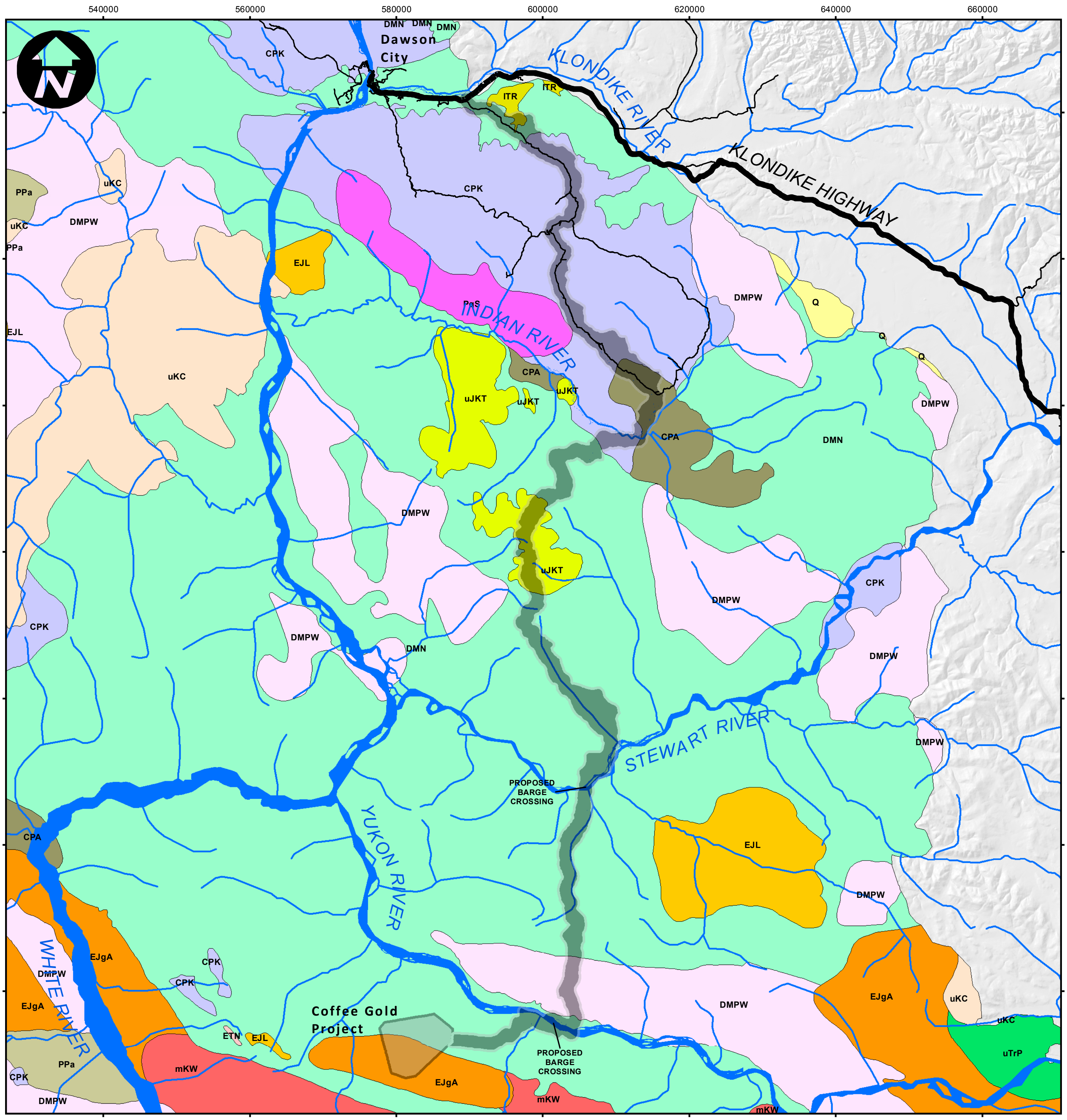


Figure 2-1. Fire history in the region encompassing the study area

2.2 Bedrock Geology

The Project area occurs mainly within the Yukon-Tanana Terrane, an accretionary sequence including former volcanic island arcs and continental shelf depositional environments (Mortensen, 1992) (**Figure 2-2**). This terrane comprises metamorphosed Paleozoic-aged schists and gneisses, intruded by Mesozoic-aged granitic rocks, and locally overlapped by volcanic rocks (Colpron et al., 2006). Devonian to Mississippian-aged quartzite and muscovite quartz-rich schist of the Nasina assemblage are the most extensive (Gordey and Makepeace, 2003). The Late Devonian- to Mississippian-aged Pelly Gneiss Suite of granitic gneisses with localized amphibolite, quartz-mica schist and phyllite occurs throughout the region. The Klondike Schist, a Carboniferous to Permian-aged assemblage of metamorphosed pelitic and volcanic rocks, with bands of marble and inclusions of phyllite, is widespread in the vicinity of Dawson. The Dawson Range Batholith intruded the schist-dominated metamorphic rocks in the mid-Cretaceous. Its Whitehorse Suite consists of granitic rocks of felsic to mafic composition; granodiorites, granites and quartz monzonites are common. During the Late Cretaceous, the andesitic Carmacks formation was emplaced across portions of the region.



Legend

- Place name
- Existing main roads
- Klondike Highway
- Watercourse
- Waterbody

Terrain stability mapping and hazard assessment study area

- Access road corridor
- Mine site area

Q	QUATERNARY: unconsolidated glacial and fluvial deposits
ITR	ROSS: terrestrial clastics
ETN	NISLING RANGE SUITE: equigranular to porphyritic rocks of intermediate to felsic composition
uKC	CARMACKS: basic volcanic strata
mKW	WHITEHORSE SUITE: equigranular felsic to intermediate granitic rocks
uJKT	TANTALUS: pebble conglomerate and quartz-chert-feldspar sandstone
EJgA	AISHIHIK SUITE: biotite-hornblende granodiorite
EJL	LONG LAKE SUITE: felsic granitic rocks
uTrP	POVOS: andesitic basalt flows, breccia, tuff, sandstone and argillite
PqS	SULPHUR CREEK SUITE: biotite quartz monzonite gneiss
CPK	KLONDIKE SCHIST: metamorphosed pelitic/volcanic rocks
CPA	ANVIL: mafic volcanics and ultramafics
PPa	AMPHIBOLITE: metamorphosed mafic rocks
DMPW	PELLY GNEISS SUITE - SW: felsic to intermediate granitic rocks
DMN	NASINA: graphitic quartzite and muscovite quartz-rich schist

COFFEE GOLD PROJECT

Bedrock Geology

0 2.5 5 10 15 20 25 km

1:700,000

Original page size: 11.00 x 8.50 in

Base mapping from Geomatic Yukon (http://www.geomaticsyukon.ca/data).

Project number: 13103

Projection: UTM Zone 7
Datum: NAD 1983
Units: metre

Figure 2-2

KAMINAK GOLD CORPORATION

PALMER ENVIRONMENTAL CONSULTING GROUP INC.

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Outcrops of intact bedrock are rare across the region. The most prominent bedrock outcrops form tors, which are erosional, castellated towers from former plateau surfaces. Tors typically form in granitic lithologies and punctuate several high summits and ridges in the mine area. Ridges and spurs composed of metamorphic rocks are typically overlain by mantles of weathered fragments of bedrock, resulting in few intact outcrops. Bedrock is also exposed in lower-slope settings, where fluvial incision has over-steepened valley walls and outpaced compensatory hillslope adjustments. This is most common within the major river valleys and in tributaries near Yukon River.

The study area is situated within an area of low seismic activity between the Denali and Tintina faults, with only several mapped earthquake epicentres occurring north of the Stewart River (Hyndman et al., 2005) (**Figure 2-3**). As such, most mass movements in the study area are triggered by processes other than earthquakes (as described further in Section 2.5).

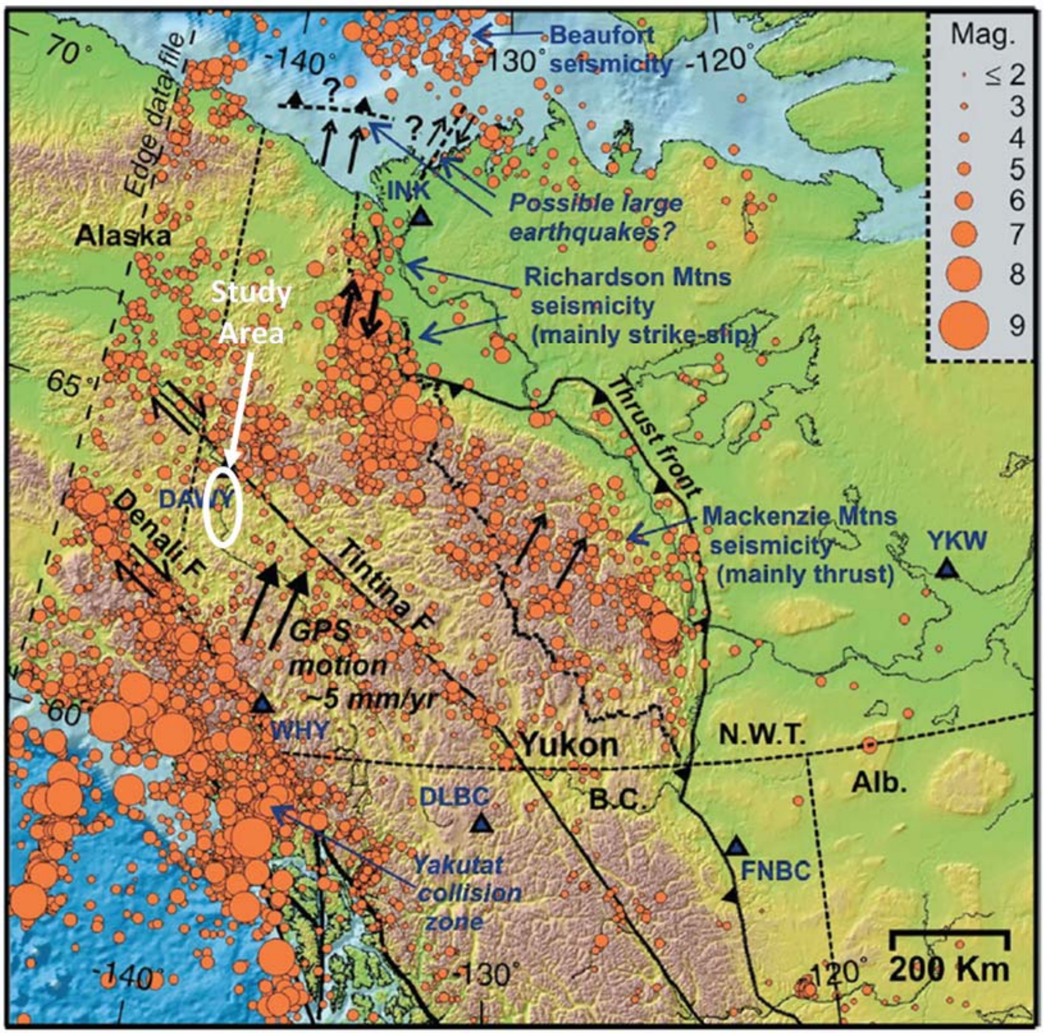


Figure 2-3. Historical instrumental seismicity in northwestern Canada (seismographs shown as triangles; modified from Hydman et al., 2005).

2.3 Surficial Geology

Nearly all of the study area remained unglaciated throughout the Pleistocene, with the exception of a few cirque glaciers that once occupied the high, north-facing, alpine headwaters of Coffee Creek, and portions of the Stewart River valley and its adjacent tributaries that were ice-covered during the pre-Reid glaciation (>200 ka) (Duk-Rodkin, 1999). Periglacial weathering and colluvial, fluvial and eolian processes have largely modified and redistributed any remnant glacial sediments. Thus, areas within the pre-Reid glacial limit, which may once have been mantled by glacial deposits (e.g., till), are mapped primarily as colluvium.

Discontinuous glaciofluvial terraces occur along the Yukon River valley, which was a major meltwater channel during pre-Reid glaciations. These terraces may be observed at several elevations, up to 250 m above the current level of the Yukon River (Huscroft, 2002; Huscroft et al., 2006). Recognition of glaciofluvial terraces is difficult in areas where fine-grained colluvium blankets the terrace surfaces.

Loess, windblown silt and fine sand, is widespread throughout the Klondike Plateau. Most loess in the region was mobilized from unvegetated outwash plains along the Donjek, White and Yukon River valleys. It was dominantly active during glacial and deglacial periods of the Pleistocene, transported by prevailing southerly winds, and katabatic winds draining off the former ice sheets (Bond and Lipovsky, 2011). Significant loess deposits accumulated in valley bottoms directly down-wind of the major outwash plains (Bond and Lipovsky, 2011), on the lee (north) side of hills (Birkeland, 1984), and in other areas where topography, vegetation and soil moisture provide suitable environments for trapping loess (Tsoar and Pye, 1987). Loess is best preserved on northerly aspects where it is effectively anchored in place by shallow permafrost, and on relatively level ground in hollows amongst boulder-sized blocks. *In situ* loess was observed in at least one road cut along the proposed access route. Much of the loess in the region has been redistributed and concentrated through periglacial, colluvial and fluvial processes. Resedimented loess mixes with organic material to form aprons on lower slopes and in valley bottoms that rival in thickness the >20 m *in situ* loess deposits preserved near the mouths of tributaries of the Donjek River (Bond and Lipovsky, 2011).

In the absence of glacial erosion, a mantle of *in situ* weathered bedrock known as felsenmeer has accumulated on level to gently sloping ground. The character of the felsenmeer depends primarily on the bedrock lithology and the intensity and depth of periglacial weathering. Large, angular clasts that detach from the underlying fractured bedrock gradually weather to cobble, gravel and eventually sand or silt-sized particles. A metre-thick, fining-upward gradation is commonly visible in pits or trenches dug within felsenmeer. Deep horizons have a jigsaw puzzle-like fit to the clasts, commonly preserving original bedrock structures. Shallow horizons have undergone sufficient disaggregation and cryoturbation to destroy any structure, and they contain a higher matrix content.

Colluvium is the most widespread surficial material within the study area and broader Klondike Plateau. Typically, it is composed of weathered bedrock and loess reworked by gravitational processes. It covers almost all slopes with thicknesses ranging from less than a metre, near ridge crests and on steep slopes, to more than ten metres in slope concavities and valley bottoms. The texture of colluvium reflects the local bedrock lithology and the amount of loess and organics intermixed with it. Colluvium derived from the weathering and entrainment of granitic rocks tends to be blocky to pebbly, with a silty-sand matrix, whereas colluvium derived from schists and gneisses is generally finer-grained, comprising cobble-sized angular fragments and a more silt-rich matrix (Schaetzl and Anderson, 2005). Slopes underlain by permafrost tend to have a higher silt content than those without permafrost, and aprons in toe-slope positions are dominated by silt and organics. These aprons are locally referred to as ‘muck’ (Tyrrell, 1917; Fraser and Burn, 1997). Colluviation occurs mainly through soil creep, solifluction, slopewash and landsliding, the relative importance of each depending on slope steepness and permafrost distribution.

Fluvial deposits occupy valley bottoms throughout the region. Headwater streams are typically confined to narrow, V-shaped valleys and have beds of cobbly gravel veneered by sand. Channel bed and bank material along meandering lower reaches are typically composed of sandy gravels overlain by silty flood deposits. Floodplains are typically absent in headwater reaches, but are hundreds of metres wide along the lower reaches of major tributaries. Inactive floodplains may be overlain by loess, and interbedded with, or overlain by, organic material.

Organic deposits are common throughout the Klondike Plateau. On well drained forested slopes free of permafrost, organic deposits are relatively thin (<15 cm) and composed predominantly of fibrous woody forest litter. On slopes with shallow permafrost and in depressions with poor drainage, poorly to moderately decomposed peaty organic material is commonly 30-40 cm thick and may exceed 100 cm. The type and thickness of organic material is closely associated with permafrost distribution and drainage conditions.

2.4 Permafrost

2.4.1 Distribution

Permafrost is ground that remains below 0ºC for more than one year. The study area is within the zone of extensive discontinuous permafrost, in which 50 to 90% of the ground is underlain by permafrost (Heginbottom, 1995). Recent permafrost modelling completed by Bonnaventure et al. (2012) for southern Yukon indicates that the distribution of permafrost within the region exhibits characteristics of both subarctic and mountain permafrost, being prevalent in valley bottoms and on northern aspects. Locally, permafrost distribution is related to slope aspect, angle and shape, soil texture and moisture, and the thickness and type of organic cover (Williams, 1995; Williams and Burn, 1996). Permafrost is most common on north-facing slopes with thick organic cover and in fine-grained colluvial aprons extending into valley bottoms (Bond and Lipovsky, 2011). Steep, well drained, south-facing slopes are invariably permafrost-free.

A variety of landforms indicates the presence of permafrost within the study area, including pingos (**Figure 2-4**). Open-system pingos are scattered across the region, commonly in slope-toe settings of small drainages where groundwater discharges to surface through discontinuities in the permafrost table (Hughes, 1969; Bond and Lipovsky, 2011). Most are collapsed and distinguished based on the ramparts encircling a small pond. Other indicators of permafrost in valley settings include thermokarst ponds and gullies, ice-wedge polygons, active layer detachments, cryoplanation terraces, solifluction lobes, stone stripes and slopewash runnels (**Figure 2-4**).

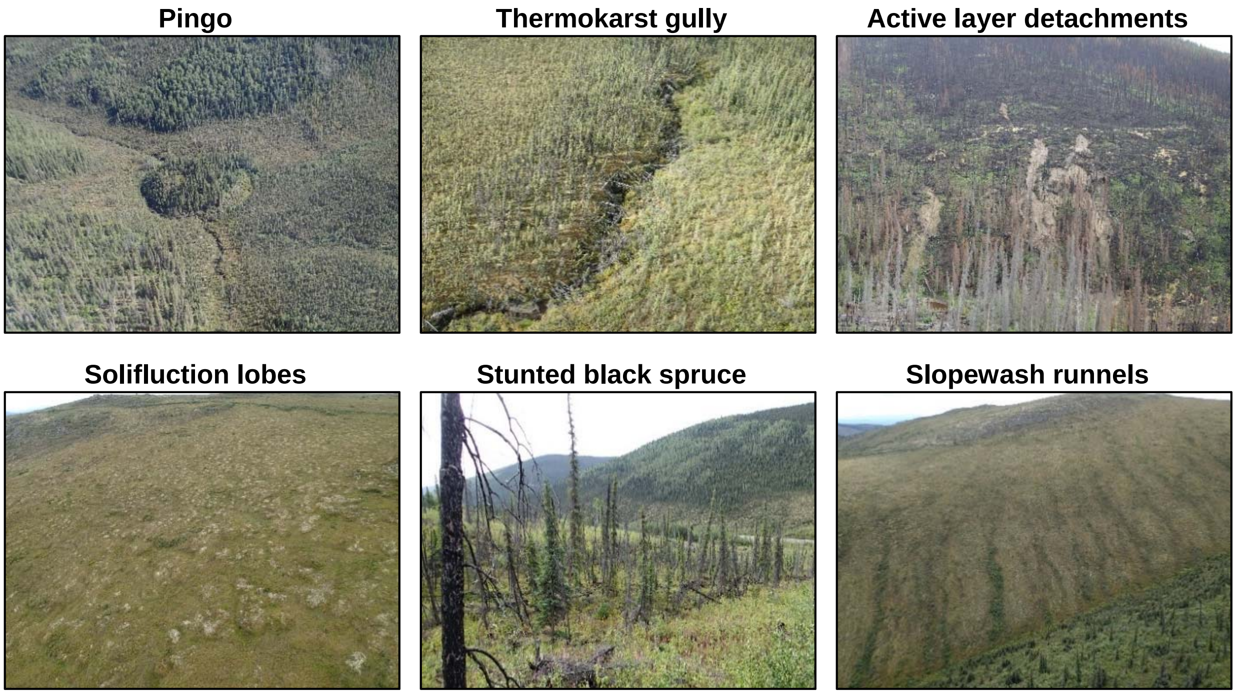


Figure 2-4. Example of features indicative of permafrost in the study area

Vegetation distribution and health can be reasonable predictors of permafrost presence or absence, although local disequilibrium of permafrost and present climate can mislead inferences. In general, deciduous trees root more deeply than coniferous trees, and are unable to grow in thin active layers where soils are permanently wet or saturated. Stands of trembling aspen are invariably restricted to permafrost-free ground (Zoltai and Pettapiece, 1973; Williams, 1995). Conversely, black spruce is tolerant of cool, saturated soils and commonly grows in areas underlain by permafrost. A sparse, stunted canopy of black spruce with thick moss cover or sedge tussocks is a reliable indicator of shallow permafrost. Mixed coniferous and deciduous forests, including Alaska birch, may or may not be underlain by permafrost. In riparian zones, vegetation patterns reflect the frequency of flooding and presence of permafrost. The most frequently flooded areas are permafrost-free and dominated by willow, alder and balsam poplar. Irregular species composition and stand structure within the valleys south of Dawson commonly reflects a combination of regrowth from forest fire and other disturbances since the Yukon gold rush (Naldrett, 1981), which complicates interpretations of permafrost distribution.

Maximum thicknesses of permafrost within the study area and broader Klondike Plateau are highly variable. Thicknesses of 60 to 85 m have been reported from the Dawson area and valley bottoms in the nearby Klondike goldfields (McConnell, 1905; Brown, 1967; Milner, 1976; EBA, 1977, 1978). Drilling in the vicinity of the Project mine area in association with hydrogeological investigations penetrated permafrost with a wide range in thickness, up to about 165 m (Lorax Environmental Services Ltd., 2016).

2.4.2 Active Layer and Depth of Permafrost

The active layer is the upper layer of ground that freezes and thaws seasonally above the permafrost table. It may be restricted to soils and unconsolidated surficial materials, or it may extend into underlying, weathered or intact bedrock. At a local scale, its thickness primarily depends on elevation, aspect, soil texture, drainage, snow pack, vegetation cover and wildfire history (Williams and Burn, 1996; McKillop et al., 2013). The active layer is generally 1 to 2 m thick within the region encompassing the study area (Yukon Ecoregions Working Group, 2004; Bond and Lipovsky, 2011). Well drained, coarse-grained soils tend to have thicker active layers than poorly drained and fine-grained areas. In areas of thick, mossy organic cover, permafrost may be encountered at depths as shallow as just a few tens of centimetres. Areas with thick organic cover and variable moisture contents exhibit the greatest spatial variability in active layer thickness (Smith et al., 2009).

Active layer thickness varies seasonally and in response to natural and anthropogenic disturbances. Each year active layer thickness increases following spring snowmelt and typically peaks in late summer, before refreezing in the autumn. Active layers thicken by up to several times their original thickness following wildfire, which burns most or all of the insulating surface organic mat, reduces interception of snow by trees (where present), lowers the surface albedo, increases exposure to solar radiation, and decreases evapotranspiration (e.g., Burn, 1998; Smith et al., 2015).

2.4.3 Ground Ice

Permafrost may or may not contain ice. The ice content of permafrost is highly variable at both the regional and local scale. Areas of intact or weathered bedrock and well drained, coarse-grained colluvial mantles with permafrost generally contain little to no visible ice. Such ice-poor permafrost is common in upland settings, on summits and along ridges and spurs, and on moderate to moderately steep valley sides with convex or straight slopes. Permafrost more commonly contains excess ice[1] in the form of thin seams and lenses in silt-rich colluvial blankets, on solifluction slopes and in inactive portions of fluvial plains. Ice-rich permafrost with massive bodies of ice is most commonly encountered in organic terrain and silt-rich colluvial complexes in valleys. Enlarging thaw lakes in silt-rich valley bottom deposits provide evidence of locally high ice contents, perhaps as high as 50% by volume (Bond and Lipovsky, 2011).

Ground ice is sensitive to melting in response to permafrost degradation (thaw). Permafrost degradation occurs naturally over different time scales in response to localized surface disturbances such as wildfire or windthrow, which alter the ground thermal regime by removing the insulating surface organics, and climate change, which can result in anomalously high late-summer rainfalls or anomalously deep winter snowpacks. Anthropogenic disturbances also alter the ground thermal regime and are a common trigger for permafrost degradation. Permafrost degradation has little to no effect on ground surface topography or stability in areas of ice-poor permafrost where the permafrost table is commonly deep within coarse-grained colluvium or weathered bedrock. Areas of ice-rich permafrost within fine-grained materials, in contrast, are susceptible to irregular subsidence and thermokarst pond formation in response to permafrost degradation.

[1] The term excess ice is used throughout the report to represent the condition in which the volume of ice in the ground exceeds the total pore volume the ground would have under natural, unfrozen conditions.

2.5 Mass Movement Processes

Most mass movements within the study area are influenced, either directly or indirectly, by permafrost or related periglacial processes. Climatic warming is contributing to the degradation of permafrost, especially on southerly aspects and in broad valley bottoms exposed to prolonged sunlight during the summer. Permafrost degradation results in an increase in the volume (mass) of surficial material available for downslope transport and degree of soil saturation provided by the release of water from thawing ground ice. Shallow landsliding (e.g., active layer detachment) occurs once the shear stress exceeds the shear strength of the material. Thermokarst subsidence and gullying may occur in gentler terrain with excess ground ice. Deep-seated failures within thick overburden or weathered bedrock occur in response to failures of weak layers or thawing of ice bodies at depth. Deep-seated permafrost failures may result from movement of groundwater within unfrozen zones (taliks) in or beneath permafrost.

In the YGS' compilation of regional-scale surficial geology mapping (Lipovsky and Bond (compilers), 2014), a number of features interpreted as paleo-landslides are identified. All were assessed in the field and/or using the high-resolution spatial data acquired specifically for this project (as described below in Section 3.1). Some of the features may have evolved over millennia of differential erosion and mass wastage, as opposed to coherent mass movements. Most exhibit subdued topography with no evidence of recent movement in ground or vegetation disturbance patterns. Only those with possible evidence of continued instability have been included in the project-specific mapping of terrain stability and hazards (Map 2, **Appendix B**).

The most common triggers for both shallow and deep-seated failures are intense or prolonged rainfall, or heat events and wildfires (**Figure 2-1**). Seasons of increased mass movements include the period from late July to early September, when active layers are thickest, permafrost is warmest and rainfall is greatest, as well as late May or early June, when erosion during snowmelt freshet freshly exposes permafrost to fluvio-thermal erosion and slumping. Slopes underlain by permafrost that have not experienced recent wildfires are more prone to active layer detachment failures immediately following a fire (Coates, 2008).

2.6 Anthropogenic Disturbance

Anthropogenic disturbances related to placer mining dating back to the Yukon gold rush of the late 19th century are widespread within most of the valleys in the study area. Valley bottoms and adjacent terraces have been most severely altered, commonly having all their surficial material mined for placer gold before being deposited in hummocky piles of placer tailings (**Photo 2-1**). Valley sides and uplands have been locally disturbed by construction of access roads and exploration teams searching for gravel terraces and the bedrock source of the placer gold. A more detailed characterization of the disturbances and their implications for project infrastructure is provided below in reference to the specific terrain unit, Anthropogenic Disturbances (Section 4.1.10).

Photo 2-1. Hummocky tailings piles from placer mining in the Indian River valley

3 Methods

PECG employed a systematic approach for completing terrain stability and hazard mapping for the Project, leveraging local knowledge of permafrost conditions and extensive experience mapping mass movement and fluvial hazards in this unglaciated region. Each main phase of work is described below.

3.1 Background Review and Consultation

PECG strengthened our pre-existing understanding of terrain characteristics and related hazards within the study area by reviewing several important data sources: aerial photography; LiDAR-derived elevation data; satellite imagery; existing bedrock, surficial and geomorphological mapping; previously collected field data; and peer-reviewed literature (**Table 3-1**).

PECG also took advantage of our existing collaborative working relationships with senior staff at Yukon Geological Survey (YGS) and Yukon Highways & Public Works (Yukon Highways) to acquire local knowledge from their field experience in the study area. We consulted Jeff Bond (Manager, Surficial Geology, YGS) about his knowledge of the stability of paleo-landslides within the study area. Our team met with staff at Yukon Highways, in Dawson, to discuss their experience with mass movement and icing hazards along the government-maintained section of the proposed access road south of Dawson. Stream crossings prone to icing, according to Yukon Highways' staff, have been included in the map inventory of potential icing hazard sites (Map 2, **Appendix B**).

3.2 Field Investigations

Field work was completed prior to completion of the terrain stability mapping due to concurrent acquisition and processing of the high-resolution aerial photography and LiDAR-derived elevation data on which the mapping of the access road corridor is now based. A thorough review of available data sources identified above in Section 3.1 in advance of field work ensured field investigations provided satisfactory representation of the diversity of terrain and hazards within the study area. Areas with the greatest potential for instability were prioritized for investigation.

Field investigations were conducted throughout the study area by a two- to three-person crew over a two-week period in mid-August 2015 (**Figure 3-1**). Jim Coates (Kryotek) additionally participated in the early phases of the field program, including an initial helicopter reconnaissance of the entire study area, in order to share his local knowledge. Conditions were mostly favourable for field work: the ground was free of frost and snow, active layer thicknesses were likely near their maxima, and weather conditions had little to no effect on progress or site access. A helicopter was used strategically for reconnaissance and site access purposes during the program, with priority for landing sites given to areas inaccessible from existing roads or trails. A 4WD pick-up truck was used for site access along existing sections of government-maintained road, as well as other sections of placer mining roads in reasonable condition. A helicopter-dropped UTV facilitated access along rougher sections of road or trail in the southern portion of the study area. Foot traverses from vehicle drop-off locations enabled access to sites inaccessible to vehicles and better afforded understandings of transitional conditions.

Table 3-1. Select data sources used for background review and project deliverables

Remotely Sensed Data	Type	Acquisition date	Scale/resolution	Source
	Black-and-white stereo aerial photography	1948	1:40,000	Yukon Government archives
	Black-and-white stereo aerial photography	1949	1:40,000 & 1:20,000	Yukon Government archives
	Black-and-white stereo aerial photography	1961	1:30,000 & 1:40,000	Yukon Government archives
	Black-and-white stereo aerial photography	1995/96	1:25,000	Yukon Government archives
	Colour stereo aerial photography (mine area)	2011	1:20,000	Kaminak
	Colour stereo aerial photography (corridor)	2015	1:30,000	Kaminak
	LiDAR-derived elevation data	2012 (mine); 2015 (corridor)	20 cm	Kaminak (McElhanney)
	Satellite imagery (GeoEye-1)	2000-2014	50 cm	Geomaticsyukon.ca

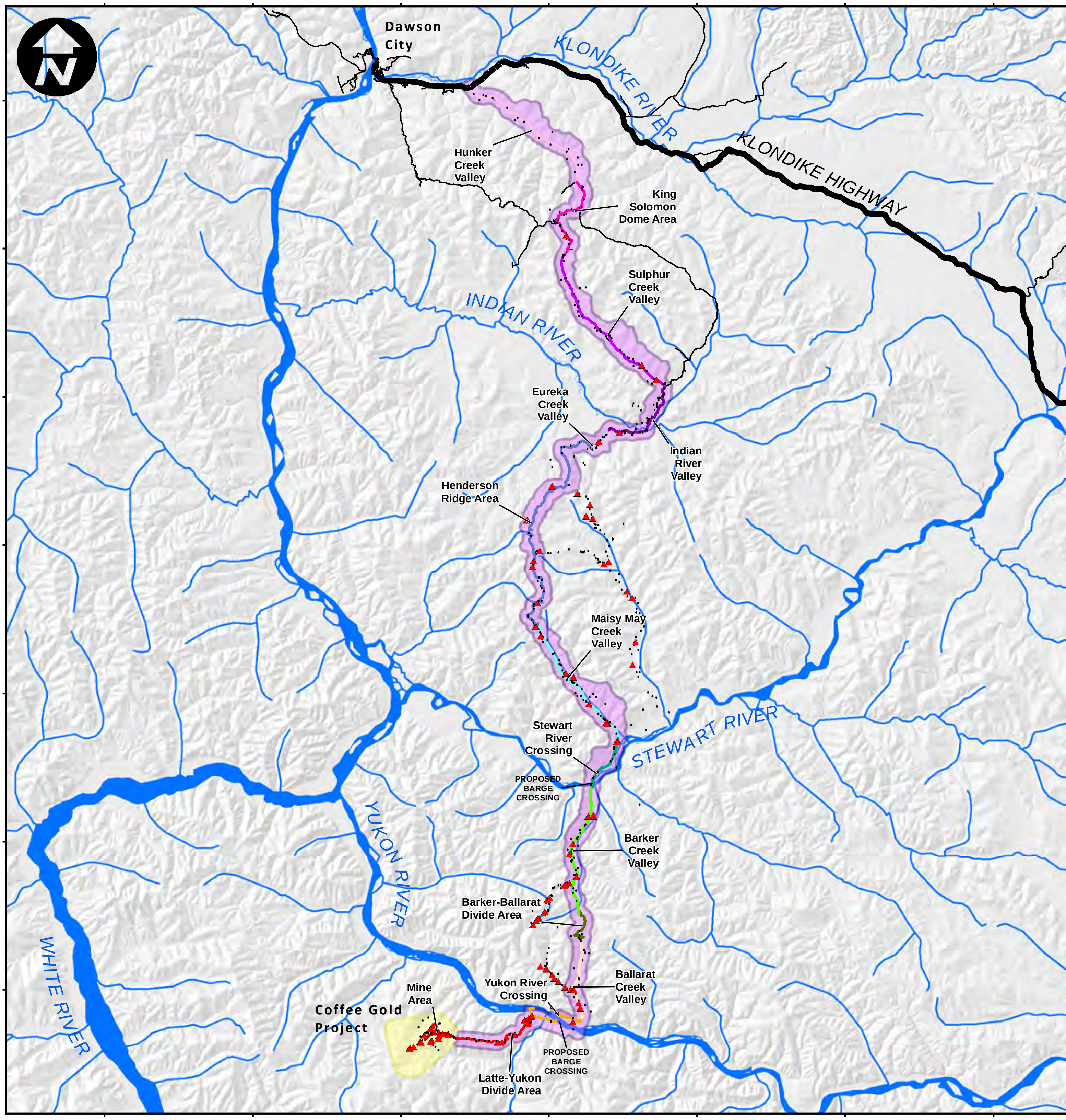
Derived Data	Type	Original data source	Resolution
	Hillshade model (PECG)	2014 LiDAR (Kaminak)	20 cm
	Slope surface model (PECG)	2012/2015 LiDAR (Kaminak)	100 cm
	Orthophotography	2015 air photos (Kaminak)	30 cm

Digital Base Data	Type	Source
	Wildfire database	Geomaticsyukon.ca
	CanVec	Geomaticsyukon.ca
	Historical earthquakes	Geomaticsyukon.ca

Existing Mapping	Type	Scale	Source
	Glacial limits	1:1,000,000	Duk-Rodkin, 1999
	Bedrock geology	1:50 000 – 1:250 000	Gordey and Makepeace (compilers), 1999
	Surficial geology	1: 50 000	Lipovsky and Bond (compilers), 2014
	Geomorphological (terrain) mapping within Coffee Gold Project claim boundary	1:20,000	AECOM, 2012

Select Peer-Reviewed Literature (full reference list in Section 9)	Title	Reference
	Evolution of Surprise Rapids landslide, Yukon Territory	Ward et al., 1992
	Stability of Frozen and Thawing Slopes in the Mackenzie Valley, Northwest Territories	Dyke, 2004
	Earthquakes and seismic hazard in the Yukon-Beaufort-Mackenzie	Hyndman et al., 2005
	Effect of forest fire on landsliding over permafrost, Steele Creek, Yukon Territory	Coates and Lewkowicz, 2005
	Morphology and geotechnique of active-layer detachment failures in discontinuous and continuous permafrost, northern Canada	Lewkowicz and Harris, 2005
	Active layer detachments following the summer 2004 forest fires near Dawson City, Yukon	Lipovsky et al., 2006
	Significant Canadian Earthquakes of the Period 1600–2006	Lamontagne et al., 2007
	A permafrost probability model for the southern Yukon and northern British Columbia, Canada	Bonnaventure et al., 2012
	Property-scale classification of surficial geology for soil geochemical sampling in the unglaciated Klondike Plateau, west-central Yukon	McKillop et al., 2013

Field Data	Type	Collector	Date	Project
	Permafrost and soil data	TT-EBA	2016	Coffee Gold Project permafrost distribution and permafrost-related geohazard mapping
	Permafrost and soil data	AECOM	2012	Coffee Gold Project geomorphological mapping study



Legend

- Place name
- Existing main roads
- Klondike Highway
- Watercourse
- Waterbody
- Visual reconnaissance field site
- Detailed field site

Terrain stability mapping and hazard assessment study area

- Access road corridor
- Mine site area

Road centreline segments

- Hunker Creek Valley
- King Solomon Dome
- Sulphur Creek Valley
- Indian River Valley
- Eureka Creek Valley
- Henderson Ridge Area
- Maisy May Creek Valley
- Stewart River Crossing
- Barker Creek Valley
- Barker-Ballarat Divide
- Ballarat Creek Valley
- Yukon River Crossing
- Latte-Yukon Divide
- Mine Area

COFFEE GOLD PROJECT

Distribution of Field Sites

0 2.5 5 10 15 20 25 km

1:700,000

Original page size: 11.00 x 8.50 in

Base mapping from Geomatic Yukon (http://www.geomaticsyukon.ca/data).
Field reconnaissance conducted by D. Sacco, C. Brown and R. McKillop in association with J. Coates (Kryotek Arctic Innovation) in August 2015.
Observations made by PECG's field crews were supplemented by observations made by other project team members at additional field sites (not shown). Refer to appendices for identification and data from detailed field sites.

Project number: 13103

Projection: UTM Zone 7
Datum: NAD 1983
Units: metre

KAMINAK GOLD CORPORATION

PALMER ENVIRONMENTAL CONSULTING GROUP INC.

Figure 3-1

Document Path: C:\Egnyte\Shared\Projects\Active\1310 - Kaminak Gold Corp\13103 - Coffee TSM\Programs\Mapping\Report figures\Field sites\Figure 3-1.mxd

Drawn by: CEB Checked by: RM 17/03/2016

In total, 96 sites were investigated on the ground in detail, including along candidate sections of access road corridor no longer under consideration ('detailed field sites' in **Figure 3-1**). At each site, a hand-dug soil pit or existing exposure (e.g., road cut) was used to examine the sub-surface. Standardized field sheets were used to record data on site characteristics (e.g., coordinates; elevation and aspect; slope position, shape and steepness), terrain characteristics (e.g., surficial material, texture, surface expression and geomorphological process), drainage conditions (e.g., drainage class; seepage depth) and vegetation (e.g., dominant tree species and ground cover), based on pertinent sections and standards of the *Field Manual for Describing Terrestrial Ecosystems* (BC Ministry of Forests and Range and BC Ministry of Environment, 2010), with an additional allowance for observations related to permafrost conditions (e.g., active layer thickness; ground ice observations) and terrain hazards. Active layer thickness was determined through a minimum of five frost probing measurements at each site. At sites most representative of common terrain units, soil horizons were examined, documented and classified to at least the Great Group level according to *The Canadian System of Soil Classification* (Soil Classification Work Group, 1998) in order to support terrestrial ecosystem mapping being completed by other project team members. A basic sketch of the soil profile, along with photographs of both the soil profile and the surrounding area, accompanied all observations. Photographs were taken of all field sites, as well as of any features of interest. Field data from all detailed sites are included in **Appendix D**.

Pertinent observations from several hundred additional sites were recorded based on visual reconnaissance during short stops along a foot traverse, vehicle drive-by or helicopter fly-over (**Figure 3-1**). Most observations related to surficial material thickness, vegetation associations, drainage and evidence of instability or permafrost characteristics. Accompanying photographic documentation was collected at the majority of observation sites. Basic field notes from visual reconnaissance sites were referenced during mapping, but are not appended due to inconsistency in their contents and formats.

3.3 Terrain and Terrain Stability Mapping

PECG completed terrain and terrain stability mapping within the 526 km^2 study area to support project engineering and environmental studies[2], in accordance with YESAB's recent publication, *Geohazards and Risk: A Proponent's Guide to Linear Infrastructure* (Guthrie and Cuervo, 2015). Terrain mapping is the process of dividing the landscape into areas (polygons) according to surficial materials, landform characteristics and geomorphological processes. Terrain stability mapping involves further consideration of drainage, slope and, in this case, permafrost characteristics, resulting in the classification of each polygon as stable, potentially unstable or unstable.

3.3.1 Mapping Protocols and Attributes

PECG completed all mapping based on field-calibrated interpretations of high-resolution digital aerial photography and LiDAR-derived elevation data (acquired at a flight scale of approximately 1:30,000), using

[2] In addition to supporting the siting and design of the proposed mine facilities and access road, mapping was completed in general accordance with bioterrain mapping protocols (e.g., includes drainage and aspect considerations) in order to support terrestrial ecosystem mapping being completed by other project team members.

softcopy photo-interpretation workstations with either PurVIEW or DAT/EM Summit Lite software packages. Polygon delineation was typically completed at a scale of 1:10,000, although larger scales (e.g., 1:2,500) were used as necessary to delineate important details. Previous geomorphological (terrain) mapping completed by AECOM (2012) within Kaminak's property south of Yukon River was adapted and refined for terrain stability mapping purposes, and to ensure consistency with mapping protocols used north of Yukon River.

Terrain (stability) polygons were delineated primarily based on the YGS' adaptation of the *Terrain Classification System for British Columbia* (Howes and Kenk, 1997) and the *Mapping and Assessing Terrain Stability Guidebook* (BC Ministry of Forests, 1999). We also consulted *A User's Guide to Terrain Stability Mapping in British Columbia* (J.M. Ryder and Associates, Terrain Analysis Inc., 2002) and *A Guide for Management of Landslide-Prone Terrain in the Pacific Northwest* (BC Ministry of Forests, 1994). Certain refinements were made based on unique conditions encountered in the study area and to better meet project-specific objectives.

Terrain stability polygons were delineated with consideration for eight main attributes, each of which is defined below, in addition to the terrain stability classes described below in Section 3.3.2. Complete explanations and descriptions of attribute values are available on the terrain mapping (Map 1) and its cover page of code definitions (**Appendix A**).

- **Surficial Material** – e.g., colluvium (C), weathered bedrock (D), alluvium (F)

  This attribute defines the surficial material present and its depositional (genetic) origin. The surficial material represents the core element of a particular terrain unit and label.

- **Surface Expression** – e.g., veneer (v), blanket (b), terrace (t)

  This attribute refers to the form, or pattern of forms, expressed by the surficial material. Up to two surface expressions describe a particular surficial material.

- **Texture** – e.g., silty (z) sand (s), mixed angular fragments (x), gravel (g)

  This attribute refers to the size, sorting and shape of the particles comprising the surficial material. Textures were assigned to all polygons, including those not investigated in the field, based on typical conditions observed at field sites and documented in previous investigations in the region (e.g., Bond and Lipovsky, 2011; McKillop et al., 2013). Such an approach is consistent with textural characterization in YGS' surficial geology mapping (Lipovsky and Bond (compilers), 2014) and aids standardization of terrain units. Up to three textures describe a particular surficial material, in order of increasing proportion[3].

- **Geomorphological Process** – e.g., gully erosion (-V), active layer detachment (-Xf)

  This attribute refers to geomorphological processes that are either occurring, or have occurred, within a polygon. Up to three geomorphological processes and respective subclasses can be identified.

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[3] This convention is used in place of YGS' opposite convention – in order of decreasing proportion – due to its consistency with verbal description (e.g., sgF is a sandy gravel fluvial deposit dominated by gravel).

- **Drainage Class** – e.g., well drained (w), imperfectly drained (i), poorly drained (p)

  This attribute refers to the speed and extent to which water is removed from the soil in relation to additions. It considers both the rate at which water is able to be removed from an area as a result of landscape characteristics (e.g., slope), and the permeability of the surficial materials themselves. In this study area, drainage class is strongly influenced by the depth to permafrost, where present. Drainage class is represented by a single value, or a range between two values.

- **Depth to Permafrost** – e.g., near-surface (n, <0.4 m), shallow (s, 0.4-1 m), deep (d, >1 m)

  This attribute refers to the estimated maximum (end of summer) depth to permafrost, inferred from vegetation and drainage indicators, and landform associations characterized based on field measurements. Depth to permafrost is locally variable, so this is considered an average for the polygon.

- **Permafrost Ice Content** – e.g., ice-poor (p), ice-moderate (m), ice-rich (r)

  This attribute refers to the relative volumetric ice content of permafrost, interpreted based on field observations of ground ice in different hydrogeomorphic settings; Kryotek's previous permafrost-related drilling and geophysical survey experience in the region; and recent research in this unglaciated region (e.g., Bond and Lipovsky, 2011; McKillop et al., 2013). Project-specific permafrost mapping and characterization undertaken concurrently by TT-EBA along the access road centreline (2016b) and within the mine area (2016c), which references geotechnical/hydrogeological drilling results from the mine area (Lorax Environmental Services Ltd., 2016), also informed ice content interpretation. This classification is not intended to apply any particular volumetric ice content (%); rather, its purpose is to distinguish areas relatively and according to distinct forms of ground ice. With approximate correlations with TT-EBA's (2016b,c) ice content classification identified in parentheses, ice-poor permafrost typically contains no visible ice (~Fn: ice not visible); ice-moderate permafrost typically contains segregated ice in the form of seams and lenses, but rarely any large ground ice bodies (~Fv: visible excess ice); and ice-rich permafrost typically contains large accumulations of segregated ice in the form of ice wedges and other massive bodies, in addition to seams and lenses (~Fi: very ice-rich)[4]. Localized differences between TT-EBA's (2016b,c) and PECG's (this study) interpretations of permafrost distribution and ice content have been reviewed, are generally minor, and are expected in light of limited ground data.

- **Slope Class** – e.g., 2 (gentle, 6-26%), 4 (moderately steep, 50-70%)

  This attribute refers to the dominant, typically average, range in slope steepness. Slope class was visually assigned based on a five-level raster model of slope class generated from the LiDAR-derived elevation data.

[4] The terms ice-poor, ice-moderate and ice-rich, as defined here, are used throughout the report.

Additional point and linear features too small to be mapped as polygons were identified using on-site symbols. Examples include thermokarst ponds (point) and slope failures (line). Whether or not a polygon encompassing an on-site symbol that represents a geomorphological process (e.g., gully erosion) was attributed as such (e.g., -V) depended on the proportional area of the polygon that is affected by the process. For example, a single gully did not necessarily require inclusion of the gullying process in the polygon label. Point or linear features occurring entirely within anthropogenic disturbance polygons were not mapped.

3.3.2 Terrain Stability Classification

Terrain stability mapping in British Columbia typically involves the assignment of a single terrain stability class to each polygon, in order to provide a relative ranking of the likelihood of a landslide occurring after timber harvesting or road construction (BC Ministry of Forests, 1999). This protocol yields a map depicting terrain stability classes after a disturbance – for example, following road construction – but does not readily distinguish the stability of polygons in the absence of disturbance. The hazards posed by a slope above and unaffected by road construction (i.e., potential effects of the environment on the Project), for example, could be inaccurately represented on a conventional terrain stability map. Particularly in this landscape of discontinuous permafrost, some of which is ice-rich and prone to thermokarst activity, it is important to differentiate terrain stability classes in both the existing and disturbed condition. As such, both existing and disturbed terrain stability classes were assigned to each polygon to enable mine facility and road design engineers to accurately evaluate risks posed locally and by hazards upslope or downslope of the proposed infrastructure.

The ‘existing terrain stability’ class represents current conditions, in the absence of any project-related activity; the ‘disturbed terrain stability’ class represents conditions following disturbance to ground conditions from road/facility construction without mitigation (**Table 3-2**). As a conservative base case, the disturbed stability class assumes typical cut-and-fill road construction without any measures to mitigate potential instability on steep slopes or from disturbance to permafrost with excess ice. Stripping or compaction of organics, and only regular surface water management, would be typical disturbances. Full details for both the existing and disturbed terrain stability classes are provided on the mapping of terrain stability and hazards (Map 2) and its cover page of code definitions (**Appendix B**).

Further modification of conventional terrain stability classes used in British Columbia was necessary to accommodate the potential for instability related to thermokarst processes. If overlooked in the siting and design of project infrastructure, thermokarst could significantly increase infrastructure (e.g., road) maintenance costs and potentially affect worker safety through its potential influence on ground stability (e.g., road surface grade) (McGregor et al., 2010). Therefore, the assignment of terrain stability classes additionally considers the presence or absence of permafrost (as shown on the cover page of the mapping of terrain stability and hazards (Map 2) in **Appendix B**).

Table 3-2. Terrain stability classification system developed for the Coffee Gold Project

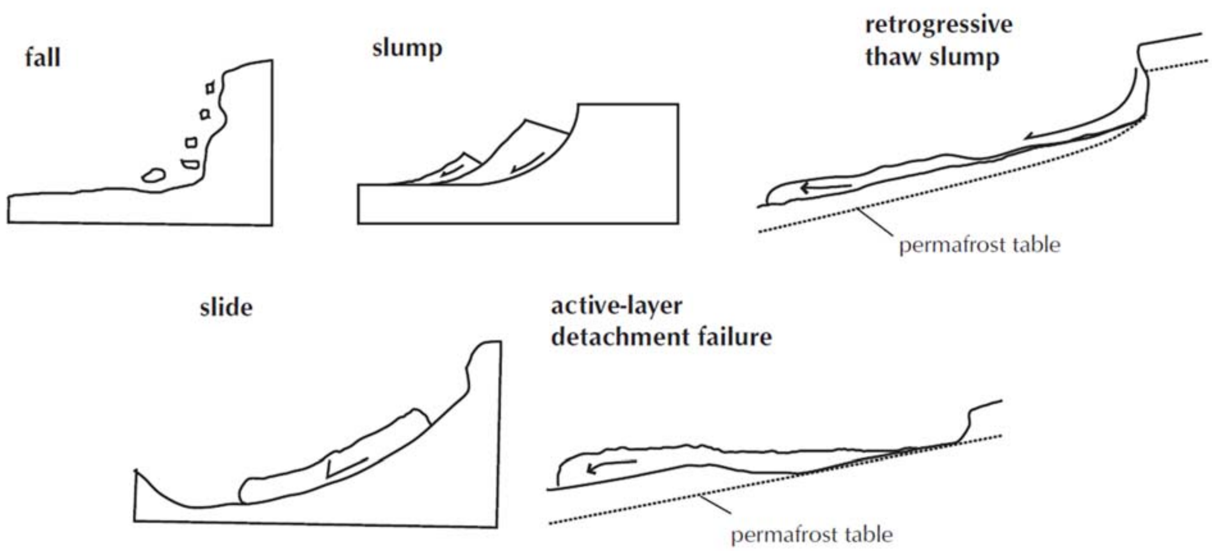
Symbol	Class	Condition	Interpretation		Common terrain characteristics	
			Existing	Disturbed	Existing	Disturbed
I	stable	permafrost	No significant stability problems.		Planar to gently sloping bedrock and weathered bedrock; active fluvial units.	Planar to gently sloping bedrock, weathered bedrock and active fluvial units with deep, ice-poor permafrost.
		no permafrost			Planar to low sloping bedrock and weathered bedrock; active fluvial units.	
II	generally stable	permafrost	Very low likelihood of slope instability.	Very low likelihood of slope instability; no thermokarst subsidence or erosion expected.	Colluvial mantles on gentle slopes; gently sloping colluvial complexes; gently sloping fluvial units; organic deposits; moderately steep bedrock and weathered bedrock.	Colluvial mantles on gentle slopes with deep, ice-poor permafrost; gently to moderately sloping fluvial units with deep, ice-poor permafrost.
		no permafrost	Very low likelihood of slope instability.		Gently to moderately sloping colluvial mantles and fluvial units; moderately steep bedrock and weathered bedrock.	
III	generally stable with minor potential for instability	permafrost	Low to moderate likelihood of slope instability.	Low to moderate likelihood of slope instability and/or minor thermokarst subsidence or erosion possible.	Poorly drained colluvial mantles on moderate slopes; moderately sloping colluvial complexes; imperfectly drained colluvial mantles on moderately steep slopes; ice-poor to ice-moderate permafrost.	Poorly drained colluvial mantles on gentle slopes; imperfectly drained colluvial mantles on moderate slopes; ice-poor to ice-moderate permafrost.
		no permafrost	Low to moderate likelihood of slope instability.		Colluvial mantles on moderately steep slopes.	
IV	potentially unstable	permafrost	Expected to contain areas with a high likelihood of slope instability.	Expected to contain areas with a high likelihood of slope instability and/or moderate thermokarst subsidence or erosion.	Poorly drained colluvial mantles on moderately steep slopes; moderately steep colluvial complexes.	Any surficial unit thicker than a veneer with ice-moderate permafrost; poorly drained colluvial mantles on moderate slopes; imperfectly drained colluvial mantles on moderately steep slopes.
		no permafrost	Expected to contain areas with a high likelihood of slope instability.		Colluvial units on moderately steep to steep slopes.	
V	unstable	permafrost	Expected to contain areas with a very high likelihood of slope instability and/or thermokarst; may or may not exhibit evidence of previous slope failure and/or thermokarst.	Expected to contain areas with a very high likelihood of slope instability and/or major thermokarst subsidence or thermal erosion; typically exhibits evidence of previous slope failure and/or thermokarst.	Any unit with evidence of slope failure and/or thermokarst subsidence or thermal erosion.	Any unit with evidence of slope failure or ice-rich permafrost; poorly drained colluvial mantles on moderately steep slopes.
		no permafrost	Expected to contain areas with a very high likelihood of slope instability; typically exhibits evidence of previous slope failure.		Any unit with evidence of slope failure; typically occur on moderately steep to steep slopes.	

3.4 Hazard Identification

Hazards posed by mass movements and fluvial processes were identified and characterized in this study.

3.4.1 Slope Failure and Thermokarst

The type and distribution of mass movement (slope failure) and thermokarst hazards within the study area were identified by assessing geomorphological process codes (polygon label), on-site symbols (point or linear features) and terrain characteristics (Map 2, **Appendix X**; see Section 4.2 for hazard process descriptions). Mass movements involve the downslope transport of material, such as soil and/or rock, under the influence of gravity. Mass movements may or may not be associated with water, snow or ice[5]. Within the study area, mass movements occur through a variety of processes in addition to landsliding. Landslide terminology used in this report follows the standards defined by Hungr et al. (2014), a recent update to the classic classifications established by Varnes (1978) and Cruden and Varnes (1996), which describe the process as well as the type of material involved in the mass movement. Where two modes of failure contribute to movement, terminology was assigned based on the apparent dominant mode. The landslide terms applied in this report are illustrated schematically in **Figure 3-2**.



Note: Excludes rock creep, which is generally considered separately from landslides. Retrogressive thaw slump also known as retrogressive thaw flow.

Figure 3-2. Schematic of landslide types in the study area (adapted from Huscroft et al., 2004)

[5] Snow avalanches were not included in this description of mass movement processes because there is no mappable evidence (e.g., vegetation patterns) of their occurrence within the study area; small loose snow or slab avalanches may occur on moderate to steep slopes in wind-loaded alpine areas.

Where more accurate representation of the role of permafrost was required, refinements to standardized landslide terminology were made based on the *Multi-language glossary of permafrost and related ground-ice terms* (van Everdingen, 2005), which is consistent with the approach applied in the regional characterization of landslides along Yukon's Alaska Highway corridor (Huscroft et al., 2004). For example, permafrost environments also uniquely include "active layer detachments" and "retrogressive thaw slumps" (also known as retrogressive thaw flows) (**Figure 3-2**), each of which is described below. Also mapped and described below as part of this assessment are rock creep (*cf*. Blais-Stevens, 2010), gullying, thermokarst subsidence, thermokarst gullying, slopewash, solifluction and pingos.

Each polygon was broadly categorized according to its dominant hazard potential in order to clearly depict the nature of hazard governing the terrain stability class of each polygon. One of three categories was used: (i) slope failure potential is dominant, (ii) thermokarst potential is dominant, or (iii) slope failure and thermokarst potential are co-dominant. A hatch pattern was overlaid to indicate the 'applicable hazard category' in mapping of terrain stability and hazards (Map 2, **Appendix B**). This designation does not indicate whether or not the polygon exhibits any evidence of such hazards; the geomorphological process codes or on-site symbols serve that purpose. The 'slope failure potential is dominant' category is the default, thus all units that do not pose a thermokarst hazard (e.g., gentle, ice-poor colluvium and even flat, permafrost-free fluvial plains) are represented by this category. A terrain unit generally must exhibit ice-moderate or ice-rich permafrost to be considered for the 'thermokarst potential is dominant' category. Polygons with ice-moderate or ice-rich permafrost and slope classes of 3 or higher are candidates for the 'slope failure and thermokarst potential are co-dominant' category.

A generalized characterization was made of the nature of hazard posed by different geomorphological processes – in terms of likelihood, magnitude and project considerations – based on review of historical aerial photography in conjunction with field observations, in addition to professional experience in the region.

3.4.2 Meander Migration

Creek and river meanders that migrate through progressive bank erosion may pose a hazard to adjacent sections of the proposed access road (see Section 5.4 for hazard details). A systematic review was completed using the 2015, high-resolution aerial photography and LiDAR-derived elevation data to identify areas subject to erosion. Road segments proposed in close proximity to the outer bank of a meander, especially if separated by alluvial or fine-textured colluvial soils, or where meandering watercourses are crossed, were identified as sites of meander migration hazard.

A more detailed, time-transgressive assessment of meander migration hazard was completed for the proposed crossings of Indian, Stewart and Yukon rivers. These locations will have important project infrastructure, and minor shifts in the river thalwegs can trigger considerable erosion of unconsolidated banks. Historical river bank locations were digitized from georeferenced, historical aerial photographs and 2015 orthophotography, and then compared to estimate bank erosion trajectories and rates.

3.4.3 Icing

Icing, which refers to wintertime accumulation of aufeis, may pose a hazard and increase road maintenance requirements at certain stream crossings and draws (see Section 5.5 for hazard details). Sites along the proposed access road interpreted to be prone to icing in winter were identified based on consultation with Yukon Highways' staff and Jim Coates (Kryotek) for the government-maintained section of road. These identified sites were used to calibrate interpretations and identify potential icing hazards along the remainder of the proposed road alignment. In general, draws that contain fluvial veneers underlain by permafrost, are densely covered with willows, and are shaded by adjacent valley sides are commonly subject to icing. No attempt was made to estimate the width or thickness of icing at particular road crossings.

3.5 Soil Erosion Potential

Soil erosion potential represents the combined likelihood and magnitude of soil erosion as a result of surface runoff over exposed soils. Knowledge of soil erosion potential in advance of construction facilitates design of erosion and sediment control measures that are commensurate with site-specific risks to project infrastructure and adjacent ecological features (e.g., fish habitat). A five-level classification was developed to rank polygons according to their soil erosion potential (**Table 3-3**), based on the general approach and criteria outlined by BC Ministry of Forests (1999) and the erosion and sedimentation risk mapping completed by PECG (2013) for Casino Mining Corporation's proposed extension to the nearby Freegold Road. In general, soil erosion potential is directly proportional to silt and/or organic content, slope gradient, ground ice content and the severity of pre-existing gullying (mapping of soil erosion potential (Map 3, **Appendix C**).

Table 3-3. Soil erosion potential classification developed for the Coffee Gold Project

Symbol	Class	General criteria	Common terrain characteristics	Management implications
VL	very low	Increasing silt and/or organic content Increasing slope gradient Increasing ground ice content Increasing severity of pre-existing gullying	Bedrock; planar weathered bedrock; planar fluvial deposits without permafrost.	No or only very minor surface erosion within small areas of exposed soil on locally steeply sloping ground (e.g., creek banks); conventional surface runoff management appropriate.
L	low		Gently to moderately sloping weathered bedrock; gently to moderately sloping, permafrost free colluvial mantles; gently to moderately sloping, permafrost-free fluvial deposits.	Expect minor erosion of fine sediments along ditch lines, cut slopes and across disturbed soils; avoid channelling water toward more sensitive downslope units.
M	moderate		Planar to gently sloping organic material; gently to moderately sloping colluvial veneers with shallow or near-surface permafrost; gently sloping colluvial blankets with shallow or near-surface permafrost; moderately steep to steeply sloping, permafrost-free veneers and thin veneers; fluvial deposits with shallow or near-surface permafrost.	Expect moderate erosion when water is channelled down road surfaces or ditches (minor thermal erosion possible in areas of permafrost); plan for preventative and remedial actions in disturbed areas, including measures to minimize concentrated surface runoff in areas of permafrost and to trap sediments.
H	high		Moderately steeply sloping colluvial veneers; moderately to moderately steeply sloping colluvial blankets with shallow to near-surface permafrost; gently sloping colluvial complexes; ridgetop saddles with silt-rich colluvial veneer.	Significant erosion problems are expected when water is channelled onto or over exposed soil on these sites (moderate thermal erosion possible in areas of permafrost), particularly on cut slopes; plan for preventative and remedial actions in disturbed areas, including measures to minimize concentrated surface runoff in areas of permafrost and to trap sediments.
VH	very high		Steeply sloping colluvial mantles with shallow or near-surface permafrost; moderate to steeply sloping colluvial complexes.	Severe surface and gully erosion problems can be created when water is channelled onto or over these sites (major thermal erosion possible in areas of permafrost), particularly on cut slopes; erosion is commonly evident in natural conditions. If area not avoidable, minimize concentrated surface runoff in areas of permafrost, minimize extent and duration of soil exposure, and promptly stabilize soils with salvaged vegetation (e.g., moss) cover or appropriate erosion control measures.

4 Terrain Description

The following sections describe the main terrain units (Section 4.1) and geomorphological processes (Section 4.2) encountered within the study area.

4.1 Terrain Units

Terrain units are defined based on a particular combination of surficial material(s), texture(s), surface expression(s) and geomorphological process(es), as well as drainage class(es), permafrost conditions and slope class. The diversity of terrain characteristics within the study area can be organized into ten terrain units for descriptive (**Table 4-1**) and geostatistical analysis purposes (**Figure 4-1**). Each terrain unit is described below according to its typical distribution, material composition, landform characteristics, permafrost conditions and geomorphological processes, and summarized in table form with standardized photographic perspectives. The descriptions incorporate directly applicable characterizations of corresponding 'landform-soil types' (LSTs) established for the unglaciated Klondike Plateau (McKillop et al., 2013) (**Table 4-1**). Colluvial terrain is subdivided into several distinct units due to significant differences in their composition, stability classification and sensitivity to disturbance. **Table 4-2** identifies standardized textures assigned to distinct colluvial terrain units based on field observations and in accordance with regional surficial geology mapping (Lipovsky and Bond (compilers), 2014).

Table 4-1. Cross-reference between main terrain units within the study area and established 'Landform-Soil Types' (McKillop et al., 2013)

Report Section	Terrain Unit	Corresponding Landform-Soil Type (LST) Number and Name
4.1.1	Bedrock and Weathered Bedrock	LST1: intact and weathered bedrock
4.1.2	Mixed Weathered Bedrock and Colluvium	LST2: mixed weathered bedrock and colluvium
4.1.3	Colluvial Mantles without Permafrost	LST10, LST11 & LST12: clast-rich colluvial blanket, veneer & thin veneer
4.1.4	Colluvial Veneers with Permafrost	LST3 & LST4: loess-rich & landslide-affected colluvial veneer
4.1.5	Colluvial Blankets with Permafrost	LST5: loess-rich colluvial blanket
4.1.6	Colluvial Complexes with Permafrost	LST6: loess-rich colluvial apron
4.1.7	Fluvial Landforms	LST8: fluvial plain
4.1.8	Glaciofluvial Terraces	LST9: glaciofluvial terrace
4.1.9	Organic Terrain	LST7: organic plain
4.1.10	Anthropogenic Disturbances	n/a

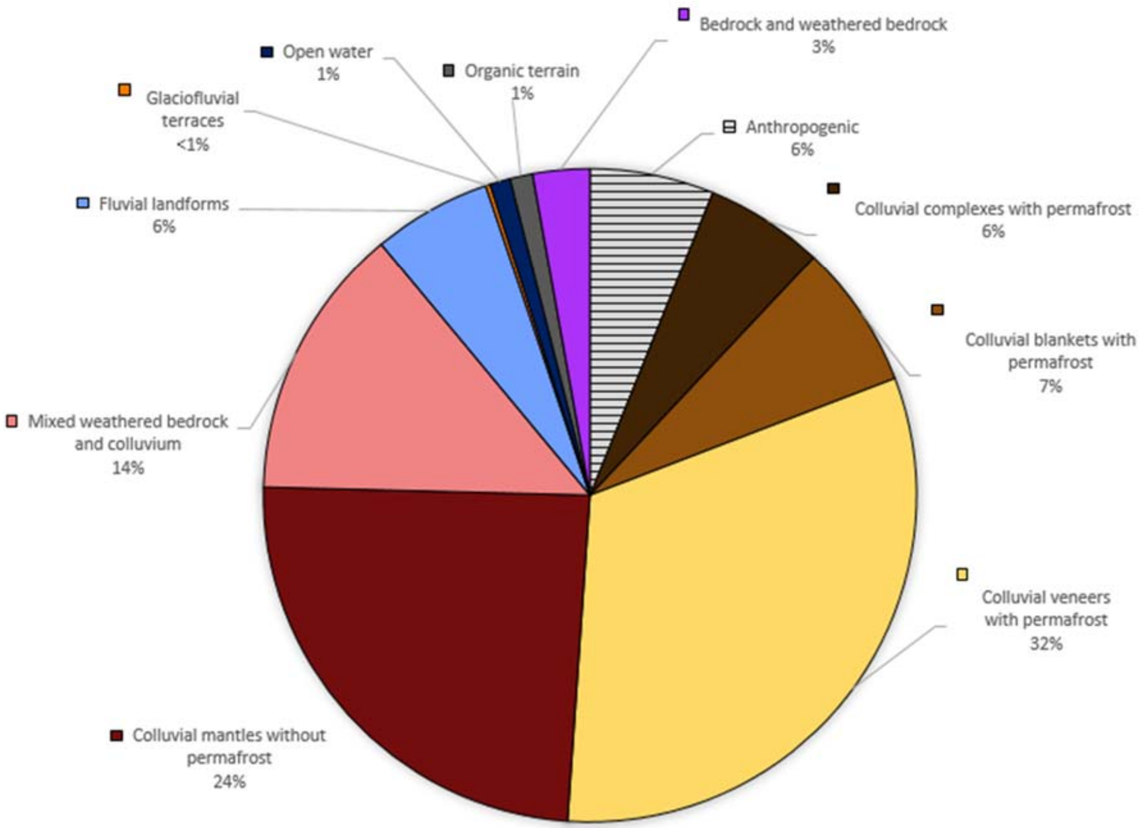


Figure 4-1. Areal proportion (%) of terrain units within the study area

Table 4-2. Standardized textures used for colluvial terrain units

Condition	Typical Texture and Landform
Colluvial mantles without permafrost	zsxCx; zsxCv; zsxCb
Colluvial veneers with permafrost	szxCv
Colluvial blankets with permafrost	sxzCb
Colluvial complexes with permafrost	xszC1a; xszC1b

Note: Lower-case letters preceding the colluvial surficial material (C) represent particular textures (i.e., z: silt; s: sand; x: angular fragments; d: mixed fragments); the lower-case letters that follow represent surface expressions (i.e., x: thin veneer; v: veneer; b: blanket; a: apron). Textural dominance increases from left to right. The replacement of x with d in the texture signifies the suspected incorporation of rounded clasts from an upslope or underlying source of water-transported deposits.

4.1.1 Bedrock and Weathered Bedrock

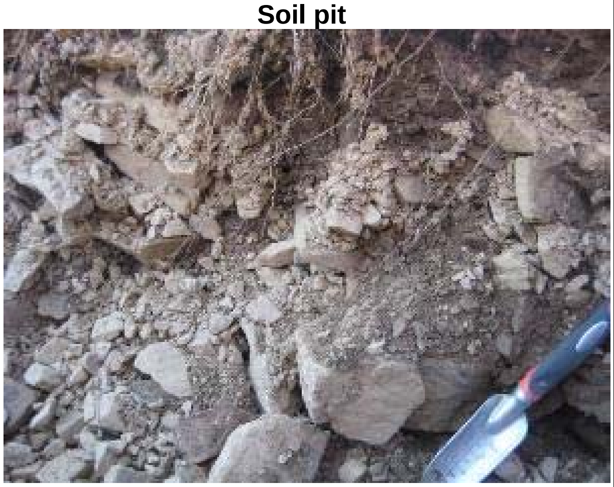
Intact (R) and weathered (D) bedrock is dominant within approximately 3% of the study area (**Figure 4-1**, **Table 4-3**). It is extensive on summits, ridges and spurs throughout the region, and small areas of it occur on isolated hills and over-steepened slope-toe scarps in some valley settings. It typically occupies crest and upper slope positions, with convex slope profiles and variable aspect and steepness.

Table 4-3. Typical characteristics of bedrock and weathered bedrock in the study area[6]

Map example

Oblique aerial view

Soil pit



General distribution	Summits; ridges and spurs; over-steepened valley sides
Common terrain units	zsxDv/Rh Rs/zsxCv-R"bV
Dominant processes	*In-situ* weathering; rockfall; gullying; cryoplanation; nivation
Drainage range	Well to rapid
Dominant slope range	Gentle to steep
Permafrost	Deep and ice-poor on northerly aspects; ice-moderate within saddles
Other characteristics	Tors and outcrop may be present; variable aspect and slopes
Hazard considerations	Localized rockfall; thermokarst subsidence in saddles

The character of landforms and associated surficial materials within this terrain unit depends on local bedrock lithology and micro-topography. Summits and ridges underlain by intrusive (granitic) bedrock, such as within the mine site area, are commonly veneered with angular blocks of felsenmeer and punctuated by tors. Tors commonly occur in clusters, surrounded by a halo of angular, weathered blocks derived from rockfall. The residual soils that accumulate within areas of granitic bedrock tend to be pebbly to sandy

[6] Terrain labels and slope classes used in this and all other summary tables in Section 4.1 defined in Howes and Kenk (1997); drainage classes defined in BC Ministry of Forests and Range and BC Ministry of Environment (2010).

(grus), except where locally overlain or intermixed with loess. In contrast, areas underlain by finer-grained schists and gneisses are commonly featureless and rounded. These rocks are more susceptible to physical and chemical weathering, thus local relief tends to be lower. Residual soils that accumulate over metamorphic rocks tend to be sandy silt with traces of clay.

Permafrost may or may not be present within this terrain unit. Where present, the permafrost table is generally deep (>1 m), ice-poor and within intact or weathered bedrock, having little influence on ground stability. Exceptions occur in isolated fractures and hollows within the bedrock surface, and in gentle saddles along broad ridges, where enough loess has been preserved to maintain shallow permafrost that may contain segregated ice. Periglacial processes such as cryoturbation, cryoplanation and nivation are widespread in this terrain unit and have not been explicitly mapped. Soil drainage ranges from rapid to very rapid on bedrock outcrops, to well to poorly drained in silt-enriched hollows amongst weathered bedrock.

4.1.2 Mixed Weathered Bedrock and Colluvium

Mixed weathered bedrock (D) and colluvium (C) is dominant within approximately 14% of the study area (**Figure 4-1, Table 4-4**). It is predominant immediately below summit areas, on the shoulders of major ridges, and along rounded, steeper spurs. Most occurrences of this terrain unit are in crest and upper slope positions, with convex slope profiles and variable aspect and steepness.

Gentle slopes of this terrain unit, particularly in areas underlain by granitic bedrock, are commonly punctuated by subdued, bedrock-controlled steps formed by differential erosion. These ‘knickpoints’ may be recognized by conspicuous patches of boulder-sized felsenmeer with a slight slope-break. Over time, material originating from these knickpoints is transported downslope by a combination of soil creep and solifluction, typically forming veneers (<1 m) on underlying bedrock. In areas underlain by metamorphic bedrock, the soils tend to have smaller clasts and a finer-grained matrix, and knickpoints are rare. A jigsaw puzzle-like arrangement of clasts distinguishes *in situ* weathered bedrock from surrounding colluviated material. Silt-rich hollows and colluvial veneers may be susceptible to instability, particularly following wildfire.

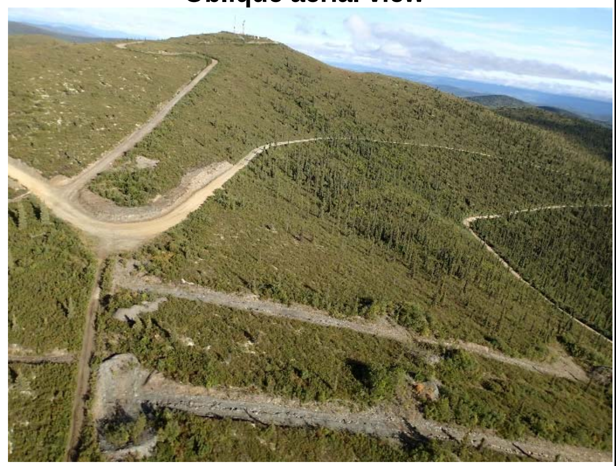
Permafrost, where present, is most common in subalpine and alpine settings and on rounded spurs with northerly aspects, and may be indicated by ponded water at surface. Soils are well drained in areas of felsenmeer to poorly drained in finer grained colluvial soils with shallow, ice-poor permafrost.

Geomorphological processes are rare in permafrost-free occurrences of this terrain unit. Some higher elevation occurrences with deep permafrost exhibit conspicuously irregular micro-topography and patches of lichen-free, angular stones indicative of the process of rock creep. The potential for small active layer detachments is restricted to localized convexities with silty colluvium, most likely following wildfire.

Table 4-4. Typical characteristics of mixed weathered bedrock and colluvium in the study area

Map example

Oblique aerial view



Soil pit

General distribution	Heavily weathered ridgetops; ridge and spur shoulders
Common terrain units	zsxDv/szxCv szxCv/zsxDv-Fg
Dominant processes	*In-situ* weathering; soil/rock creep
Drainage range	Imperfect to well
Dominant slope range	Gentle to moderate
Permafrost	Deep and ice-poor where dominantly D; shallow where dominantly C
Other characteristics	Smooth convex slopes; scrub vegetation; may contain knickpoints
Hazard considerations	Soil/rock creep; active layer detachments possible where silty colluvium is dominant

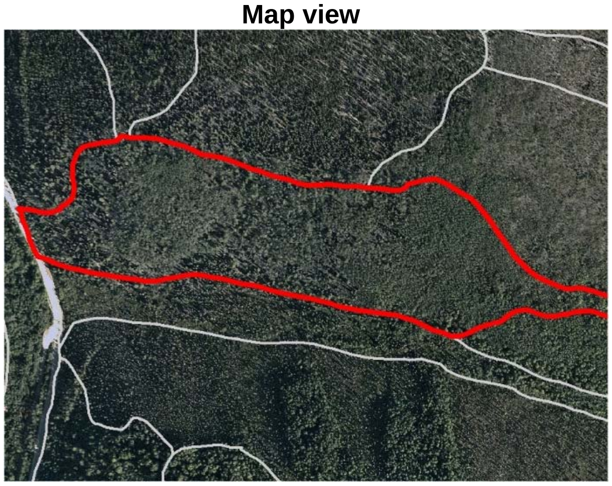
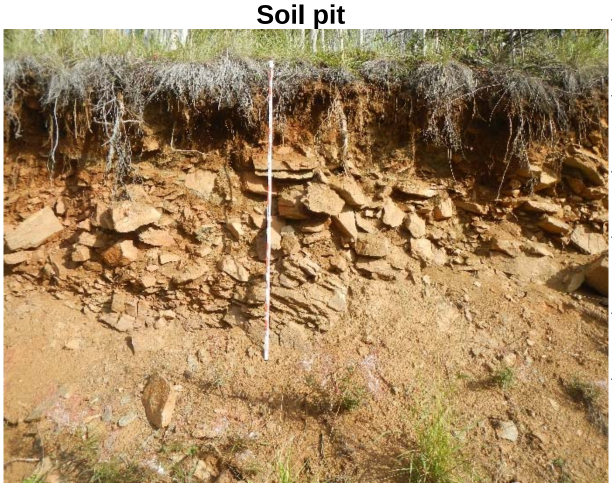
4.1.3 Colluvial Mantles without Permafrost

Colluvial mantles without permafrost are the second most common terrain unit, dominant within about 24% of the study area (**Figure 4-1, Table 4-5**). This terrain unit is most commonly represented by a colluvial veneer (Cv). Less commonly, it is represented by a thin colluvial veneer (Cx), colluvial blanket (Cb) or colluvial mantle of variable thickness (Cw). It generally occurs in mid slope positions with moderate to steep gradients. This terrain unit can occur on all aspects but is dominantly found on southerly, convex or straight slopes.

Permafrost-free colluvium is typically derived from bedrock and dominated by angular clasts and a sandy to silty-sand matrix. It is locally overlain by a thin veneer of loess (Bond and Lipovsky, 2011). The thickness of colluvium in this terrain unit ranges from <0.2 m (thin colluvial veneer), to <1 m (colluvial veneer), to >1 m (colluvial blanket). Permafrost-free colluvial blankets rarely accumulate more than a few metres of material. Small outcrops are common, particularly at convex slope-breaks and on steep, south-facing slopes mapped as thin colluvial veneers (Cx).

Soil creep and sheetwash are the principal mechanisms transporting material downslope in this terrain unit and locally impart a crude stratification, although rockfall and debris slides also have rare occurrences in steep or gullied terrain. Soils are generally moderately well to rapidly drained.

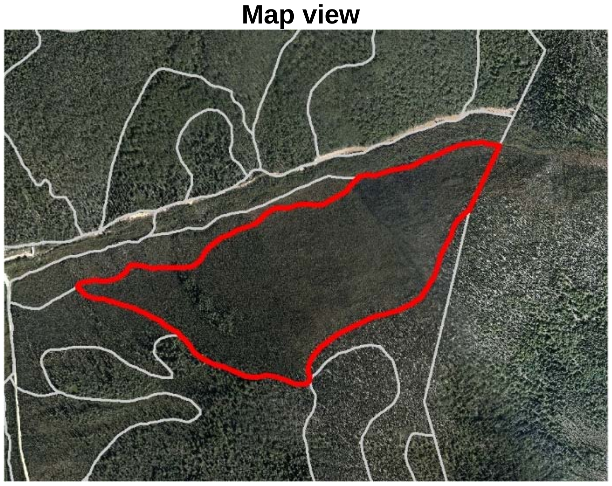
Table 4-5. Typical characteristics of colluvial mantles without permafrost in the study area

<table>
<tr><td>Map view
</td><td colspan="2">Oblique aerial view
</td></tr>
<tr><td rowspan="8">Soil pit
</td><td>General distribution</td><td>Slopes with southerly aspects</td></tr>
<tr><td>Common terrain units</td><td>zsxCx; zsxCv; zsxCb; zsxCw-V</td></tr>
<tr><td>Dominant processes</td><td>Soil creep</td></tr>
<tr><td>Drainage range</td><td>Imperfect to rapid</td></tr>
<tr><td>Dominant slope range</td><td>Gentle to moderately steep</td></tr>
<tr><td>Permafrost</td><td>n/a</td></tr>
<tr><td>Other characteristics</td><td>Typically convex slopes; dominated by deciduous or mixed forest</td></tr>
<tr><td>Hazard considerations</td><td>Soil creep; gullying</td></tr>
</table>

4.1.4 Colluvial Veneers with Permafrost

Colluvial veneers (Cv) with permafrost are the most extensive terrain unit, dominant within about 32% of the study area (**Figure 4-1, Table 4-6**). They most commonly occur on gentle to steep slopes with convex upper-slope or straight mid-slope positions. This terrain unit occurs on slopes with all aspects, although it is dominantly on northerly aspects.

Table 4-6. Typical characteristics of colluvial veneers with permafrost in the study area

<table>
<tr><td>Map view
</td><td colspan="2">Oblique aerial view
</td></tr>
<tr><td rowspan="8">Soil pit
</td><td>General distribution</td><td>Upper and mid-slopes with northerly aspects</td></tr>
<tr><td>Common terrain units</td><td>szxCv
szxCv-SX”f</td></tr>
<tr><td>Dominant processes</td><td>Active layer detachments; solifluction; slopewash; cryoturbation</td></tr>
<tr><td>Drainage range</td><td>Imperfect to poor</td></tr>
<tr><td>Dominant slope range</td><td>Gentle to moderately steep</td></tr>
<tr><td>Permafrost</td><td>Typically ice-poor and shallow</td></tr>
<tr><td>Other characteristics</td><td>Convex to straight slopes; dominantly stunted black spruce</td></tr>
<tr><td>Hazard considerations</td><td>Active layer detachments; slumping; slope wash; soil creep</td></tr>
</table>

The colluvium in this terrain unit is generally less than one metre thick (Cv), may contain isolated patches of weathered bedrock (Cw), and follows underlying topography. It is typically derived from detachment and entrainment of angular, weathered bedrock clasts, except below some terraces where it may contain rounded clasts of fluvial or glaciofluvial origin. Silt derived from loess is intermixed with the bedrock-derived material, with a decreasing concentration with depth (**Table 4-2**).

Permafrost within this terrain unit contributes to the higher silt content in comparison to permafrost-free colluvial veneers (Section 4.1.3) by inhibiting its erosion from regular surface runoff processes. Permafrost is typically shallow (0.4 to 1 m), but can be near-surface (<0.4 m) on poorly drained slopes with northerly aspects, or deep (>1 m) on convex rolls and spurs. Permafrost is generally ice-poor, containing little to no visible (segregated) ice, but may be ice-moderate and contain minor seams and lenses of ground ice on poorly drained slopes with northerly aspects. Soils are typically imperfectly to poorly drained, depending on the silt content and depth to permafrost.

A number of permafrost and periglacial processes commonly occur in association with this terrain unit, as described below in Section 4.2: active layer detachments, slumps, rock creep, slopewash and solifluction. Although active layer detachments can occur within all colluvial terrain units with permafrost, they are most common in colluvial veneers on moderate to moderately steep slopes.

4.1.5 Colluvial Blankets with Permafrost

Colluvial blankets (Cb) with permafrost are dominant within about 7% of the study area (**Figure 4-1, Table 4-7**). They typically occur in concavities in mid- to lower-slope positions. Although this terrain unit occurs on all aspects, it is most common on gentle to moderate slopes with northerly aspects.

Colluvial blankets with have a higher silt content than colluvial veneers with permafrost because they generally form in concavities that trap silt (**Table 4-2**). Blankets generally follow underlying bedrock topography and may be in the order of 10 m deep in concavities on gentle slopes. This terrain unit has a distinctly smooth surface expression, with no abrupt breaks-in-slope or gullies. Upper soil horizons are commonly dominated by loess-derived silt; the proportion of silt intermixed with bedrock-derived colluvium decreases with depth.

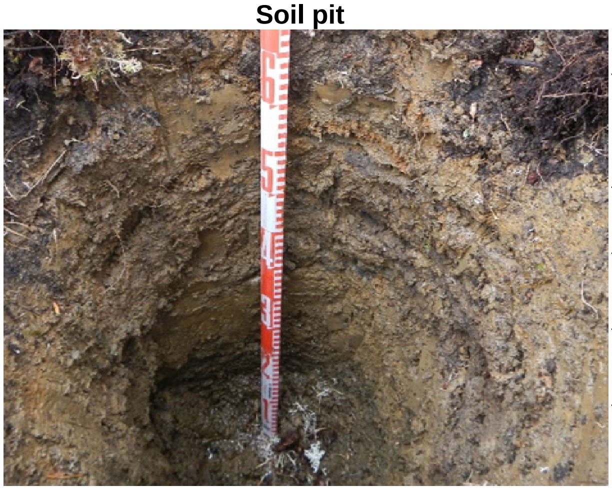
Permafrost within this terrain unit is generally shallow (0.4 to 1 m) or near-surface (<0.4 m). It typically exhibits moderate ice content in the form of pore ice and segregated seams and lenses, particularly in the siltier upper horizons. Soils are typically imperfectly to poorly drained, in some cases with discrete differences due to the presence of slopewash runnels, also known as water tracks. Dwarf willows growing along the runnels have a different appearance from the dwarf birches dominating the shrub cover, giving the slopes a distinct lineated, flow-like pattern. Active layer detachments occur, albeit less commonly than on steeper veneers.

Table 4-7. Typical characteristics of colluvial blankets with permafrost in the study area

Map view

Oblique aerial view

Soil pit



General distribution	Mid to lower slopes and within concavities
Common terrain units	sxzCb sxzCb-S
Dominant processes	Slow downslope creep; thermokarst subsidence; solifluction; slopewash
Drainage range	Imperfect to poor
Dominant slope range	Gentle to moderate
Permafrost	Typically ice-moderate and shallow
Other characteristics	Smooth surface; occurs on concave slopes; dominated by stunted spruce
Hazard considerations	Thermokarst subsidence; active layer detachments

4.1.6 Colluvial Complexes with Permafrost

Colluvial complexes (C1) occur mainly as blankets (b) and aprons (a), and represent an important, project-specific classification of terrain that occupies approximately 6% of the study area (**Figure 4-1, Table 4-8**). This terrain unit has a straight or concave profile and occurs on all aspects. Aprons and blankets predominantly occur in toe slope positions and lower-slope hollows, respectively. Commonly demarcating the upper limits of an apron is a conspicuous concave slope-break that typically coincides with an abrupt downslope reduction in soil drainage. In cross-section, aprons form a wedge, with the thickest portion in the valley bottom and thinner material up-slope, while blankets generally conform to the underlying topography.

This terrain unit is well described by Huscroft (2002) as “colluvial eolian complexes”, owing to their complex sedimentology and origin, and represents the main occurrence of Klondike ‘muck’ (Tyrrell, 1917; Fraser and Burn, 1997). It is an aggradational landform, built up over time through the delivery of sediments from upslope by minor incremental and episodic colluvial and fluvial additions. These aprons consist of primary and redeposited loess, fluvial and slopewash sediments, bedrock-derived colluvium and organic material. Many, if not all, colluvial complexes are still active based on observation of the recent deposition of sediment and woody debris from upper valley sides.

The sedimentology of this terrain unit is highly variable, depending primarily on steepness and upslope drainage area. The slope of the aprons is an indicator of their internal composition. In general, colluvial complexes with gentler slopes in the lower portions of larger basins have higher silt and organic contents than slightly steeper ones in narrow headwater tributaries, where inclusions of mass movement deposits may be encountered (**Table 4-2**).

Aggradation of permafrost within the colluvial complexes generally kept pace with the deposition and accumulation of loess during the late Pleistocene (Fraser, 1995). A thick cover of mosses with high insulating value has enabled the permafrost to persist near-surface, even during the relatively warm Holocene. Surface organics in this terrain unit are relatively thick and commonly extend beneath the permafrost table. Soil drainage is imperfect to very poor, due to shallow or near-surface permafrost, loess-rich soil and gentle gradients.

This terrain unit typically contains ice-rich permafrost with ground ice in the form of excess pore ice, segregated seams and lenses, and massive bodies (Bond and Lipovsky, 2011). One such body of ground ice was observed during field reconnaissance in a recent placer mining excavation in a tributary to Maisy May Creek (**Photo 4-1**). Gentle colluvial complex aprons may have ice-rich permafrost up to 30 m thick, such as observed in boreholes within 20 km of the proposed mine area (J. Coates, Kryotek, 2015). Thermokarst activity occurs through both natural and anthropogenic disturbance in some of these ice-rich complexes.

Photo 4-1. Massive ice exposed by recent placer mining in a tributary to Maisy May Creek (2 m-long stadia rod for scale)

Table 4-8. Typical characteristics of colluvial complexes in the study area

Map view	**Oblique aerial view**
	

Soil pit

General distribution	Toe-slope position on all aspects
Common terrain units	xszC1a-Xt xszC1b
Dominant processes	Thermokarst subsidence and thermal erosion
Drainage range	Imperfect to very poor
Dominant slope range	Gentle to moderate
Permafrost	Typically near surface and ice-rich
Other characteristics	Dominated by stunted spruce; contain Klondike 'muck'
Hazard considerations	Thermokarst subsidence; slumping if debuttressed

4.1.7 Fluvial Landforms

Fluvial landforms, including channels and floodplains (FAp or Fp), terraces (Ft) and fans (Ff), occupy approximately 6% of the study area (**Figure 4-1**, **Table 4-9**). The characteristics of this terrain unit transition from headwater reaches to main branches. In headwater reaches within V-shaped valleys (i.e., first- to second-order streams), fluvial sands and subangular to subrounded clasts commonly veneer colluvial blankets. Along streams of intermediate size (i.e., second- to third-order streams), subrounded to rounded gravel forms the bed of the meandering channel, and banks may include sand and silt deposited during flood events. Floodplains are narrow and discontinuous. Along the largest meandering watercourses (i.e., third to fourth-order streams), bed material consists of rounded to well-rounded gravel and sand, and bank exposures indicate that the wide, continuous floodplains are composed of sand, silt and locally interbedded organics. Organic deposits are commonly associated with broad floodplains alongside Yukon River and its major tributaries.

Fluvial terraces, commonly perched on bedrock terraces adjacent to some of the larger tributaries such as Indian River, Barker Creek and Coffee Creek, are a testament to the marked incision that occurred during the Pleistocene (Bond and Lipovsky, 2011). Many of these terraces are blanketed in loess and colluvium, making their recognition in the field challenging. However, the sharp break-in-slope formed by the terrace scarp is usually recognizable in aerial photographs and LiDAR-derived elevation models. Years of modification and downslope transport have resulted in a modification from planar to gentle slopes. The stream-deposited sediment in these fluvial terraces is generally a mixture of sand and rounded gravel.

Fluvial fans exist at the mouths of moderate to large tributaries, where they are less confined and channel gradients decrease abruptly. Where they exhibit steeper gradients than regular fluvial plains and terraces, they contain coarser-grained sand and gravel and less silt. Clasts may be subangular at the apices of the fans of small, steep drainages, due to the relatively short transport distance and duration. Some low-gradient fans exhibit similarities to the silt-dominated colluvial complexes describe above (Section 4.1.6).

Plains typically exhibit negligible slope with variable or no aspect, except along the bottoms of headwater tributaries with gentle to moderate slopes. The Stewart and Yukon rivers have the widest and most continuous fluvial plains within the region, but narrower, discontinuous fluvial plains also occur in association with its tributaries. In general, the width and continuity of fluvial plains increases proportionally with stream order (Strahler, 1952).

Most fluvial environments are subject to meander migration through progressive bank erosion or avulsion. Numerous oxbows alongside meandering streams indicate periods of instability; some enlarge through thermokarst processes. Areas of the floodplain farther from the active channel may be sufficiently stable that organic material can accumulate at the surface. Unless buried by flood sediments, these organics thicken and may promote the growth of underlying permafrost.

The depth to permafrost varies spatially and temporally within this terrain unit as a function of organic matter thickness and proximity to permanently flowing streams. Permafrost is generally absent or deep in frequently flooded sites, because an appreciable organic layer is unable to accumulate in areas prone to erosion and sedimentation. Sites with an intermediate flooding regime typically have no permafrost, or deep permafrost below the rooting zone of riparian vegetation. Stable terraces accumulate enough organics, which act as an insulator, that permafrost commonly aggrades (Viereck, 1973; Zoltai and Pettapiece, 1973).

Soils within this terrain unit are well drained in areas of active fluvial processes to very poorly drained in oxbows and areas of shallow or near-surface permafrost. An abrupt change in vegetation from a tall, dense canopy of trees to stunted or no trees commonly signifies the edge of shallow permafrost.

Table 4-9. Typical characteristics of fluvial landforms in the study area

<table>
<tr><th>Map view
</th><th colspan="2">Oblique aerial view
</th></tr>
<tr><td rowspan="8">Soil pit
</td><td>General distribution</td><td>Valley bottoms; elevated terraces</td></tr>
<tr><td>Common terrain units</td><td>zsgFAp-M
zsgFt</td></tr>
<tr><td>Dominant processes</td><td>Thermokarst subsidence; meandering</td></tr>
<tr><td>Drainage range</td><td>Well to very poor</td></tr>
<tr><td>Dominant slope range</td><td>Planar to gentle</td></tr>
<tr><td>Permafrost</td><td>Presence, ice content and depth vary depending on location</td></tr>
<tr><td>Other characteristics</td><td>May be interbedded with organic deposits on inactive floodplains</td></tr>
<tr><td>Hazard considerations</td><td>Thermokarst subsidence; meander migration</td></tr>
</table>

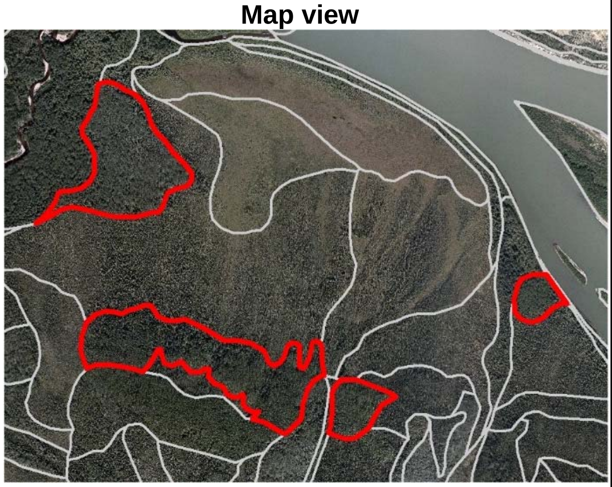
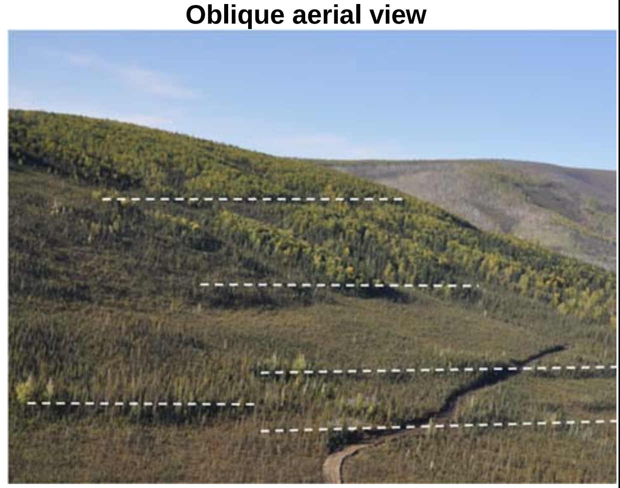
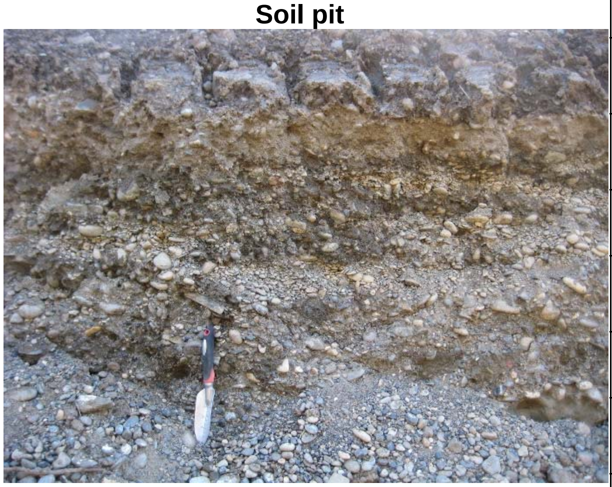
4.1.8 Glaciofluvial Terraces

Glaciofluvial terraces (FGt) are rare within the study area, representing less than 1% (**Figure 4-1**, **Table 4-10**). They only occur above the modern Yukon River, which was filled to varying elevations with a braided meltwater channel through most of the Pleistocene glaciations. Glaciofluvial terraces are distinguished from fluvial terraces based on their landscape position, thickness and the inclusion of well rounded cobbles with lithologies foreign to the local watershed.

Glaciofluvial terraces can be identified both in aerial photographs and during helicopter fly-overs. Glaciofluvial sand and gravel overlies some of the rock benches alongside the modern Yukon River, which formed in response to its flow reversal (Tempelman-Kluit, 1980; Jackson et al., 2008). Colluviation from upslope areas and along the terrace scarp has made the terrace forms almost unrecognizable (oblique aerial view in **Table 4-10**). The subtle slope-break and linearity in vegetation patterns are the key diagnostic characteristics.

Broader glaciofluvial terraces parallel the Yukon River at lower elevations. The Coffee Creek airstrip is built on a terrace less than 10 m above the modern river level. Its coarse sand and gravel base is overlain by a discontinuous veneer of fine-grained flood deposits and loess. Although glaciofluvial terraces tend to be well drained, permafrost was encountered during gravel extraction at a depth of about 5 m.

Table 4-10. Typical characteristics of glaciofluvial terraces in the study area

<table>
<tr><th>Map view</th><th colspan="2">Oblique aerial view</th></tr>
<tr><td></td><td colspan="2"></td></tr>
<tr><td rowspan="8">Soil pit
</td><td>General distribution</td><td>Elevated benches above the Yukon River</td></tr>
<tr><td>Common terrain units</td><td>zsgFGt</td></tr>
<tr><td>Dominant processes</td><td>Gullying</td></tr>
<tr><td>Drainage range</td><td>Moderate to well</td></tr>
<tr><td>Dominant slope range</td><td>Planar to gentle</td></tr>
<tr><td>Permafrost</td><td>Deep and ice-poor</td></tr>
<tr><td>Other characteristics</td><td>Typically contain rounded clasts of foreign lithology</td></tr>
<tr><td>Hazard considerations</td><td>Gully processes along terrace scarps</td></tr>
</table>

4.1.9 Organic Terrain

Organic terrain, defined by its flat surface and infilling of shallow depressions with organic material (mostly peat moss), occupies only about 1% of the study area (**Figure 4-1**, **Table 4-11**). It exhibits different thicknesses – veneer (<1 m; Ov), blanket (>1 m; Ob) and plain (variable; Op) – depending on micro-topography, drainage and local disturbance history. Organic terrain is most commonly mapped on inactive portions of floodplains and terraces alongside the major watercourses. In this landscape, nearly all surfaces have some accumulation of organics; however, thin veneers (x) were not mapped.

Table 4-11. Typical characteristics of organic terrain in the study area

<table>
<tr><td>Map view
</td><td colspan="2">Oblique aerial view
</td></tr>
<tr><td rowspan="8">Soil pit
</td><td>General distribution</td><td>Floodplains and valley bottoms</td></tr>
<tr><td>Common terrain units</td><td>eOp-Xt</td></tr>
<tr><td>Dominant processes</td><td>Thermokarst subsidence; inundation</td></tr>
<tr><td>Drainage</td><td>Poor to very poor</td></tr>
<tr><td>Dominant slope range</td><td>Planar</td></tr>
<tr><td>Permafrost</td><td>Typically shallow and ice-rich</td></tr>
<tr><td>Other characteristics</td><td>Surface water common</td></tr>
<tr><td>Hazard considerations</td><td>Thermokarst subsidence; flooding</td></tr>
</table>

Organic terrain is commonly underlain by fine-grained flood deposits, typically overlying fluvial sand and gravel. The degree of decomposition of organic material within the study area varies, but is dominantly relatively low. Fibric organics are most common, and used as the standard texture (**Table 4-11**).

Permafrost is ubiquitous with organic terrain. It is commonly near-surface (<0.4 m) or shallow (0.4 to 1 m), and ice-rich. Natural and anthropogenic thermokarst subsidence within wetlands indicate massive bodies of ice are likely present. Drainage is poor to very poor throughout organic terrain due to the shallowness of permafrost and topographic position.

4.1.10 Anthropogenic Disturbances

Anthropogenic disturbance from placer mining activity is widespread along the valleys of the larger tributaries, occupying approximately 6% of the study area (**Figure 4-1**, **Table 4-12**). The access road has been proposed along these valleys to avoid disturbing and potentially impacting other, more pristine terrain. The severity of disturbance ranges from the stripping of surface organics to complete excavation (mining) and displacement of surficial materials down to bedrock. Linear disturbances such as roads and minor surface disturbances such as ATV tracks were not discretely mapped.

Alterations to the ground thermal regime in association with placer mining are deliberate and intended to promote thawing of silt-rich shallow permafrost to allow mining of underlying fluvial gravels. The process of placer mining and tailings pile formation so drastically alters the thermal and hydrogeological properties of the materials that permafrost is unlikely to re-establish itself under current climate conditions.

Notwithstanding the widespread removal of permafrost in association with placer mining activity, remnant areas of ground with ice-rich permafrost may occur in some areas, especially underlying sections of valleys that were less severely disturbed. Numerous ponds amongst the placer tailings are generally inferred to be present and controlled by local groundwater, which flows readily through the permeable gravels, but some may be prone to enlargement through thermokarst subsidence and gullying (TT-EBA, 2016b,c).

The unreliability of interpretations of material properties and permafrost conditions within areas of anthropogenic disturbance precludes assignment of terrain stability, hazard or soil erosion potential classes. Field investigation is required to properly assess ground conditions and their implications for road alignment and design. Therefore, such areas have been excluded from interpretive mapping and depicted with a neutral hatch pattern without a label (Maps 1 to 3, **Appendices A** to **C**).

Table 4-12. Typical characteristics of anthropogenic disturbances in the study area

<table>
<tr><td>Map view
</td><td colspan="2">Oblique aerial view
</td></tr>
<tr><td rowspan="8">Soil pit
(n/a due to variability)</td><td>General distribution</td><td>Valley bottoms and terraces</td></tr>
<tr><td>Common terrain units</td><td>A</td></tr>
<tr><td>Dominant processes</td><td>n/a</td></tr>
<tr><td>Drainage</td><td>n/a</td></tr>
<tr><td>Dominant slope range</td><td>n/a</td></tr>
<tr><td>Permafrost</td><td>Typically degraded due to disturbance; deep and potentially ice-rich where it remains</td></tr>
<tr><td>Other characteristics</td><td>Deciduous vegetation</td></tr>
<tr><td>Hazard considerations</td><td>Unpredictability requires site-specific investigation</td></tr>
</table>

4.2 Geomorphological Processes

A variety of geomorphological processes were mapped within the study area, including mass movement, erosional, fluvial and periglacial processes (Howes and Kenk, 1997). Subclasses of these primary processes were distinguished where necessary to more accurately represent different potential hazard characteristics and implications.

4.2.1 Rockfall (-Rb)

Rockfall is the rapid detachment, fall, rolling and bouncing of rock fragments (Hungr et al., 2014). Rockfall occurrences within the study area are restricted to bedrock bluffs (**Photo 4-2**) and steep colluvial slopes with bedrock outcrops. Active rockfall zones are recognized by the presence of an unweathered patch of bedrock bluff upslope and/or a pile of lichen-free rubbly debris at the base of the bluff. Rockfall is typically recurrent and most likely to occur during periods of freeze-thaw (frost shatter) or rapid and prolonged warming (thermal cracking).

Photo 4-2. Recent rockfall on bluff adjacent to proposed road alignment north of Stewart River

4.2.2 Debris Slides (-Rs)

A debris slide is the slow to rapid sliding of a mass of surficial material on a shallow, planar surface parallel with the ground (Hungr et al., 2014). Debris slides are distinguished from the more specific process of active layer detachment, which occurs only on slopes underlain by permafrost. Debris slides within the study area most commonly occur on steep, south-facing slopes at the over-steepened base of valley sides, typically in association with thin colluvial veneers.

4.2.3 Rock Slumps (-Fm)

A rock slump, or rotational slide, is the slow sliding of a mass of weak rock on a cylindrical or other rotational rupture surface that is not structurally controlled (Hungr et al., 2014). Rock slumps within the study area occur on slopes with and without permafrost, showing little relation to aspect or topographic characteristics. Rock slumps tend to occur as discrete, albeit slow, events, and they may advance upslope over time through retrogressive failures. Virtually all mapped examples of rock slumps appear old or dormant, and are likely no longer sensitive to disturbance. Occurring in areas without the potential to affect proposed infrastructure footprints, mapped rock slumps do not represent hazards to the project (as noted below in Section 5.3).

4.2.4 Rock Creep (-Fg)

Rock creep is the slow movement of angular debris under periglacial conditions (Howes and Kenk, 1997). Within the study area, rock creep occurs on the northerly shoulders of summits and ridges in subalpine to alpine settings with mostly ice-poor permafrost. It is recognized by a conspicuously irregular, undulating slope typified by patches of fresh talus amongst intact and weathered bedrock (**Photo 4-3**). Slopes prone to rock creep are likely only slightly sensitive to surface disturbance, due to their skeletal and typically ice-poor composition.

Photo 4-3. Henderson Ridge Road traversing a slope exhibiting rock creep

4.2.5 Gullying (-V)

Gullying is the modification of unconsolidated (surficial material) and consolidated (bedrock) surfaces by various processes such as surface runoff, mass movement and snow avalanching, resulting in the formation of parallel and sub-parallel long, narrow ravines (Howes and Kenk, 1997). The gullying process has been applied to terrain units (polygons) that exhibit such morphology to an extent that distinguishes them from surrounding, more uniform slopes. Gullies occur in all surficial materials and on bedrock slopes, typically elevating the potential for instability. Most gullies are formed through fluvial incision over millennia and, in this semi-arid, unglaciated setting, are not subject to debris flows (except in association with active layer detachments on slopes underlain by permafrost). The most conspicuous gullies are delineated on the maps with line symbols.

4.2.6 Solifluction (-S)

Solifluction is the slow, gravitational downslope movement of saturated, non-frozen overburden across a frozen or otherwise impermeable substrate. More accurately, in this study area, gelifluction is the form of solifluction that has been mapped due to the movement of material within the active layer on the permafrost table. Solifluction occurs most commonly on convex northerly slopes veneered or blanketed in colluvium in subalpine or alpine environments within the study area (**Figure 2-4**). The solifluction lobes that typify this form of mass movement may comprise silty material rich in organics or clast-rich material bound together by ground ice. Solifluction slopes have generally been mapped as having ice-moderate, shallow permafrost.

4.2.7 Active Layer Detachments (-Xf)

An active layer detachment, referred to more generically for mapping purposes by Howes and Kenk (1997) as a thaw flow slide, is a shallow form of debris slide that occurs within the active layer on top of the permafrost table (**Photo 4-4**). Active layer detachments typically occur in response to intense or prolonged rainfall or snowmelt, high air temperatures, or surface disturbances (e.g., wildfire, windthrow, anthropogenic ground alteration). Active layer detachments exhibit widespread coverage throughout the study area, but are restricted to initiation on slopes underlain by permafrost. They initiate on gentle to steep slopes, commonly just above a convex roll much like a snow avalanche. They have runout distances of up to several hundreds of metres and can transport woody vegetation and underlying colluvial material from ridge shoulders to slope-toe aprons. Following their initial occurrence, permafrost exposed on their sliding surface begins to thaw, and the active layer thickens. Continued slides, flows and gullying are common, until active layer thickening ceases. The headscarps of active layer detachments may migrate retrogressively upslope through gradual thawing and sloughing. The paths of former active layer detachments are commonly recognized by the anomalous stripe of deciduous trees (e.g., alder, birch) that colonize above the locally depressed permafrost table.

Terrain units (polygons) that exhibit a history of active layer detachments are assigned this process label (-Xf); discrete failures are also delineated with line symbols. Retrogressive thaw flows, also known as retrogressive thaw slumps (**Figure 3-2**), are commonly initiated by small active layer detachments and have been mapped with line symbols due to their small size within the study area.

Photo 4-4. Active layer detachments on recently burned east valley side of Barker Creek

4.2.8 Thermokarst Subsidence (-Xt)

Thermokarst subsidence is the formation of ground-surface depressions created by the thawing of ice-rich permafrost and associated soil subsidence (Howes and Kenk, 1997). Terrain units (polygons) inferred to have ice-moderate or ice-rich permafrost are generally susceptible to thermokarst, although the form and severity of such thermokarst also depends on material properties, depth to permafrost and the form of ground ice. The melting of massive ice bodies produces the most conspicuous thermokarst depressions, which may or may not contain standing water. Thermokarst occurs naturally, such as in response to windthrow or wildfire, but is accelerated through anthropogenic disturbance to surface organic cover and drainage patterns. Thermokarst subsidence is most common on planar to gentle slopes, but can occur on moderate slopes. Discrete thermokarst subsidence features, whether or not filled with water, are mapped using point symbols.

4.2.9 Thermal Erosion (-Xe)

Thermal erosion is the process of gully formation initiated by heat transfer from water bodies, typically flowing streams, to underlying permafrost. Thermal erosion can also occur due to heat transfer along the shorelines of standing water bodies. Thermokarst gullies are commonly distinguished by anomalously low width-to-depth ratios, indicative of relatively rapid incision into ice-moderate or ice-rich permafrost, and tension cracks along the crests of their side walls. Trees growing along the edges of such gullies gradually tilt inward toward the gully; straight trunks that have not had an opportunity to adjust their growth habitat upward are indicative of relatively rapid gully enlargement (**Photo 4-5**). Retrogressive erosion of thermokarst gullies is common and can lengthen gullies that initiate on over-steepened slope toes by orders of magnitude upslope. Within the study area, thermokarst gullying is most commonly associated with ice-rich colluvial complexes and ice-moderate colluvial blankets. Natural and anthropogenic alterations in surface runoff patterns, especially where surface runoff becomes concentrated, can trigger thermokarst gullying. Significant thermokarst gullies are mapped using line symbols.

Photo 4-5. Thermokarst gully with inward-tilting trees on collapsing sidewalls

4.2.10 Slopewash (-Xs)

Slopewash, sometimes referred to as sheetwash, is the mobilization and redistribution of fine material by water flowing down the surface or within the shallow subsurface of smooth slopes that are typically underlain by permafrost. Slopewash exhibits widespread occurrence in permafrost terrain, but is most prevalent on slopes demarcated by downslope, parallel to sub-parallel runnels also known as water tracks. Such slopes that are distinguishable on the basis of these runnels have been mapped with this process label (-Xs) (**Figure 2-4**). The runnels are readily distinguished by the growth of dwarf willows, which contrast with surrounding dominance of dwarf birch. The concentration of surface runoff in slopewash runnels leads to local depression of the permafrost table, which in some cases can trigger thermokarst gullying. Slopewash runnels require consideration in drainage management strategies along roadways, as their thicker active layer allows seepage to continue well into winter, when icing can occur.

4.2.11 Pingo (-Xn)

Pingo development, in an 'open system' in this study area, is the process by which groundwater discharge (seepage) through permafrost freezes and accumulates at or close to the ground surface, forming an ice-cored and earth-covered mound (**Figure 2-4**). Intact and collapsed pingos, typified by a small pond enclosed by a hummocky rampart, are scattered throughout the study area and the broader Klondike Plateau region. They range in size from only several metres in diameter and less than a metre high, to several tens of metres in diameter and roughly ten metres high. They occur most commonly in the narrow valley bottoms of headwater tributaries infilled with silt-rich colluvium. The conditions that allow pingos to form – a continuous source of groundwater upwelling beneath and through permafrost – are best avoided by road construction. Pingos provide definitive evidence of locally ice-rich permafrost.

4.2.12 Meander Migration (-M or -I)

Much of the existing and proposed access road follows valley bottoms with meandering streams (-M) or irregularly sinuous channels (-I) and crosses the lowermost reaches of headwater drainages. Stream channels adjust their planform geometry naturally through bank erosion and meander processes including loop extension, down-valley migration and cut-off (avulsion). Where existing or proposed sections of road encroach within the meander belt of rivers and their major tributaries within the study area, they may be exposed to meander migration hazard. The rate of progression of meanders depends on a variety of factors, including stream power (a function of discharge and slope), meander geometry (e.g., radius of curvature) and the composition and topography of bank areas. Anthropogenic disturbances can accelerate bank erosion through perturbations to natural channel patterns. Segments of the proposed road centreline potentially subject to meander migration processes are identified in the mapping of terrain stability and hazards (Map 2, **Appendix B**).

5 Terrain Stability and Hazards

5.1 Terrain Stability

As discussed in Section 3.2.2, each polygon was attributed with an 'existing' or 'disturbed' stability class. The terrain stability mapping (Map 2) in **Appendix B** reveals that the majority (70%) of the study area has an existing terrain stability class[7] of 'generally stable' (Class II) (**Figure 5-1**). This is expected given the gentle to moderate slopes that predominate on lower valley sides and in uplands. Approximately 8% of the study area is considered 'potentially unstable' (Class IV, 1%) or 'unstable' (Class V, 7%), mostly represented by steep, gullied slopes and areas of permafrost with visible (excess) ground ice already exhibiting thermokarst activity.

The disturbed terrain stability class is defined in terms of the worst case scenario of ground disturbances in association with conventional cut-and-fill road construction, without any mitigation measures to address potential instabilities related to permafrost or sidecast on steep slopes. This allows for the establishment of improved baseline references, and better highlights areas that warrant special design consideration. This approach for communicating terrain hazard conditions enables engineers responsible for designing the mine facilities and access road to make more informed and site-specific decisions about appropriate construction techniques. Furthermore, it allows project risk assessments to be specifically tailored to different circumstances.

According to the disturbed terrain stability class, the proportion of terrain stability polygons with a 'generally stable' (Class II) rating drops from 70% (existing) to 33% (disturbed) (**Figure 5-1**). Many of these polygons become 'generally stable with minor potential for instability' (Class III, 30%) or 'potentially unstable' (Class IV, 16%) if disturbed without mitigation. This notable increase in terrain stability class reflects the sensitivity of permafrost terrain to active layer detachments and/or thermokarst following disturbance. The 13% areal coverage of 'unstable' (Class V) polygons in the disturbed condition is largely attributable to enhanced potential for thermokarst subsidence or gullying in areas with ice-rich permafrost.

The distinction between existing and disturbed terrain stability classes allows accurate representation of potential upslope (e.g., active layer detachments) or downslope (e.g., thermokarst gullying) hazards that are unaffected by proposed infrastructure footprints. This format of mapping distinguishes natural hazards, which may be triggered by occurrences such as wildfire, from those potentially exacerbated or initiated by project-related disturbance. For example, a particular polygon crossed by the proposed road may have a disturbed terrain stability class of IV (potentially unstable). Its existing terrain stability class, however, may only be II (generally stable). Therefore, the potential hazard posed by terrain conditions within this polygon could be recognized as being appreciably lower if the road passes beneath it than if it actually crosses it.

[7] The existing terrain stability class is included in the label, as shown in the legend, but the polygons are colour-symbolized according to the disturbed terrain stability class.

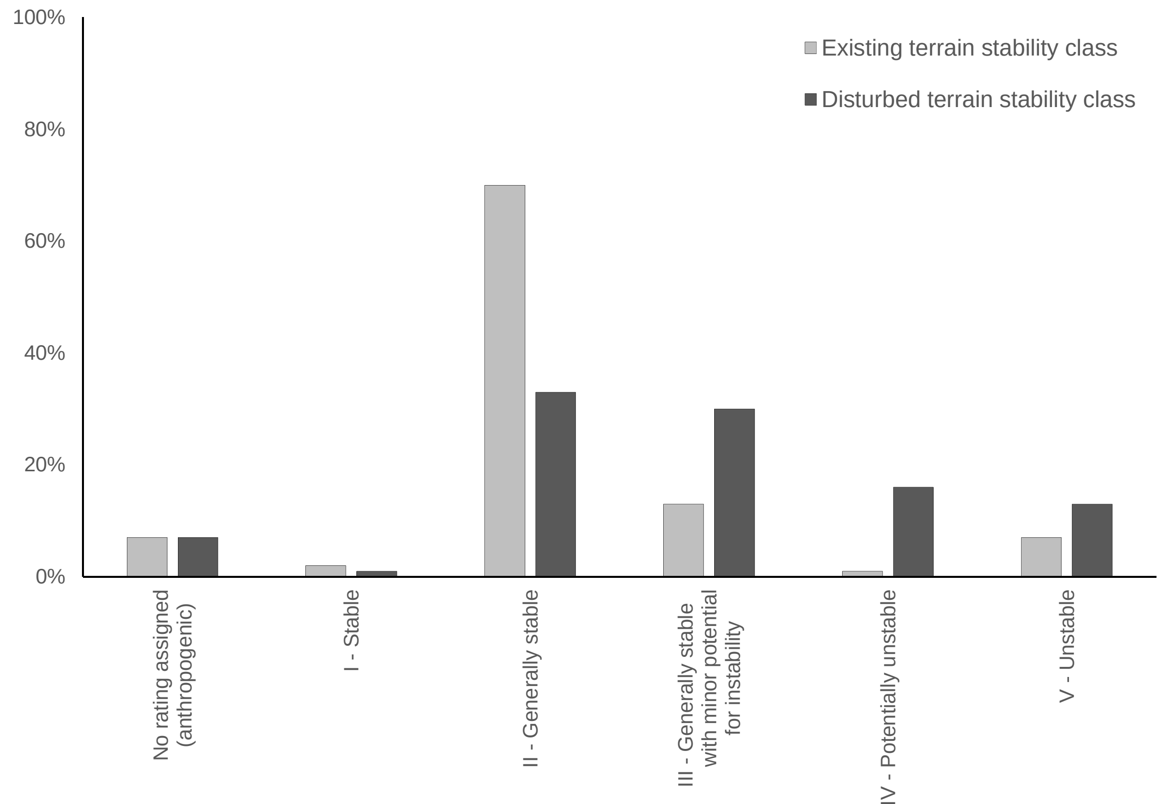


Figure 5-1. Histogram of existing and disturbed terrain stability classification in the study area

5.2 Hazards Overview

The mapping of terrain (Map 1, **Appendix A**) and terrain stability and hazards (Map 2, **Appendix B**), together, identify various forms of hazards through the assignment of geomorphological process codes (polygon-scale) and discrete geomorphological processes (point or linear features) in addition to the actual terrain stability classes. **Table 5-1** outlines the likelihood and potential magnitude of hazard occurrence over the mine life, generalized according to each of the identified hazards with the potential to affect proposed project infrastructure footprints[8]. Project considerations are also included in order to better communicate the implications of different processes for infrastructure design and future maintenance requirements. A geographic breakdown of hazard distribution within each of the 14 study area sections identified in **Figure 1-1** is provided in **Table 5-2**, followed by a descriptive summary of hazard distribution within main physiographic settings in sections 5.3.1 to 5.3.3.

[8] Only terrain characteristics and processes that may pose hazards to project infrastructure footprints are considered in this and following sections; rock slumps, which have only been mapped well beyond areas of proposed infrastructure (Map 1, **Appendix A**), are excluded.

Table 5-1. Generalized characteristics and considerations for hazards with the potential to affect proposed project infrastructure footprints

Hazard	Likelihood (over mine life)	Magnitude	Project considerations
Rockfall	High – typically recurrent and frequent, where present; freshness of talus at base of bluff indicative of recency	Moderate – generally small in volume, but rapid and dense	Plan for rockfall below bluffs, especially in areas of fresh deposits (avoid or mitigate), and on steep slopes with small bedrock outcrops
Debris slide	Moderate – most likely to occur on steep slopes exhibiting history of debris sliding, especially within or adjacent to recent scars	High – generally small to moderate in volume, but rapid and moderately dense	Avoid debris slide slopes and runout zones
Rock creep	High – periodic movement expected; freshness of patches of rock debris indicative of recency	Low – small volume, short distance, slow movements of angular rock debris	Expect increased maintenance and allow for minor settlement and shifting of rock debris
Gullying	High – periodic and localized gully erosion processes (e.g., fluvial incision, side wall mass wastage)	Low – generally incremental and localized incision, and minor surface sloughing	Minimize crossings of gullied slopes, especially where underlain by permafrost, and expect increased maintenance
Solifluction	High – near-continuous, incremental movement	Low – small volume, short distance, slow movements of silt-rich debris	Expect increased maintenance and allow for minor settlement and shifting of surficial material
Active layer detachment	Moderate – most likely to occur on recently disturbed or burned slopes, slopes with previous failures (including within existing scars), or in steep and/or gullied terrain especially downslope of any sites of newly concentrated surface runoff	Moderate – small to moderate in volume; generally rapidly transports organic-rich surficial material tens to hundreds of metres downslope	Avoid slopes that exhibit a history of active layer detachments, or otherwise accommodate their possible occurrence, minimize disturbance to surface organics and drainage, and expect increased maintenance for debris removal
Thermokarst subsidence	Moderate – gradual or periodic settlement, especially in areas of ice-rich permafrost	Low – isolated, slow deepening of ground surface depressions, formation and expansion of ringing tension cracks, and possible slow, inward slumping	Minimize disturbance to surface organics and drainage in areas of ice-moderate to ice-rich permafrost through appropriate gravel embankments/pads and water management, and expect increased maintenance that could involve localized road reconstruction; consider monitoring settlement
Thermal erosion	Moderate – gradual or periodic incision, especially in areas of ice-rich permafrost	Low – localized, slow, commonly retrogressive incision of rills or gullies, formation and expansion of adjacent tension cracks, and possible slow, inward slumping	Avoid or minimize concentrating surface runoff in areas of ice-moderate to ice-rich permafrost, especially into pre-existing gullies, and expect increased maintenance that could involve localized road reconstruction; consider monitoring incision
Slopewash	High – seasonal slopewash and transport of fine sediments within runnels; near-continuous seepage	Low – localized, slow transport of fine sediments, and seepage and icing especially in runnels	Accommodate seepage-induced icing accumulation especially within intercepted runnels, expect increased maintenance due to fine sediment delivery adjacent to road, and manage downslope drainage
Pingo	High – continuous upwelling and freezing of groundwater through permafrost forming ice-cored mound(s)	Moderate – isolated, slow heaving (growth) or subsidence (melting) of ice core, with potential for ringing tension crack formation and expansion, and possible slumping	Avoid the limits and immediate vicinities of pingos, due to the potential for long-term and locally severe ground instability if disturbed
Meander migration	High – episodic erosion of banks, mainly along the outside of meanders, in association with high flow events	Moderate – destabilization of road by incremental erosion or undercutting and slumping	Accommodate natural meander migration processes, where possible, by maintaining setbacks appropriate to the site; otherwise, proactively protect the road from erosion using appropriately sized riprap or alternative measures
Icing	High – annual formation of ice (aufeis), mainly in streams and seepage areas, from as early as October to as late as June	Low – incremental, seepage-induced accumulation and persistence of ice (aufeis) with maximum thicknesses of up to several metres and typical widths of tens of metres	Each year, accommodate at least six months of seepage-induced icing accumulation and persistence, especially at stream and slopewash runnel crossings, and across low-lying floodplains, and plan for associated maintenance

Note: Hazards within the broader study area but without the potential to affect proposed project infrastructure footprints (e.g., rock slumps) are not included

Table 5-2. Geographic distribution of hazards with the potential to affect proposed project infrastructure footprints

Geographic section (as identified in Figure 1-1)	Associated map sheets (Appendices A & B)	Hazard process with potential to affect project infrastructure footprints											Special considerations (mapping polygon ID referenced in parentheses)
		Rockfall	Debris slide	Rock creep	Gullying	Solifluction	Active layer	Thermokarst	Slopewash	Pingo	Meander migration	Icing	
Hunker Creek Valley[c]	1-4						x	x			x	x	Narrow section of valley with instability above road alignment (4446)
King Solomon Dome Area[u]	4-6					x		x	x			x	
Sulphur Creek Valley[c]	6-10							x			x	x	Tributary crossing affected by severe thermokarst gullying and icing (3993); parts of road along Sulphur Creek valley that cross ice-rich aprons have caused downslope thermokarst gullying
Indian River Valley[r]	10-12				x			x			x	x	
Eureka Creek Valley[c]	12,13							x			x	x	
Henderson Ridge Area[u]	13-18			x				x				x	
Maisy May Creek Valley[c]	18-21		x				x	x			x	x	Debris slide affecting road alignment (1681)
Stewart River Crossing[r]	21,22	x			x			x			x		
Barker Creek Valley[c]	22-25						x	x			x	x	Tributary crossing affected by severe thermokarst gullying and icing (1310,1311)
Barker-Ballarat Divide Area[u]	25,26						x	x	x			x	
Ballarat Creek Valley[c]	26-28		x					x		x	x	x	Debris slides initiated above road alignment (1681); road alignment very close to pingo (1598)
Yukon River Crossing[r]	28,29	x	x		x			x			x		Active rockfall and rock slides above road alignment (1816)
Latte-Yukon Divide Area[u]	29,30, 31						x	x					
Mine Area[u]	31,32	x	x	x	x	x		x	x				

Notes:

Physiographic setting indicated by lower-case letter superscript: [u] = upland; [c] = creek valley; [r] = river valley

Thermokarst includes subsidence and related gullying

Hazards within the broader study area but without the potential to affect proposed project infrastructure footprints (e.g., rock slumps) are not included

5.3 Slope Failure and Thermokarst

As discussed in Section 3.4.1, each polygon was more broadly categorized according to its dominant potential hazard – slope failure, thermokarst or both – in order to highlight those areas where thermokarst activity is possible in addition to default instability related to slope failure. This hazard category is not intended to represent the existing or imminence of thermokarst (or slope failure); its aim is to rule out certain areas from the possibility of thermokarst activity. ‘Thermokarst potential’ dominates the applicable hazard category within approximately 15% of the study area (**Figure 5-2**). Such areas are generally characterized by planar to gentle topography with ice-moderate or ice-rich permafrost. The potential for thermokarst outweighs the remote possibility of slope failure in these areas. Approximately 4% of the study area has been categorized co-dominantly with ‘slope failure and thermokarst potential’. Such areas are distinguished from those dominated only by thermokarst potential by their slope class of moderate (class 3) or higher. A category of ‘slope failure potential dominant’ applies to all other areas (74%), except anthropogenic and open water areas (not applicable, 7%), irrespective of the possibility of slope failure (e.g., fluvial plains).

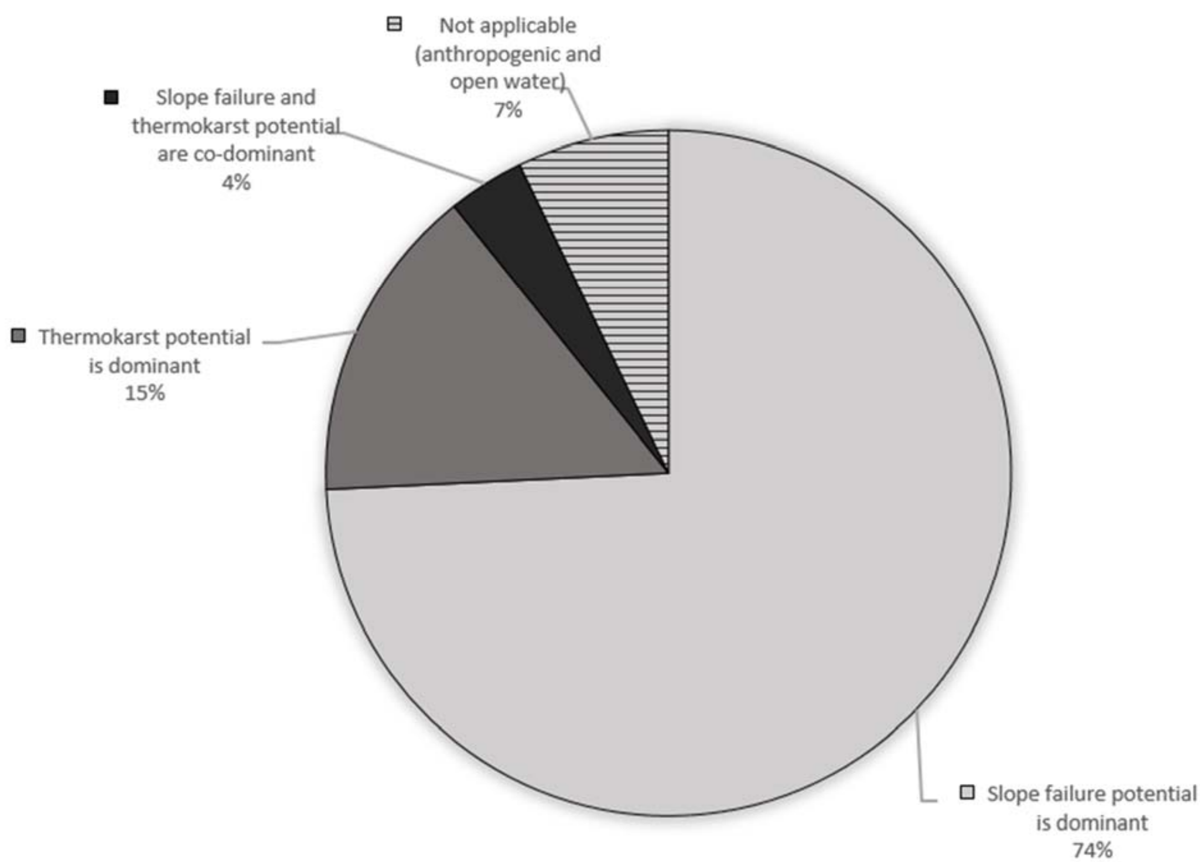


Figure 5-2. Areal proportion (%) of applicable hazard categories in the study area

The distribution of terrain hazards within and immediately surrounding the footprints of proposed project infrastructure is characterized below in relation to three physiographic settings: uplands (Section 5.3.1), creek valleys (Section 5.3.2) and river valleys (Section 5.3.3). A geographic breakdown (based on the sections defined in **Figure 1-1**) of the dominant geomorphological processes that may pose hazards to the footprints of proposed project infrastructure, including any special considerations, is provided in **Table 5-2**. This inventory specifically considers hazards with the potential to affect the footprints of proposed road or mine facilities due to their relative proximity and position. Hazards may affect the footprints locally (e.g., thermokarst subsidence), upslope (e.g., active layer detachment running out into or across footprint) or downslope (e.g., retrogressive erosion of thermokarst gullies) of the footprints. Hazards within the broader study area but without the potential to affect the proposed project infrastructure are not included.

5.3.1 Uplands

Uplands encompass summits, ridges and spurs that are generally composed of weathered and intact bedrock with colluvium in ridge-shoulder and upper-slope positions. Summits composed of granitic bedrock commonly exhibit tors, while metamorphic units generally form rounded smooth surfaces. Loess-derived colluvium becomes trapped within depressions and saddles along ridges resulting in a veneer of silt-rich colluvium. The fine-grained nature of these deposits commonly preserves permafrost with moderate ice content. Thermokarst subsidence is likely if disturbed. Rockfall commonly occurs from tors and steep-sided bedrock summits; however, no immediate rockfall hazards have been identified adjacent to the proposed road alignment in this physiographic setting. In general, uplands pose minimal hazards to infrastructure.

The following sections of the study area (**Figure 1-1**) exhibit terrain units, processes and hazards associated with upland settings:

- King Solomon Dome Area
- Henderson Ridge Area
- Barker-Ballarat Divide Area
- Latte-Yukon Divide Area
- Mine Area

5.3.1.1 Proposed Mine Facilities

A brief characterization of the specific terrain conditions and hazards in the vicinity of each of the main proposed mine facilities (Maps 1 and 2 in **Appendices A** and **B**, respectively) is provided below:

- **Open pit** – The open pit straddles the drainage divide separating the headwaters of Halfway Creek (north) and "Latte Creek" (south). It will be excavated mainly within terrain units in summit, ridge and spur settings, and will extend into colluvial veneers slopes with a southerly aspect. Most of the pit limits are within terrain with deep, ice-poor permafrost, which has little effect on ground stability or the ultimate rim of the pit. Portions of the pit will extend onto slopes with active rock creep (similar to solifluction) (northern limit), ice-moderate permafrost (western limit) and gullied terrain (southern limit). Care will need to be taken in managing surface runoff and designing the rim of the pit in such areas, to avoid retrogressive gullying and settlement of the thin overburden cap.

- **Waste Rock Dumps** – Kaminak is proposing to dump waste rock in three primary areas known as the west, south and north waste rock storage facilities (WRSFs), and in a smaller dump farther west:
  - The West WRSF is proposed on a laterally-convex hillside veneered with colluvium above upper Halfway Creek. Permafrost is interpreted to be continuous throughout the area encompassing this facility, but ice-poor and shallow to deep. The southwestern portion of the facility extends into a terrain unit subject to minor gullying and a fringing colluvial complex blanket with shallow, potentially ice-rich permafrost. The design of the lower toe of the West WRSF will need to consider the possibility of several metres of ice-rich permafrost in the draw at its southwestern limit.
  - The South WRSF is proposed to fill the upper portion of a small, first order tributary valley with an overall southerly aspect. The design of this facility will require careful planning and site preparation, as the western valley side has shallow, ice-moderate permafrost, although slopewash is the only active geomorphological process mapped. The eastern valley side exhibits subdued gullies with permafrost suspected in some of their lower portions.
  - The North WRSF is proposed to partly fill a moderately sloping, north-facing headwater basin. Although most of the footprint is within colluvial veneer terrain units, some areas have thicker colluvium and all have permafrost, some of which is ice-moderate. Site preparation will need to be conducted carefully given the localized potential for thermokarst, rock creep and slopewash.
  - A much smaller, unnamed waste rock dump is proposed on an east-southeasterly aspect opposite the West WRSF. It is situated mostly on weathered bedrock or a colluvial veneer with shallow to deep, ice-poor permafrost, except at its southern limit where it extends into the bottom of a draw infilled with fluvial and colluvial material that may contain some ground ice at depth.
- **Heap Leach Facility (HLF) Area** – The HLF Area, which includes the heap leach pad and event pond, is proposed to be situated on a gentle, broad ridge separating the headwaters of Halfway Creek and “Latte Creek”. The footprint is dominantly within weathered bedrock that transitions to gentle colluvial slopes along its margin; permafrost is shallow to deep and mostly ice-poor. Small portions of the footprint exhibit evidence of solifluction and related rock creep, which will need to be factored into the design. The northwestern corner of the footprint extends onto a gentle colluvial blanket inferred to have ice-moderate permafrost. A small active layer detachment occurred recently on this gentle slope.
- **Stockpiles** – Two main ore stockpiles are proposed, mainly on rounded ridges or their shoulders. The eastern stockpile is situated on the shoulder of a rounded ridge, where permafrost is inferred to be shallow but ice-poor. The stockpile immediately north of the HLF straddles a colluvial veneer exhibiting evidence of solifluction and a colluvial blanket dissected by a headwater draw with minor fluvial deposits, all of which is inferred to be underlain by ice-moderate permafrost. Solifluction is a slow (mm to cm/yr) process through which material moves downslope on the permafrost table, but its presence warrants consideration in the site preparation for this stockpile.

- **Plant Site Area** – The processing plant is proposed on the crest of a broad, near-level section of ridge dividing Halfway Creek and “Latte Creek”. The ground is a veneer of weathered bedrock and colluvium, with shallow to deep, ice-poor permafrost. There are no significant stability concerns within its footprint.

5.3.2 Creek Valleys

Creek valleys can be divided into valley side and valley bottom positions. Valley sides are dominantly composed of colluvial mantles. Convex slopes are typically mantled by veneers, whereas convex slopes are mantled by blankets. Draws occurring on valley sides typically contain colluvial blankets overlain by a veneer of fluvial material. On southerly aspect slopes (i.e., permafrost free), the dominant hazards are associated with rockfall, debris slides and gullying. Northerly aspect slopes (i.e., permafrost) are prone to active layer detachments, especially after fire or anthropogenic disturbance. Downslope movement of material may also occur through solifluction and slopewash. Draws are susceptible to thermokarst subsidence and may pose an icing hazard when roads are constructed across them.

Creek valley bottoms are typified by colluvial complexes that overlie fluvial deposits, active and inactive fluvial deposits with varying amounts of organic covers, and anthropogenic material. Disturbance of colluvial complexes without explicit regard for the protection of ice-rich permafrost may trigger thermokarst subsidence or gullying. Steeper complexes may additionally be susceptible to active layer detachments. Active fluvial units may be subject to bank erosion and meander migration. Fluvial units covered by organics can have significant amounts of ground ice, making them susceptible to thermokarst subsidence.

The following sections of the study area (**Figure 1-1**) exhibit terrain units, processes and hazards associated with creek valley settings:

- Hunker Creek Valley
- Sulphur Creek Valley
- Eureka Creek Valley
- Maisy May Creek Valley
- Barker Creek Valley
- Ballarat Creek Valley

5.3.3 River Valleys

River valleys are distinguished from creek valleys based on their larger size (width and depth) and more benched topography. Similar to creek valleys, river valleys can be separated into valley sides and bottoms. Valley sides are typically high and locally steep. Southerly aspects are prone to rockfall, rock slides, debris slides and gullying. Active layer detachments can occur on slopes with northerly aspects, although such hazards are not posed to proposed infrastructure footprints.

River valley bottoms are dominantly composed of wide fluvial plains, large fans aggraded from the mouths of tributaries, and colluvial complexes. Thick organic deposits and organic mantles are common on flood plains and fans, and typically signify ice-rich permafrost and increased potential for thermokarst subsidence or erosion. Fluvial deposits in the toe-slope position are commonly overlain by ice-rich colluvial complexes and are also at risk of thermokarst subsidence or erosion. Fluvial deposits closer to the rivers do not typically contain extensive permafrost and are not susceptible to subsidence; however, they may be subject to bank erosion.

The following sections of the study area (**Figure 1-1**) exhibit terrain units, processes and hazards associated with river valley settings:

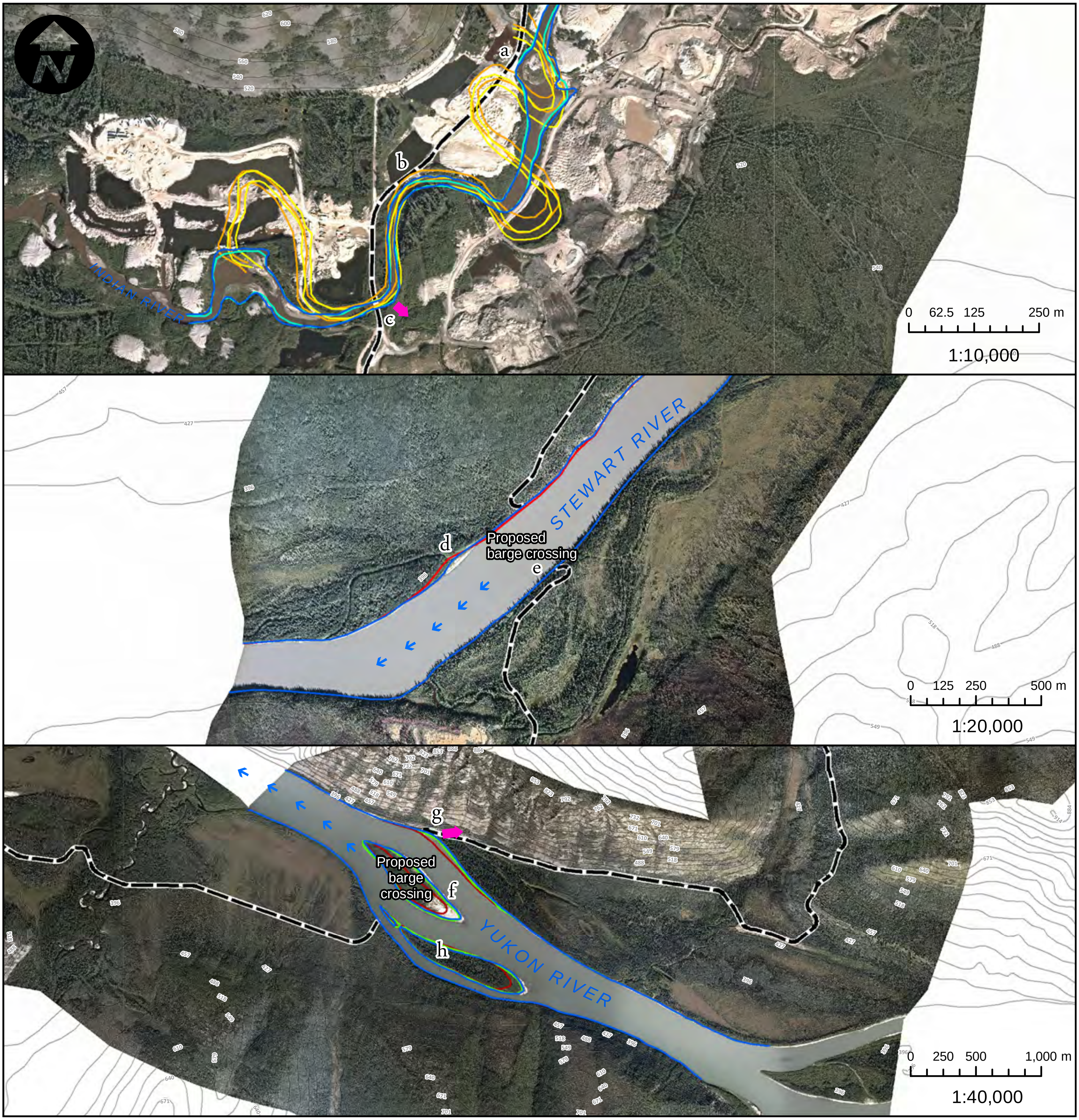
- Indian River Valley
- Stewart River Crossing
- Yukon River Crossing

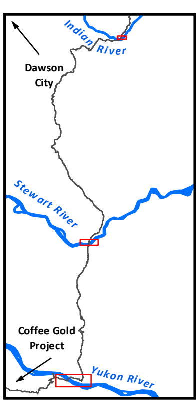
5.4 Meander Migration

A total of 44 meander-road encroachment sites constituting meander migration hazards were identified along the proposed access road (Map 2, **Appendix B**). Some of these sites already exhibit undercut and collapsing road embankments in need of maintenance and erosion protection. The results of the more detailed assessments of each of the three river crossings are provided in the following sections and in **Figure 5-3**.

5.4.1 Indian River Bridge

Indian River exhibits a tortuous meander pattern within a broad, flat valley with widespread disturbance from placer mining (**Figure 5-3**). Its meander pattern in the vicinity of the existing bridge crossing was altered sometime between 1977 and 2009 through local channel realignment, presumably to accommodate different stages of placer mining within the valley bottom. The river encroaches alongside the existing road at two locations upstream of the crossing (a and b in **Figure 5-3**), where previous riprap placement or maintenance appears to have inhibited erosion of the road embankment. The historical channel overlays at these two locations do not indicate any systematic migration of the meanders. Immediately upstream of the crossing, at the apex of another meander (c in **Figure 5-3**), the historical channel overlays reveal bank erosion occurring with a southeastward trajectory at an average rate of 0.3 m/yr (between 1961 and 2015). Without intervention, this trend could result in undermining or outflanking of the southern abutment of the existing bridge. The position, span and abutment protection of the crossing structure should account for the erosion hazard posed by this actively migrating meander. An allowance should also be made for flooding and scour caused by ice jam failure.





Legend

- Road centreline (includes existing and proposed sections)
- ~30 m topographic contour
- Meander trajectory
- a — Locations referenced in the report

River banks (year)

- 1948
- 1949
- 1961
- 1977
- 2004
- 2009
- 2010
- 2015

COFFEE GOLD PROJECT

River Meander Migration Hazards

Original page size: 8.50 x 11.00 in

Meander delineation completed by R. McKillop and C. Brown using softcopy photo-interpretation.
Base mapping from Geomatic Yukon (http://www.geomaticsyukon.ca/data)

Project number: 13103

Projection: UTM Zone 7
Datum: NAD 1983
Units: metre

Figure 5-3

KAMINAK GOLD CORPORATION

PALMER ENVIRONMENTAL CONSULTING GROUP INC.

Document Path: C:\Egnyte\Shared\Projects\Active\13103 - Kaminak Gold Corp\13103 - Coffee TSM\Programs\Meander migration hazard\Figure 5-3.mxd

Drawn by: CEB Checked by: RM 18/03/2016

5.4.2 Stewart River Barge Crossing

Stewart River exhibits a sinuous channel pattern in the vicinity of its proposed barge crossing, immediately upstream of the confluence with Barker Creek (**Figure 5-3**). The northern bank is defined by a relatively stable bedrock bluff east of the proposed northern barge landing. The amount of bank erosion suggested by the historical overlay analysis is negligible and within the error of georeferencing the historical aerial photographs on which the overlays are based. Minor deposition and stabilization of a side bar occurred between 1949 and 2015 a few hundred metres downstream of the proposed northern barge landing (d in **Figure 5-3**). The proposed southern barge landing is situated along the edge of a low fluvial terrace, or inactive portion of floodplain (e in **Figure 5-3**). Although field reconnaissance documented at least some erosion along this southern bank, based on leaning trees and localized undercutting and slumping, the coincidence of historical bank positions with that delineated based on the 2015 aerial photography indicates that observed bank instability is localized and has not resulted in systematic erosion. Given the size of the river, and the erodibility of the bank materials, some degree of localized bank failure and retreat should be accommodated in the design of the southern barge landing. An allowance should also be made for flooding and scour caused by ice jams, which form annually.

5.4.3 Yukon River Barge Crossing

Yukon River exhibits a sinuous to anastomosing channel pattern in the vicinity of its proposed barge crossing, just upstream of the confluence with Coffee Creek (**Figure 5-3**). The river has numerous side and mid-channel bars, exhibiting varying degrees of stability, as well as back channels that may only convey water during floods. The existence and distribution of bars along the main channel affect bank erosion patterns through their localized deflection and/or splitting of the thalweg. The persistence and slight growth of a relatively large mid-channel bar at the proposed barge crossing (f in **Figure 5-3**), since at least 1948, may have contributed to the systematic erosion of the northern river bank that is documented through the historical overlay analysis. Erosion of the northern bank immediately upstream of the proposed northern barge landing (g in **Figure 5-3**), which is situated at the interface between fluvial deposits and the toe of a steep, rocky hillside, has occurred at an average rate of 1.3 m/yr between 1948 and 2015. Depending on the exact positioning and design of the proposed northern barge landing, continued erosion of this bank may necessitate proactive riprap placement to mitigate the hazard. No significant erosion appears to have occurred along the southern bank in the vicinity of the proposed barge landing, likely due to partial protection afforded by the adjacent vegetated bar (h in **Figure 5-3**) from the more erosive thalweg. An allowance should also be made for flooding and scour caused by ice jams, which form annually.

5.5 Icing

Icing, locally known as 'glaciation', is the accumulation of ice (aufeis) during winter along streams and large slopewash runnels that receive near-continuous groundwater seepage from unfrozen portions of active layers or adjacent permafrost-free ground (**Photo 5-1**). Icings form through the accretion of layers of ice, attaining thicknesses of up to several metres and widths of several tens of metres. Icings within the study area locally initiate in October and may persist until early June where thickest and most shaded. Lorax Environmental Services Ltd.'s (2015) wintertime monitoring of ice along streams draining the proposed mine area confirm that thicknesses of more than 1 m are common, particularly along headwater reaches.

Photo 5-1. Example of icing spanning the bottom of a headwater drainage in the Klondike Plateau

A total of 77 sites known or inferred to be prone to wintertime icing were identified along the proposed access road (Map 2, **Appendix B**). Some of these sites, as reported by Yukon Highways and Jim Coates (Kryotek), require significant efforts to break up and remove the ice in the spring before the road is drivable by regular vehicles. Large accumulations of aufeis along stream beds and low-lying areas of floodplains can also increase the width (and height) of flooding if intense rainfall or snowmelt occurs before the ice has thinned and broken up. Allowances should be made in the design of crossings of icing-prone drainages for both the formation and failure of aufeis, as well as potential flooding in excess of that predicted by regular hydrological analysis.

5.6 Other Hazard Considerations

Several other processes were noted as potential hazards through the mapping process, but delineation of their limits requires site-specific investigation and analysis of detailed hydrological and topographic data beyond the scope of this assessment:

- **Flooding** – Sections of road crossing or traversing low-lying areas alongside modern streams may be subject to temporary flooding (inundation) during intense or prolonged rainfall or snowmelt. Ice jams, which can also significantly raise water levels, are common along the rivers and their major tributaries. Riparian vegetation patterns and soil profiles provide indicators of the approximate limits and frequency of flooding.

- **Ice Jams and Scour** – Virtually continuous covers of ice form during the winter months along creeks and rivers within the study area. Thicknesses vary spatially and temporally, but locally can exceed one metre. Small areas of open water that punctuate otherwise continuous ice cover occur in areas of sustained groundwater discharge, along the toes of terraces or valley sides. Open water commonly also persists locally in the Stewart and Yukon rivers, in areas of hyporheic exchange near the downstream limits of large gravel bars. During the winter, the ice flexes and buckles, continually shifting under the hydraulic influence of water flowing beneath. Ice jams form in local constrictions within the channel, or at abrupt bends, commonly at similar locations each year. Water impounded by ice jams can flood extensive areas of the valley bottom not normally exposed to flooding due solely to meteoric (hydrologic) events. In the spring, the ice jams break up and release thick slabs of ice downstream. Depending on the size of the ice jams, and the timing, duration and mechanisms of ice jam failure, breaches can result in widespread scour and ice block stranding along banks and riparian zones downstream.
- **Degradation and Aggradation** – Degradation, also known as channel down-cutting, is the lowering of stream bed elevation due to erosion overwhelming deposition at a reach scale. Aggradation, or channel infilling, is the raising of stream bed elevation due to deposition outpacing erosion at a reach scale. Both degradation and aggradation along streams may pose hazards to crossing structures (e.g., culverts or bridges) if not recognized and accommodated in the design. Degradation can lead to undermining of abutments, potentially destabilizing crossing structures, and perching of culverts, forming barriers to upstream fish migration. Aggradation can reduce the hydraulic capacity of the channel or crossing structures by partial infilling, which in turn can increase the frequency of overbank flooding and the potential for road overtopping.

5.7 Soil Erosion Potential

Soil erosion potential was an attribute interpreted in association with terrain and terrain stability mapping, as outlined above in Section 3.5. Nearly half (49%) of the study area was assigned a soil erosion potential ranking of moderate (**Figure 5-4**), which reflects the counterbalancing effects of silt within the soil (i.e., highly erodible) with the predominantly gentle to moderate slopes (i.e., less prone to erosion). Approximately 13% of the study area exhibits high or very high soil erosion potential, due to their ground ice contents and appreciable proportions of silt intermixed with organics. Thermal erosion was considered in association with areas of ice-moderate or ice-rich permafrost.

The management of surface runoff and sediment during the construction of the proposed mine facilities and access road will be particularly important in areas directly upslope of fish habitat. Consideration will also need to be given to swales or gullies with the potential to transport sediments into downstream fish-bearing watercourses. Erosion and sediment control measures should be designed, implemented, monitored and maintained with the greatest attention given to erosion-prone slopes upslope of fish habitat.

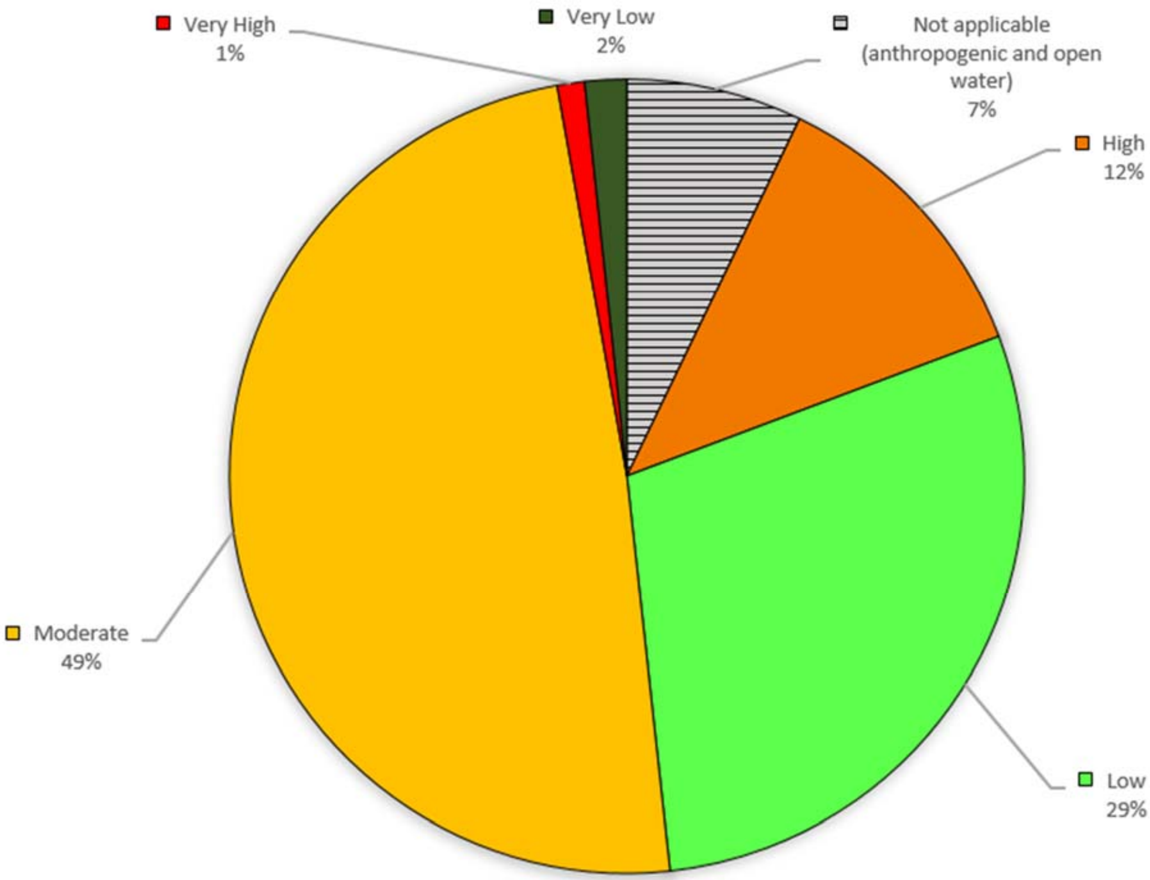


Figure 5-4. Areal proportion (%) of soil erosion potential

6 Project Design Considerations

The information presented in this report and its accompanying maps (**Appendices A** to **C**) provides a basis for planning, designing, constructing and maintaining project infrastructure in ways that minimize long-term costs and potential effects on the environment. It also informs rehabilitation practices during and following operations. The identification and characterization of geomorphological processes and the potential hazards they pose to the Project facilitate assessment of site-specific risks and measures to avoid or mitigate these risks. The following two sections highlight opportunities to avoid or minimize risks based on advance knowledge of terrain and permafrost conditions.

6.1 Hazard Avoidance

Hazard avoidance is a guiding principle Kaminak has embraced in the siting and routing of its mine facilities and access road, respectively. The final footprints of the proposed mine facilities and access road should be located to avoid areas prone to mass movement, slope erosion or fluvial processes, where feasible. Project infrastructure should avoid crossing, or upslope and downslope exposure to, areas mapped as having an existing terrain stability class of V due to past or imminent slope failure. Careful site preparation and design will be required in areas where project infrastructure unavoidably crosses areas with an existing terrain stability class of V due to existing thermokarst activity (as described further below in Section 6.2). Such terrain occurs locally in some valley bottoms along which the access road is proposed. Similar attention should be given to areas with a disturbed terrain stability class of V but with a lower existing terrain stability class (e.g., gentle colluvial complex apron with ice-rich permafrost), in order to avoid triggering instability.

In some cases, hazard avoidance may also be achieved through careful site preparation that eliminates or alters the conditions responsible for the hazard. For example, in rare situations where key mine facilities cannot reasonably avoid encroachment into areas with ice-rich permafrost, thawing and excavation of the ice-rich surficial material could be considered prior to construction.

6.2 Effective Hazard Mitigation

In areas where hazard avoidance is not possible or practicable, Kaminak will apply hazard mitigation measures applicable to site-specific conditions and commensurate with associated risks to the Project. Examples of general strategies for mitigating the main forms of hazard within the study area, if and where subsequent risk assessment establishes the need, are identified in the following sections.

6.2.1 Slope failure

Reducing the likelihood or magnitude of slope failures may or may not be possible in areas where the hazard cannot be avoided. The management of surface runoff will be critical on slopes underlain by permafrost; unnatural concentrations can quickly saturate the active layer and reduce its effective shear strength resulting in active layer detachments, or cause subsidence in ice-moderate or ice-rich settings. In addition, consideration could be given to modifying slope geometry to lessen initiation potential, altering surface and groundwater drainage patterns in an attempt to reduce the water content of the surficial material, or introducing active or passive external forces to increase shear strength. Monitoring changes to the morphology of disturbed slopes is recommended at locations of suspected instability.

Opportunities to limit and manage the runout of potential slope failures should also be considered where the hazard is likely and unavoidable. Measures exist for controlling the trajectory of the mass movement, such as deflection berms. In order to help control the runout limits, passive or active measures could be considered individually or in combination. For example, ditching alongside a section of road exposed to rockfall represents a passive measure to accommodate (and accumulate) rockfall debris. Constructing physical barriers to intercept rockfall debris, such as an earthen berm, represents more active mitigation.

Considerations for addressing minor hazards posed by geomorphological processes such as solifluction and slopewash are included above in **Table 5-1**.

6.2.2 Thermokarst

Minimizing the potential for initiating or exacerbating thermokarst is one of the most important engineering objectives in the routing and design of the proposed access road. The over-arching principle is to protect the integrity of the core of the road embankment through the maintenance of the local ground thermal regime (McGregor et al., 2010). Specific design, construction and maintenance techniques aimed at maintaining or minimizing change to the ground thermal regime are available for areas where ice-moderate or ice-rich permafrost cannot reasonably be avoided. Below is a summarized list of effective mitigation measures from the technical memorandum prepared for this project by TT-EBA (2016a) (**Appendix E**):

- Avoiding cuts and ditches wherever possible to limit disturbance to the active layer;
- Restricting the movement of equipment used to clear the right-of-way, in order to minimize disturbance to surface organics;
- Removing snow cover prior to construction of the road embankment, if constructed in winter, to reduce settlement during the thaw period;
- Using an end-dumping method to construct the road embankment to avoid unnecessary damage to vegetation;
- Avoiding high fills and side-slopes wherever possible to limit potential for mass movement within the road embankment;
- Constructing a road embankment with a thickness sufficient to maintain or even slightly decrease existing active layer thickness;
- Avoiding concentration and ponding of water alongside the road embankment, by doing so, if necessary, a reasonable distance from the embankment (in order to avoid degrading permafrost at the edge of the embankment); and
- Preventing snow accumulation on the lee side of the embankment, which can inhibit cold penetration during winter and increase active layer thickness.

Careful planning of road maintenance is required. Judgment must be used to determine when routine maintenance will suffice, and when to escalate activities to rehabilitation (McGregor et al., 2010). If localized thermokarst subsidence or gullying becomes particularly severe, consideration may need to be given to thawing and removing the underlying ice-rich permafrost and reconstructing the section of road. This technique, although not preferred, is commonly used by placer miners in the region.

6.2.3 Meander migration

Sections of the proposed access road exposed to meander migration hazards may require erosion protection in order to avoid impact to the embankment. Riprap is the most common and straightforward measure to inhibit the erosion of a road embankment, although other more proactive measures such as in-stream flow 'training' (e.g., rock veins or steam barbs to shift thalweg position) or local channel realignment are options worth considering, especially if riprap continues to be undermined and collapse. Banks should be stabilized prior to impingement along the road embankment, although additional riprap placement may also be required following major floods.

The exact positioning and design of the barge landings at proposed crossings of the Stewart and Yukon Rivers should account for the trajectories and rates of bank erosion documented above in sections 5.4.2 and 5.4.3. Consideration should also be given to the implications of ice formation, jamming, scouring and break-up in the vicinity of the landing sites.

6.2.4 Icing

The design of crossing structures along the proposed access road at streams and seepage areas prone to icing should accommodate ice accumulation and springtime flooding before or during break-up as best as possible. Pre-construction monitoring of the stream crossings of greatest concern would valuably inform crossing design, providing insight on site-specific icing thickness and extent. Measures to mitigate potential effects of icing may include locally enlarged entrance areas to culverts; installation of multiple culverts, some raised relative to the others; and local drainage diversions. Considering the implications of any contemplated measures to underlying or adjacent ice-rich permafrost will be necessary.

7 Conclusions

Terrain stability and hazard mapping completed for the Coffee Gold Project depicts the distribution and characteristics of terrain units, processes and hazards within a 526 km^2 study area that encompasses the proposed mine area and its access road from Dawson. This report and its accompanying maps support engineering and environmental studies being completed as the project advances its proposal submission to YESAB. Several key results warrant highlighting:

1. The siting and design of proposed mine facilities and the access road should account for the widespread occurrence of permafrost in valley bottoms, on northerly aspects and within hillside hollows;
2. The primary mass movement hazards that may affect the footprints of the proposed mine facilities and access road, where not avoided, are rockfall, debris slides, active layer detachments and thermokarst;
3. Disturbance to the ground thermal regime of colluvial complexes rich in silt, organics and segregated ground ice, as well as silty mantles with excess ground ice in saddles and on concave slopes, should be minimized in order to inhibit thermokarst;
4. Active layer detachments commonly initiate on moderate slopes, just above a convex slope-break, with increased likelihood after fire or other surface disturbances;
5. The potential for thermokarst gullies to retrogressively erode upslope should be accommodated in the road alignment and design;
6. Erosion protection (e.g., riprap) will likely be required along sections of the proposed access road where a meandering channel encroaches, including at the three proposed river crossings; and
7. Special consideration is needed in the design of drainage crossings along the proposed access road that are prone to icing, which can form as early as October and persist as late as June.

8 Statement of Limitations

This report (including its appended maps) has been prepared by the Consultant (Palmer Environmental Consulting Group Inc. (PECG)) for the benefit of the Client (Kaminak Gold Corporation) in accordance with the agreement between Consultant and Client, including the scope of work detailed therein (the "Agreement"). The report and the information it provides may be used and relied upon only by Client, except (1) as agreed to in writing by Consultant and Client, (2) as required by-law, or (3) to the extent used by governmental reviewing agencies for the purpose of obtaining permits or approvals.

The extent of this study was limited to the specific scope of work for which we were retained and that is described in this report. PECG has assumed that the information and data provided by the client or any secondary sources of information are factual and accurate. PECG accepts no responsibility for any deficiency, misstatement or inaccuracy contained in this report as a result of omissions, misinterpretations or negligent acts from relied-upon data. Judgment has been used by PECG in interpreting terrain stability and hazards based on desktop-based interpretation calibrated by field observations at sites representative of the diversity of conditions within the study area. Ground conditions may differ from those interpreted at a polygon scale, even where investigated in the field, due to inherent variability in terrain characteristics.

PECG is not a guarantor of the terrain, permafrost or hazard conditions within each of the mapped polygons, but warrants only that its work was undertaken and its report prepared in a manner consistent with the level of skill and diligence normally exercised by competent geoscience professionals practicing in Yukon. Our findings, conclusions and recommendations should be evaluated in light of the limited scope of our work.

9 References

AECOM, 2012. Geomorphological Mapping and Landscape Model Development for Strategic Soil Geochemical Sampling at the Coffee Gold Project, Yukon Territory. Prepared for Kaminak Gold Corporation, March, 2012.

BC Ministry of Forests, 1994. A Guide for Management of Landslide-Prone Terrain in the Pacific Northwest, 2nd Edition. Land Management Handbook Number 18, 220 p.

BC Ministry of Forests, 1999. Mapping and Assessing Terrain Stability Guidebook 2nd ed., For. Prac. Br. B.C. Min. For., Victoria B.C. Forest Practices Code of British Columbia Guidebook.

BC Ministry of Forests and Range and BC Ministry of Environment, 2010. Field Manual for Describing Terrestrial Ecosystems 2nd Edition. Research Branch, BC Ministry of Forests and Range and Resources Inventory Branch, BC Ministry of Environment, Victoria, 266 p.

Birkeland, P.W., 1984. Soils and Geomorphology. Oxford University Press, New York, 372 p.

Blais-Stevens, A., Couture, R. and Page, A., 2010. Landslide inventory along the Alaska Highway Corridor, Yukon. Geological Survey of Canada, Open File 6654.

Bond, J.D. and Lipovsky, P.S., 2011. Surficial geology, soils and permafrost of the northern Dawson Range. *In*: Yukon Exploration and Geology 2010, K.E. MacFarlane, L.H. Weston and C. Relf (eds.), Yukon Geological Survey, p. 19-32.

Bonnaventure, P.P., Lewkowicz, A.G., Kremer, M. and Sawada, M.C., 2012. A permafrost probability model for the southern Yukon and northern British Columbia, Canada. Permafrost and Periglacial Processes, vol. 23, p. 52-68.

Brown, R.J.E., 1967. Permafrost investigations in British Columbia and Yukon Territory. National Research Council of Canada, Division of Building Research, Technical Paper 253.

Burn, C.R., 1998. The response (1958-1997) of permafrost and near-surface ground temperatures to forest fire, Takhini River valley, southern Yukon Territory. Canadian Journal of Earth Sciences 35: 184-199.

Coates, J., 2008. The impact of forest fire on permafrost slopes, Klondike area, Yukon Territory. Unpublished MSc thesis, University of Ottawa, Ontario, Canada, 208 p.

Coates, J. and Lewkowicz, A.G., 2005. Effect of forest fire on landsliding over permafrost, Steele Creek, Yukon Territory. Canadian Association of Geographers, Ontario Division Annual Conference, University of Ottawa, October 2005.

Colpron, M., Nelson, J.L. and Murphy, D.C., 2006. A tectonostratigraphic framework for the pericratonic terranes of the northern Cordillera. In: Paleozoic Evolution and Metallogeny of Pericratonic Terranes at the Ancient Pacific Margin of North America, M. Colpron and J.L. Nelson (eds.), Geological Association of Canada, Special Paper 45, p.1-23.

Cruden, D.M. and Varnes, D.J., 1996. Landslide types and processes. *In*: Turner, A.K. and Schuster, R.L. (eds.) Landslides investigation and mitigation. Transportation research board, US National Research Council. Special Report 247, Washington, DC, Chapter 3, p. 36–75.

Duk-Rodkin, A., 1999. Glacial limits map of Yukon Territory. Geological Survey of Canada Open File 3694; Exploration and Geological Services Division, Yukon Region, Indian and Northern Affairs Canada, Geoscience Map 1999-2, scale 1:1 000 000.

Dyke, L.D., 2004. Stability of Frozen and Thawing Slopes in the Mackenzie Valley, Northwest Territories. *In:* Proceedings of the 57th Canadian Geotechnical Conference, Quebec City, Quebec, Session 1G, p. 31-38.

EBA Engineering Consultants Ltd., 1977. Geotechnical investigations for utilities design, Dawson City, Yukon. Report submitted to Stanley Associates Engineering Ltd, Whitehorse, Yukon, 28 p.

EBA Engineering Consultants Ltd., 1978. Utilities geotechnical design, Dawson City, Yukon. Report submitted to Stanley Associates Engineering Ltd, Whitehorse, Yukon.

Fraser, T.A. and Burn, C.R., 1997. On the nature and origin of “muck” deposits, Klondike area, Yukon Territory. Canadian Journal of Earth Sciences, vol. 34, p. 1333-1344.

Gordey, S.P. and Makepeace, A.J. (compilers), 2003. Yukon digital geology, version 2.0. Geological Survey of Canada Open File 1749, and Yukon Geological Survey Open File 2003-9(D), 2 CD-ROMS.

Guthrie, R.H. and Cuervo, V. 2015. Geohazards and Risk: A Proponent’s Guide to Linear Infrastructure. Yukon Environmental and Socio-economic Assessment Board, Whitehorse, YT, 47 pp + Appendices.

Heginbottom, J.A., 1995. Canada Permafrost. National Atlas Information Service, Geomatics Canada and Terrain Sciences Division, Geological Survey of Canada, 1:7 500 000 scale.

Hegginbottom, J.A., Dubreuil, M.A. and Harker, P.T., 1995. Permafrost Map of Canada. *In*: The National Atlas of Canada, 5th Edition (1978-1995), Natural Resources Canada, sheet MCR 4177, 1:7,500,000 scale.

Howes, D.E. and Kenk, E., 1997. Terrain Classification System for British Columbia (Version 2). Province of British Columbia, Resource Inventory Branch, Ministry of Environment, Lands and Parks; Recreational Fisheries Branch, Ministry of Environment; and Surveys and Resources Mapping Branch, Ministry of Crown Lands, 102 p.

Hughes, O.L., 1969. Distribution of open-system pingos in central Yukon Territory with respect to glacial limits. Geological Survey of Canada, Paper 69, 34 p.

Hungr, O., Leroueil, S. and Picarelli, L., 2014. The Varnes classification of landslide types, an update. Landslides 11, p. 167-194.

Huscroft, C.A., 2002. Late Cenozoic history of the Yukon River valley, Fort Selkirk to the Stevenson Ridge map area (115 I/13, 14 & J/13, 14, 15). Unpublished MSc thesis, Simon Fraser University, Vancouver, Canada, 111 p + appendices.

Huscroft, C.A., Lipovsky, P.S. and Bond, J.D., 2004. A regional characterization of landslides in the Alaska Highway corridor, Yukon. Yukon Geological Survey, Open File 2004-18, 65 pp.

Huscroft, C.A., Ward, B.C., Jackson, L.E., Jr. and Tarnocai, C.E., 2006. Investigation of high-level glaciofluvial terraces and re-evaluation of the established soil stratigraphy for Early and Middle Pleistocene surfaces, central Yukon, Canada. Boreas, vol. 35, p. 96-105.

Hyndman, R.D., Cassidy, J.F., Adams, J., Rogers, G.C. and Mazzotti, S., 2005. Earthquakes and seismic hazard in the Yukon-Beaufort-Mackenzie. Canadian Society of Exploration Geophysicists Recorder 30(5), p. 1-17.

J.M. Ryder and Associates, Terrain Analysis Inc., 2002. A User's Guide to Terrain Stability Mapping in British Columbia. Final Draft, January 2002, 89 p.

Jackson, L.E., Huscroft, C.A., Ward B.C. and Villeneuve, M., 2008. Age of volcanism of the Wolverine Volcanic Centre, west-central Yukon Territory, Canada and its implications for the history of Yukon River. Eos Trans. AGU, 89(53) Fall Meet. Suppl., San Francisco, CA, December 15-19, 2008, abstract V41D-2110.

JDS Energy & Mining Inc., 2016. NI 43-101 Feasibility Study Technical Report for the Coffee Gold Project, Yukon Territory, Canada. Prepared for Kaminak Gold Corporation, February 18, 2016.

Lamontagne, M., Halchuk, S., Cassidy, J.F. and Rogers, G.C. 2007. Significant Canadian Earthquakes 1600-2006, Geological Survey of Canada, Open File 5539, 1 CD-ROM.

Lewkowicz, A.G. and Harris, C., 2005. Morphology and geotechnique of active-layer detachment failures in discontinuous and continuous permafrost, northern Canada. Geomorphology 69, p. 275-297.

Lipovsky, P.S., Coates, J., Lewkowicz, A.G. and Trochim, E., 2006. Active-layer detachments following the summer 2004 forest fires near Dawson City, Yukon. *In:* Emond, D.S., Bradshaw, G.D., Lewis, L.L. and Weston, L.H. (eds.), Yukon Exploration and Geology 2005. Whitehorse, Yukon Geological Survey, p. 175-194.

Lipovsky, P.S. and Bond, J.D. (compilers), 2014. Yukon digital surficial geology compilation, digital release 1, 08-Apr-2014, Yukon Geological Survey.

Lorax Environmental Services Ltd., 2015. Aufeis Thickness, Coffee Gold Project. Figure prepared for Kaminak Gold Corporation, August 31, 2015.

Lorax Environmental Services Ltd., 2016. Depth of Permafrost, Coffee Gold Project. Summary table prepared for Kaminak Gold Corporation, January 15, 2016.

Mathews, W.H., 1986. Physiography of the Canadian Cordillera. Geological Survey of Canada, Map 1701A, 1:5 000 000 scale.

McConnell, R.G. 1905. Report on the Klondike goldfields. *In*: Annual report of the Geological Survey of Canada, vol. 14, p. 1-71.

McGregor, R., Hayley, D.W., Wilkins, G., Hoeve, E., Grozic, E., Roujanski, V. and Jansen, A. 2010. Guidelines for Development and Management of Transportation Infrastructure in Permafrost Regions. Transportation Association of Canada.

McKillop, R., Turner, D., Johnston, K. and Bond, J., 2013. Property-scale classification of surficial geology for soil geochemical sampling in the unglaciated Klondike Plateau, west-central Yukon. Yukon Geological Survey, Open File 2013-15, 85 p., including appendices.

Milner, M. W., 1976. Geomorphology of the Klondike Placer Goldfields. Final Report, Contract OSV 5-0047, Department of Indian Affairs and Northern Development.

Mortensen, J.K., 1992. Pre-mid-Mesozoic tectonic evolution of the Yukon-Tanana terrane, Yukon and Alaska. Tectonics, vol. 11, no. 4, p. 836-853.

Naldrett, D.L., 1981. Aspects of the surficial geology and permafrost conditions, Klondike goldfields and Dawson City, Yukon Territory. Unpublished MSc thesis, University of Ottawa, Ottawa, Canada, 150 p.

Palmer Environmental Consulting Group Inc., 2013. Casino Project: Freegold Road Extension – Erosion and Sedimentation Risk Assessment Report. Prepared for Casino Mining Corporation, October 25, 2013.

Schaetzl, R. J. and Anderson, S., 2005. Soils Genesis and Geomorphology. Cambridge University Press. New York.

Soil Classification Work Group, 1998. The Canadian System of Soil Classification. Agriculture and Agri-Food Canadian Publication, Third Edition 1646 (Revised). 187 pp.

Smith, C.A.S., Meikle, J.C. and Roots, C.F. (eds.), 2004. Ecoregions of the Yukon Territory: Biophysical properties of Yukon landscapes. Agriculture and Agri-Food Canada, PARC Technical Bulletin No. 04-01, Summerland, British Columbia, p. 8-10.

Smith, S.L., Riseborough, D.W. and Bonnaventure, P.P., 2015. Eighteen year record of forest fire effects on ground thermal regimes and permafrost in the central Mackenzie Valley, NWT, Canada. Permafrost and Periglacial Processes, Wiley Online Library, DOI: 10.1002/ppp.1849.

Smith, C.A.S., Sanborn, P.T., Bond, J.D. and Frank, G., 2009. Genesis of Turbic Cryosols on north-facing slopes in a dissected, unglaciated landscape, west-central Yukon Territory. Canadian Journal of Soil Science, vol. 89, p. 611-622.

Strahler, A.N., 1952. Hypsometric (area-altitude) analysis of erosional topography. Geological Society of American Bulletin, vol. 63, p. 1117-1142.

Tempelman-Kluit, D., 1980. Evolution of physiography and drainage in southern Yukon. Canadian Journal of Earth Sciences, vol. 17, p. 1189-1203.

Tetra Tech EBA, 2016a. Geotechnical Considerations for Road Design in Areas Underlain by Permafrost. Prepared for Kaminak Gold Corporation, March 3, 2016.

Tetra Tech EBA, 2016b. Map of Permafrost Distribution along Proposed Kaminak Road Alignment (incl. Technical Memo). Prepared for Kaminak Gold Corporation, March 3, 2016.

Tetra Tech EBA, 2016c. Permafrost Distribution and Permafrost-Related Geohazard Mapping within the Coffee Property (incl. Technical Memo). Prepared for Kaminak Gold Corporation, December 21, 2015.

Tsoar, H. and Pye, K., 1987. Dust transport and the question of desert loess formation. Sedimentology, vol. 30, p. 139-153.

Tyrrell, J. B., 1917. Frozen muck in the Klondike District. Transcriptions of the Royal Society of Canada, sect. 4, 39-46.

van Everdingen, R. (ed.), 2005. Multi-language glossary of permafrost and related ground-ice terms. Original publication in 1998. Boulder, CO: National Snow and Ice Data Center.

Varnes, D.J., 1978. Slope movement types and processes. *In*: Schuster, R.L. and Krizek, R.J. (eds.) Landslides, analysis and control, special report 176: Transportation research board, National Academy of Sciences, Washington, DC, p. 11–33.

Viereck, L.A., 1973. Ecological effects of river flooding and forest fires on permafrost in the taiga of Alaska. Proceedings, Second International Conference on Permafrost, National Academy of Science, Washington, D.C., p. 60-67.

Ward, B., Jackson, L.E. Jr. and Savigny, K.W., 1992. Evolution of Surprise Rapids landslide, Yukon Territory. Geological Survey of Canada, Paper 90-18, 25 pp.

Williams, D. J., 1995. Predicting the location of permafrost in central Yukon Territory. Unpublished MA thesis, Carleton University, Ottawa, Canada, 136 p.

Williams, J. and Burn, C.R., 1996. Surficial characteristics associated with the occurence of permafrost near Mayo, central Yukon Territory, Canada. Permafrost and Periglacial Processes., vol. 7, p.193-206.

Yoshikawa K., Bolton, W.R., Romanovsky, V.E., Fukuda, M. and Hinzman, L.D., 2003. Impacts of wildfire on the permafrost in the Boreal forests of interior Alaska. Journal of Geophysical Research 107, 8148.

Zoltai, S.C. and Pettapiece, W.W., 1973. Studies of vegetation, landform and permafrost in the Mackenzie Valley: Terrain, vegetation and permafrost relationships in the northern part of the Mackenzie Valley and northern Yukon. Report submitted to Environmental-Social Program Northern Pipelines, 105 p.

Appendix A

Map 1 – Terrain

Coffee Gold Project Terrain Map Code Definitions

KAMINAK GOLD CORPORATION

PALMER ENVIRONMENTAL CONSULTING GROUP INC.

Textures

Symbol	Name	Size (mm)	Description
a	blocks	>256	Angular particles.
b	boulders	>256	Rounded and subrounded particles.
k	cobbles	64 - 256	Rounded and subrounded particles.
p	pebbles	2 - 64	Rounded and subrounded particles.
s	sand	2 - .062	
z	silt	.062 - .002	
c	clay	<.002	
d	mixed fragments	>2	Mix of rounded and angular particles.
g	gravel	>2	Mix of boulders, cobbles and pebbles.
x	angular fragments	>2	Mix of rubble and blocks.
r	rubble	2 - 256	Angular particles.
e	fibric		Well-preserved fibre (40% or more) that can be identified as to botanical origin upon rubbing.

Surficial Materials

Symbol	Name	Assumed status	Description
A	anthropogenic	(A)	Artificial materials, or geological materials so modified by human activities that their original physical properties (e.g. structure, cohesion, compaction) have been drastically altered. Typically related to placer mining activity in valleys, where the extent and severity of disturbance varies from stripping of surface organics to complete excavation of material to bedrock.
C	colluvial	(A)	Materials that have reached their present position as a result of direct, gravity-induced movement. Generally consists of massive to moderately well-stratified, non-sorted to poorly sorted sediments. Veneers are dominantly composed of angular fragments with lesser amounts of silt and sand, while blankets and aprons that most commonly form in concave or slope toe positions generally have higher contents of silt.
C1	colluvial complex	(A)	A mixture of sand, silt, organic materials and minor amounts of angular fragments that has reached its present position as a result of direct, gravity-induced movement. Typically forms aprons or blankets along the base of valley sides and valley bottoms, and consists dominantly of sandy silt with ice-rich permafrost. Locally known in the Klondike region as "black muck".
D	weathered bedrock	(A)	Bedrock decomposed or disintegrated *in situ* by mechanical and/or chemical weathering processes. Generally consists of angular rock fragments ranging in size from coarse sand to blocks. Typically occurs on ridge crests and gentle upper slopes.
F	fluvial	(I)	Materials transported and deposited by streams and rivers. Generally consists of rounded gravels with interstitial sand and silt. Thick deposits typically occur on valley bottom floodplains/fans and terraces. Thin deposits occur within draws or on slopes where water is flowing over the permafrost table.
FG	glaciofluvial	(I)	Materials transported and deposited by glacial meltwater. Deposits range from non-sorted, massive gravels to well-sorted, stratified gravels, and only occur as terraces alongside the Yukon River.
O	organic	(A)	Organic materials resulting from the accumulation and decay of vegetative matter. Contains at least 30% organic matter by weight. Saturated deposits of accumulated mosses, sedges, or other hydrophytic vegetation are typical. Accumulations of leaf litter, twigs, branches and mosses are found in drier areas. Thin organic deposits are widespread in the area, occur in many different environments, and are only included in the map label where they influence the physical properties of the unit.
R	bedrock	n/a	Intact rock outcrops that may be covered by a thin mantle (<10 cm thick) of unconsolidated or organic materials. Typically occur on ridge crests (e.g. tors) and along the base of over-steepened slopes.

Qualifiers

Symbol	Name	Description
A	active	Used to qualify surficial materials and geomorphological processes with regard to their current states of activity
I	inactive	

Surface Expressions

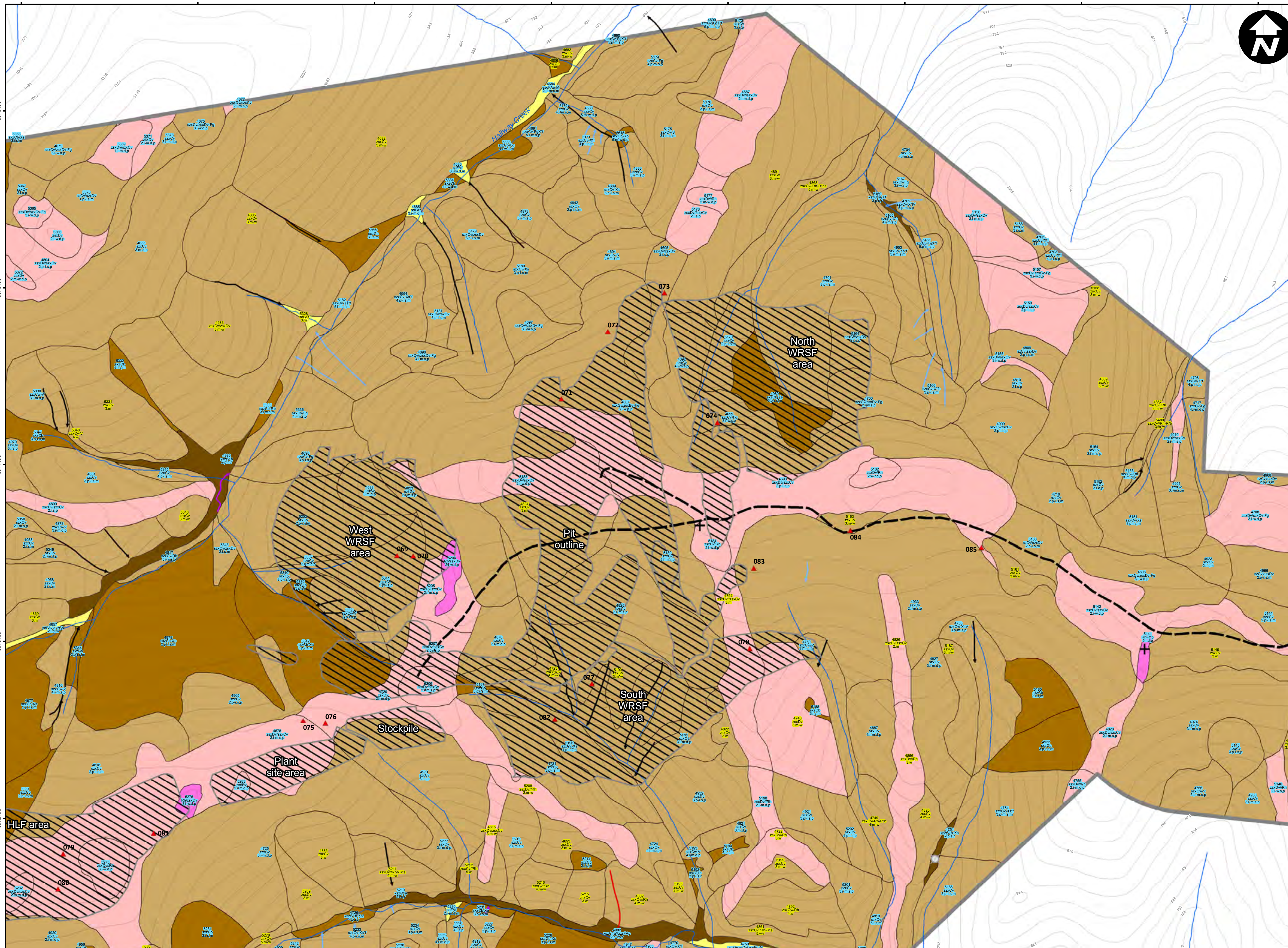
Symbol	Name	Description
a	moderate slope	A unidirectional surface with a slope of 27-50%; longitudinal profile is either straight, or slightly concave or convex; relief of local surface irregularities is less than 1 m.
b	blanket	A mantle of unconsolidated materials >1 m thick; blankets are thick enough to mask minor irregularities of the underlying surface, but still conform to general underlying topography.
c	cone	A cone-shaped accumulation of sediment with a relatively smooth surface and a slope steeper than 26%; longitudinal profile is either straight, or slightly concave or convex.
f	fan	A relatively smooth sector of a cone exhibiting a slope gradient less than or equal to 26%; longitudinal profile is either straight, or slightly concave or convex.
a	apron (colluvium only)	Complex of coalescent cones, fans or constructional sloping surfaces, usually in a slope toe position.
h	hummocky	Steep-sided hillocks and hollows with multidirectional slopes, dominantly between 26 and 70%, and relief greater than 1 m; bedrock slopes may be locally steeper.
j	gentle slope	A unidirectional surface with a slope of 6-25%; longitudinal profile is either straight, or slightly concave or convex; relief of local surface irregularities is less than 1 m.
k	moderately steep slope	A unidirectional surface with a slope of 50-70%; longitudinal profile is either straight, or slightly concave or convex; relief of local surface irregularities is less than 1 m.
p	plain	A level or very gently sloping unidirectional surface with a gradient of 0 to 5%; longitudinal profile is either straight, or slightly concave or convex; relief of local surface irregularities is less then 1 m.
r	ridged	Assemblage of parallel or sub-parallel elongate hillocks with slopes dominantly between 26 and 70% and relief greater than 1 m; bedrock slopes may be locally steeper.
s	steep slope	A unidirectional surface with a slope of >70%; the longitudinal profile is either straight, or slightly concave or convex; local surface irregularities have a relief less than 1 m.
t	terraced	A single feature or assemblage of step-like forms where each step consists of a scarp face and a horizontal or gently inclined surface above it.
u	undulating	Gently sloping hillocks and hollows with multidirectional slopes up to 26% and relief greater than 1 m.
v	veneer	A layer of unconsolidated material 10 cm to 1 m thick; too thin to mask the minor irregularities of the surface of the underlying material.
w	mantle of variable thickness	A layer or discontinuous layer of surficial material of variable thickness (0 to about 3 m) that fills or partially fills depressions in an irregular substrate. It is generally too thin to mask prominent irregularities in the underlying material.
x	thin veneer	Similar to veneer; 2 to 20 cm thick.

Geomorphological Processes

Symbol	Name	Assumed Status	Description
F	slow mass movements	(A)	Slow downslope movement of masses of cohesive or non-cohesive surficial material by creeping, flowing, or sliding.
I	irregularly sinuous channels	(A)	A clearly defined main channel displaying irregular turns and bends without repetition of similar features. Back channels may be common, and minor side channels and a few bars and islands may be present, but regular and irregular meanders are absent.
M	meandering channels	(A)	A clearly defined channel characterized by regular patterns of bends.
R	rapid mass movements	(A)	Rapid downslope movement by falling, rolling, sliding or flowing of dry, moist or saturated surficial materials and/or bedrock.
S	solifluction	(A)	Slow gravitational downslope movement of lobate forms composed of saturated surficial materials across a frozen or otherwise impermeable substrate.
V	gully erosion	(A)	Parallel/subparallel long, narrow ravines due to erosion by various processes.
X	permafrost	(A)	Processes controlled by the presence of permafrost.

Geomorphological Process Subclass

Symbol	Name	Description
"	initiation zone	Polygon includes sites or zones where mass movement processes initiate; used to distinguish initiation zones from runout zones.
Permafrost Processes		
e	thermal erosion	Gullies and depressions created by melting of permafrost due to heat transfer from water bodies, typically flowing streams.
f	thaw flow slides	Shallow slope failures within the active layer caused by the thawing of permafrost.
n	pingos	A mound of earth-covered ice where groundwater discharge (seepage) through permafrost freezes and accumulates at or close to the ground surface.
s	sheetwash	The mobilization and redistribution of fine material by water flowing down the surface or within the shallow subsurface of smooth slopes, typically underlain by permafrost.
t	thermokarst subsidence	Surface depressions created by thawing of permafrost, typically containing standing water.
Mass Movement Processes		
b	rockfall	Descent of masses of bedrock by falling, bouncing and rolling.
g	rock creep	Slow down-slope movement of angular debris under periglacial conditions.
m	slump in bedrock	Sliding of internally cohesive masses of bedrock along a slip plane that is concave upward or planar.
r	rockslide	Descent of large masses of disintegrating bedrock by sliding.
s	debris slide	Sliding of disintegrating mass of surficial material.
u	slump in surficial material	Sliding of internally cohesive masses of surficial material along a slip plane that is concave upward or planar.



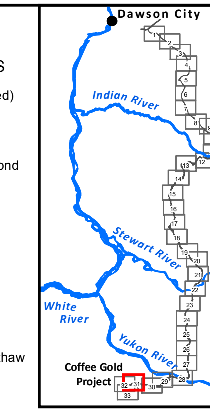
Legend

ON-SITE SYMBOLS

- Pingo (collapsed)
- Pingo
- Thermokarst pond
- Tor
- Active layer detachment
- Debris slide
- Gully
- Retrogressive thaw flow
- Rock slide
- Slump
- Thermokarst gully

Permafrost absent (inferred)
Permafrost present (inferred)

- Study area
- Palmer Environmental detailed field site and ID
- Road centreline (includes existing and proposed sections)
- Proposed mine facilities
- Waterbody
- ~30 m topographic contour



SURFICIAL MATERIAL (DOMINANT)

- Anthropogenic (A)
- Organic (O)
- Fluvial (F)
- Thin colluvial veneer (Cx)
- Colluvial veneer (Cv) or mantle of variable thickness (Cw)
- Colluvial blanket (Cb or C1b)
- Colluvial apron (Ca or C1a), fan (Cf), cone (Cc); undulating (Cu), or hummocky (Ch) deposits
- Glaciofluvial (FG)
- Weathered bedrock (D)
- Bedrock (R)

LABEL FORMAT

1
sxzCb/sdFAv-Xe
2.i-p.s,m

Texture of terrain component 2 (increasing order of dominance); Unique polygon identifier; Terrain component delimiter; Surficial material of terrain component 1; Surficial material of terrain component 2; Activity qualifier of terrain component 2; Texture of terrain component 1 (increasing order of dominance); Geomorphological process and subclass code for whole polygon; Surface expression(s) of terrain component 1; Surface expression(s) of terrain component 2; Slope class; Drainage class(es); Depth to permafrost; Permafrost ice content

SURFACE EXPRESSION

a	moderate slope
b	blanket
c	cone
f	fan
a	apron (colluvial polygons only)
h	hummocky
j	gentle slope
k	moderately steep slope
m	rolling
p	plain
r	ridge(s)
s	steep slope
t	terrace(s)
u	undulating
v	veneer
w	mantle of variable thickness
x	thin veneer

GEOMORPHOLOGICAL PROCESS AND SUBCLASS

F	Slow mass movements	g – rock creep; m – slump (bedrock); u – slump (surficial material); " – initiation zone
I	Irregularly sinuous channels	
M	Meandering channels	
R	Rapid mass movements	b – rockfall; m – slump (bedrock); r – rockslide; s – debris slide; " – initiation zone
S	Solifluction	
V	Gully erosion	
X	Permafrost processes	e – thermokarst (thermal erosion); f – thaw flow slides; s – sheetwash; t – thermokarst (subsidence); n – pingo; " – initiation zone

TEXTURE

a	blocks
b	boulders
k	cobbles
p	pebbles
s	sand
z	silt
c	clay
d	mixed fragments
g	gravel
x	angular fragments
r	rubble
e	fibric

DELIMITER AND MATERIAL SUBTYPE

/	the component in front of this symbol is more extensive than the component that follows
//	the component in front this symbol is much more extensive than the component that follows
\	the component in front of this symbol overlies the component that follows
1	project-specific subtype of colluvial complex

DOMINANT SLOPE CLASS

1	planar
2	gentle
3	moderate
4	moderately steep
5	steep

DRAINAGE CLASS

x	very rapid
r	rapid
w	well
m	moderately well
i	imperfect
p	poor
v	very poor

ACTIVITY QUALIFIER

A	active
I	inactive

DEPTH TO PERMAFROST

n	near surface
s	shallow
d	deep

PERMAFROST ICE CONTENT

p	ice-poor
m	ice-moderate
r	ice-rich

Refer to "Terrain Codes Definitions" at beginning of map book for definitions of all terminology

COFFEE GOLD PROJECT

Terrain

0 87.5 175 350 525 700 m

1:20,000

Original page size: 11.00 x 17.00 in

Base mapping from Geomatics Yukon and Natural Resources Canada
Terrain mapping completed by D. Sacco, C. Brown and R. McKillop using softcopy photo-interpretation systems at a view (zoom) scale of 1:10,000, following field reconnaissance conducted in association with J. Coates (Kryotek Arctic Innovation) in August 2015. Terrain codes are from the Yukon Geological Survey's adaptation of the Terrain Classification System for British Columbia (Howes and Kenk, 1997). Typical textures inferred based on observed landform associations.

Project number: 13103

Projection: UTM Zone 7
Datum: NAD 1983
Units: metre

Map 1

Sheet 31 of 33

KAMINAK GOLD CORPORATION

PALMER ENVIRONMENTAL CONSULTING GROUP INC.

Drawn by: CEB Checked by: RM 03/03/2016

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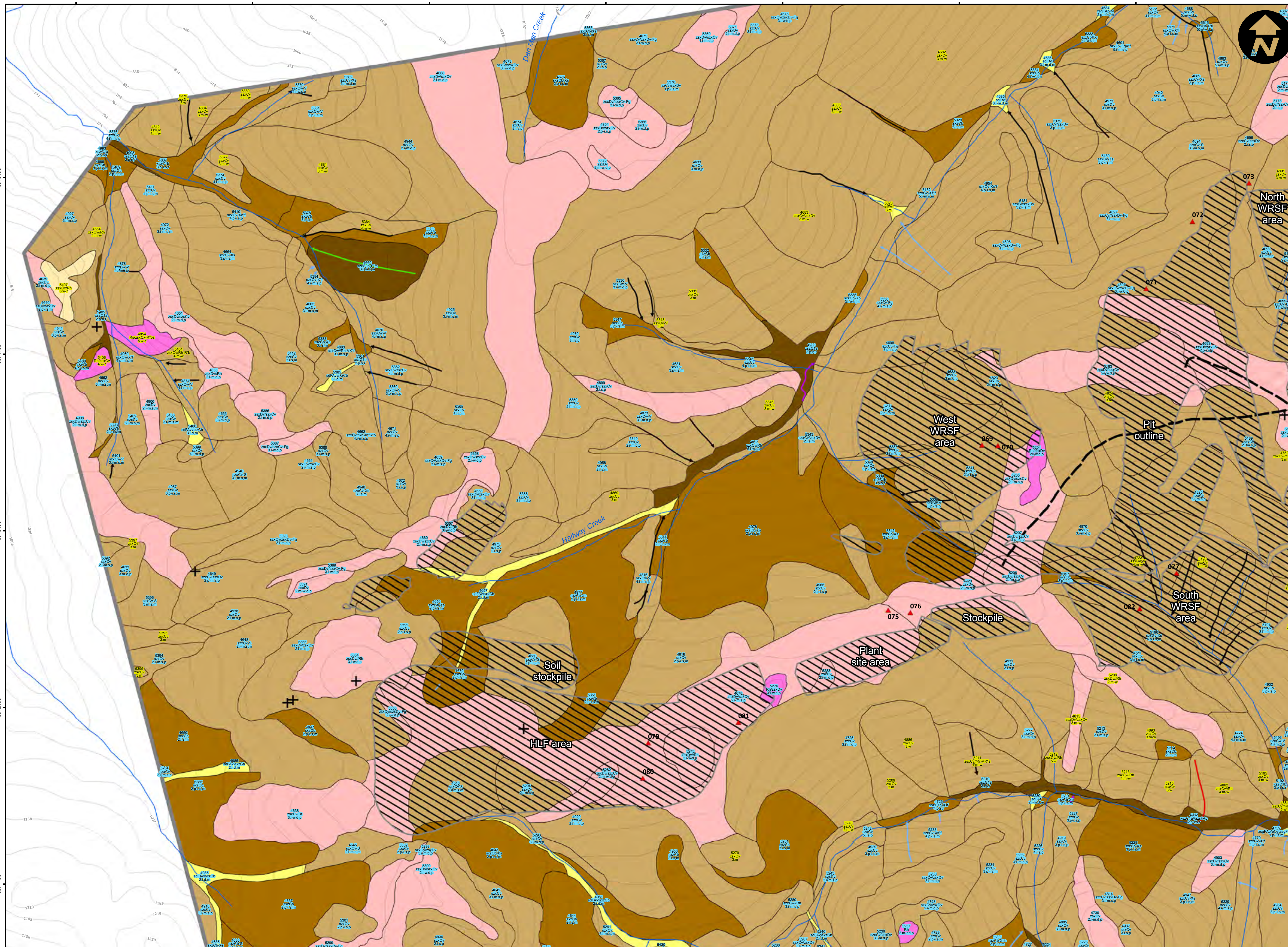

Legend

ON-SITE SYMBOLS
- Pingo (collapsed)
- Pingo
- Thermokarst pond
- Tor
- Active layer detachment
- Debris slide
- Gully
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Permafrost absent (inferred)
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- Road centreline (includes existing and proposed sections)
- Proposed mine facilities
- Waterbody
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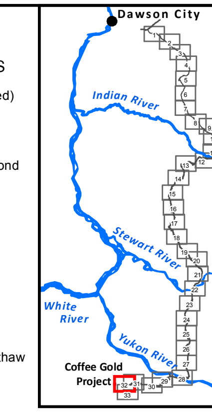

SURFICIAL MATERIAL (DOMINANT)
- Anthropogenic (A)
- Organic (O)
- Fluvial (F)
- Thin colluvial veneer (Cx)
- Colluvial veneer (Cv) or mantle of variable thickness (Cw)
- Colluvial blanket (Cb or C1b)
- Colluvial apron (Ca or C1a), fan (Cf), cone (Cc); undulating (Cu), or hummocky (Ch) deposits
- Glaciofluvial (FG)
- Weathered bedrock (D)
- Bedrock (R)

LABEL FORMAT

sxzCb/sdFAv-Xe
2.i-p.s,m

Terrain component delimiter; Texture of terrain component 2 (increasing order of dominance); Unique polygon identifier; Surficial material of terrain component 2; Surficial material of terrain component 1; Activity qualifier of terrain component 2; Texture of terrain component 1 (increasing order of dominance); Geomorphological process and subclass code for whole polygon; Surface expression(s) of terrain component 1; Surface expression(s) of terrain component 2; Slope class; Drainage class(es); Depth to permafrost; Permafrost ice content

SURFACE EXPRESSION
- a moderate slope
- b blanket
- c cone
- f fan
- a apron (colluvial polygons only)
- h hummocky
- j gentle slope
- k moderately steep slope
- m rolling
- p plain
- r ridge(s)
- s steep slope
- t terrace(s)
- u undulating
- v veneer
- w mantle of variable thickness
- x thin veneer

GEOMORPHOLOGICAL PROCESS AND SUBCLASS
- F Slow mass movements: g – rock creep; m – slump (bedrock); u – slump (surficial material); " – initiation zone
- I Irregularly sinuous channels
- M Meandering channels
- R Rapid mass movements: b – rockfall; m – slump (bedrock); r – rockslide; s – debris slide; " – initiation zone
- S Solifluction
- V Gully erosion
- X Permafrost processes: e – thermokarst (thermal erosion); f – thaw flow slides; s – sheetwash; t – thermokarst (subsidence); n – pingo; " – initiation zone

TEXTURE
- a blocks
- b boulders
- k cobbles
- p pebbles
- s sand
- z silt
- c clay
- d mixed fragments
- g gravel
- x angular fragments
- r rubble
- e fibric

DELIMITER AND MATERIAL SUBTYPE
- / the component in front of this symbol is more extensive than the component that follows
- // the component in front this symbol is much more extensive than the component that follows
- \ the component in front of this symbol overlies the component that follows
- 1 project-specific subtype of colluvial complex

DOMINANT SLOPE CLASS
- 1 planar
- 2 gentle
- 3 moderate
- 4 moderately steep
- 5 steep

DRAINAGE CLASS
- x very rapid
- r rapid
- w well
- m moderately well
- i imperfect
- p poor
- v very poor

ACTIVITY QUALIFIER
- A active
- I inactive

DEPTH TO PERMAFROST
- n near surface
- s shallow
- d deep

PERMAFROST ICE CONTENT
- p ice-poor
- m ice-moderate
- r ice-rich

Refer to "Terrain Codes Definitions" at beginning of map book for definitions of all terminology

COFFEE GOLD PROJECT
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Project number: 13103

Projection: UTM Zone 7
Datum: NAD 1983
Units: metre

Map 1

Sheet 32 of 33

KAMINAK GOLD CORPORATION

PALMER ENVIRONMENTAL CONSULTING GROUP INC.

Drawn by: CEB Checked by: RM 03/03/2016

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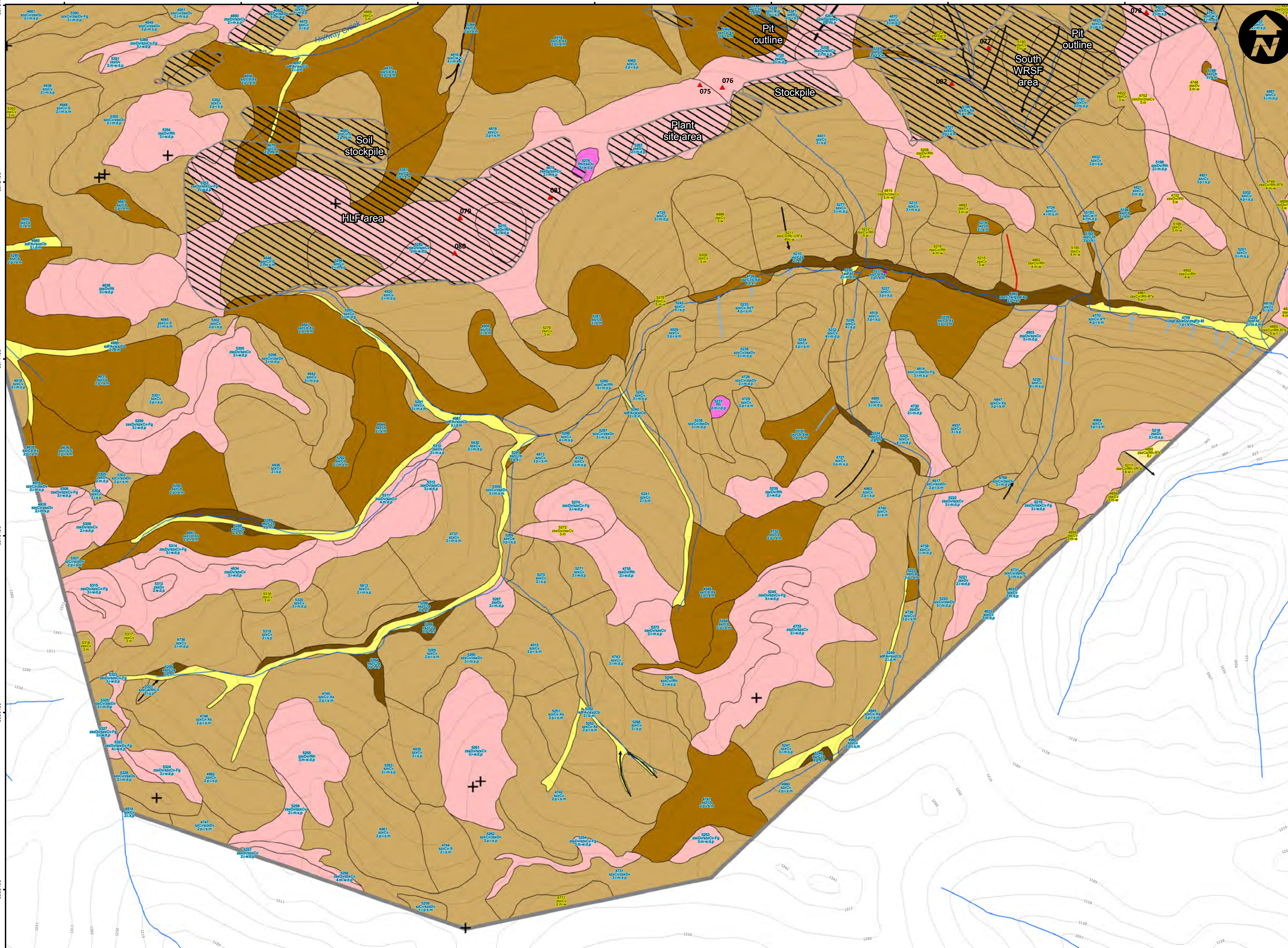

Legend

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Dawson City · Indian River · Stewart River · White River · Yukon River · Coffee Gold Project

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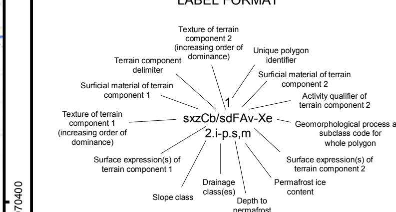
- Glaciofluvial (FG)
- Weathered bedrock (D)
- Bedrock (R)

LABEL FORMAT



SURFACE EXPRESSION

a	moderate slope
b	blanket
c	cone
f	fan
a	apron (colluvial polygons only)
h	hummocky
j	gentle slope
k	moderately steep slope
m	rolling
p	plain
r	ridge(s)
s	steep slope
t	terrace(s)
u	undulating
v	veneer
w	mantle of variable thickness
x	thin veneer

GEOMORPHOLOGICAL PROCESS AND SUBCLASS

F	Slow mass movements	g – rock creep m – slump (bedrock) u – slump (surficial material) " – initiation zone
I	Irregularly sinuous channels	
M	Meandering channels	
R	Rapid mass movements	b – rockfall m – slump (bedrock) r – rockslide s – debris slide " – initiation zone
S	Solifluction	
V	Gully erosion	
X	Permafrost processes	e – thermokarst (thermal erosion) f – thaw flow slides s – sheetwash t – thermokarst (subsidence) n – pingo " – initiation zone

TEXTURE

a	blocks
b	boulders
k	cobbles
p	pebbles
s	sand
z	silt
c	clay
d	mixed fragments
g	gravel
x	angular fragments
r	rubble
e	fibric

DELIMITER AND MATERIAL SUBTYPE

/	the component in front of this symbol is more extensive than the component that follows
//	the component in front this symbol is much more extensive than the component that follows
\	the component in front of this symbol overlies the component that follows
1	project-specific subtype of colluvial complex

DOMINANT SLOPE CLASS

1	planar
2	gentle
3	moderate
4	moderately steep
5	steep

DRAINAGE CLASS

x	very rapid
r	rapid
w	well
m	moderately well
i	imperfect
p	poor
v	very poor

ACTIVITY QUALIFIER

A	active
I	inactive

DEPTH TO PERMAFROST

n	near surface
s	shallow
d	deep

PERMAFROST ICE CONTENT

p	ice-poor
m	ice-moderate
r	ice-rich

Refer to "Terrain Codes Definitions" at beginning of map book for definitions of all terminology

COFFEE GOLD PROJECT

Terrain

0 87.5 175 350 525 700 m

1:20,000

Original page size: 11.00 x 17.00 in

Base mapping from Geomatics Yukon and Natural Resources Canada
Terrain mapping completed by D. Sacco, C. Brown and R. McKillop using softcopy photo-interpretation systems at a view (zoom) scale of 1:10,000, following field reconnaissance conducted in association with J. Coates (Kryotek Arctic Innovation) in August 2015. Terrain codes are from the Yukon Geological Survey's adaptation of the Terrain Classification System for British Columbia (Howes and Kenk, 1997). Typical textures inferred based on observed landform associations.

Project number: 13103

Projection: UTM Zone 7
Datum: NAD 1983
Units: metre

Map 1

Sheet 33 of 33

KAMINAK GOLD CORPORATION

PALMER ENVIRONMENTAL CONSULTING GROUP INC.

Drawn by: CEB Checked by: RM 03/03/2016

Document Path: C:\Egnyte\Shared\Projects\Active\1310 - Kaminak Gold Corp\13103 - Coffee TSM\Programs\Mapping\Report figures\Terrain map\Terrain map_11x17_landscape.mxd

Appendix B

Map 2 – Terrain Stability and Hazards

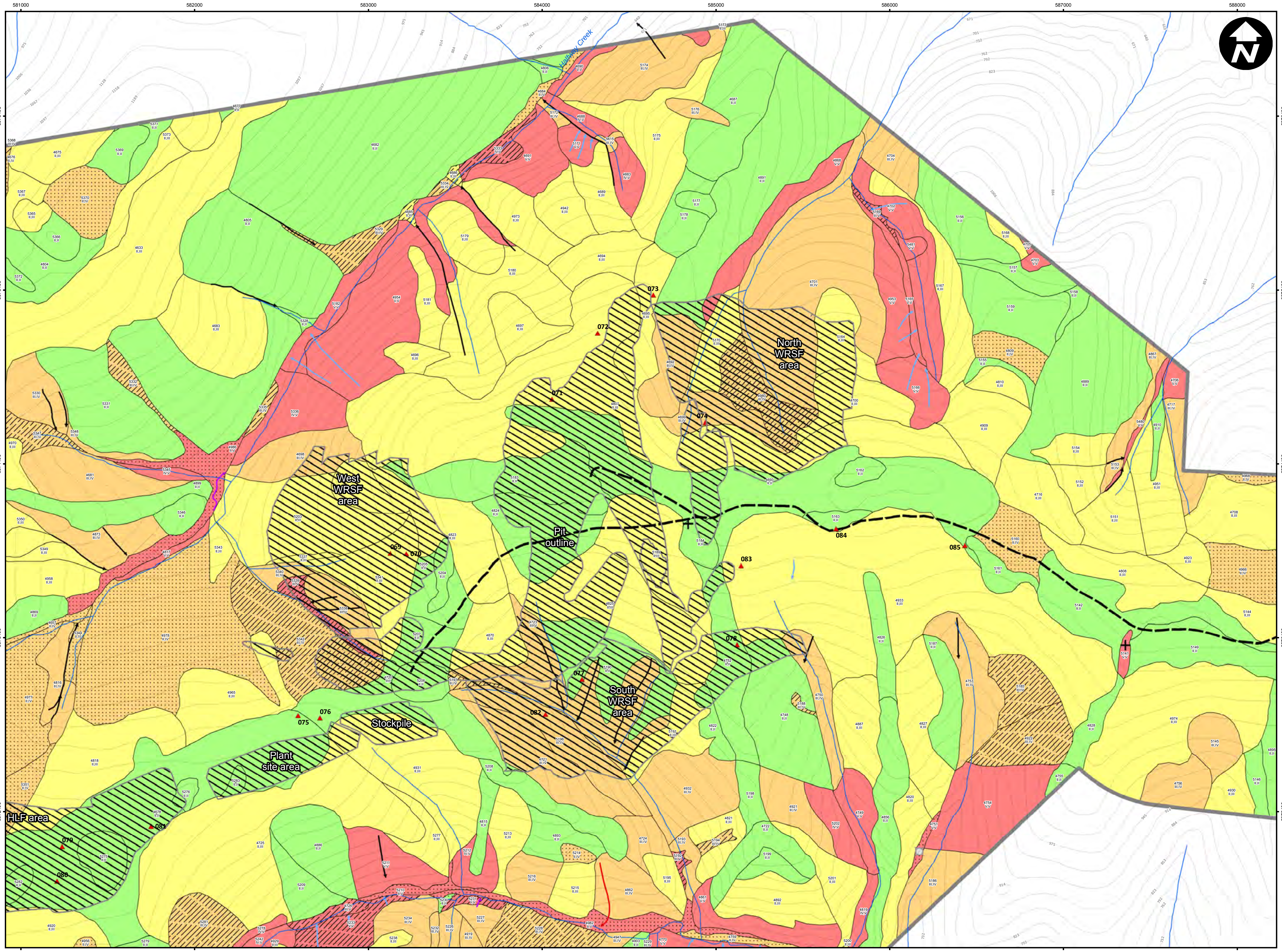
Coffee Gold Project Terrain Stability and Hazards Map Code Definitions

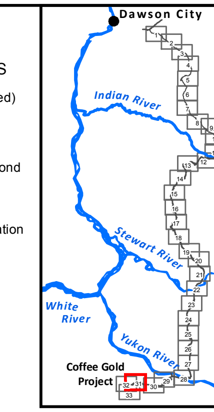
Terrain Stability Class

Symbol	Class	Condition	Interpretation		Common terrain characteristics	
			Existing (current conditions)	Disturbed (following disturbance to ground conditions from road/facility construction without mitigation)	Existing (current conditions)	Disturbed (following disturbance to ground conditions from road/facility construction without mitigation)
I	stable	permafrost	No significant stability problems.		Planar to gently sloping bedrock and weathered bedrock; active fluvial units.	Planar to gently sloping bedrock, weathered bedrock and active fluvial units with deep, ice-poor permafrost.
		no permafrost			Planar to low sloping bedrock and weathered bedrock; active fluvial units.	
II	generally stable	permafrost	Very low likelihood of slope instability.	Very low likelihood of slope instability; no thermokarst subsidence or erosion expected.	Colluvial mantles on gentle slopes; gently sloping colluvial complexes; gently sloping fluvial units; organic deposits; moderately steep bedrock and weathered bedrock.	Colluvial mantles on gentle slopes with deep, ice-poor permafrost; gently to moderately sloping fluvial units with deep, ice-poor permafrost.
		no permafrost	Very low likelihood of slope instability.		Gently to moderately sloping colluvial mantles and fluvial units; moderately steep bedrock and weathered bedrock.	
III	generally stable with minor potential for instability	permafrost	Low to moderate likelihood of slope instability.	Low to moderate likelihood of slope instability and/or minor thermokarst subsidence or erosion possible.	Poorly drained colluvial mantles on moderate slopes; moderately sloping colluvial complexes; imperfectly drained colluvial mantles on moderately steep slopes; ice-poor to ice-moderate permafrost.	Poorly drained colluvial mantles on gentle slopes; imperfectly drained colluvial mantles on moderate slopes; ice-poor to ice-moderate permafrost.
		no permafrost	Low to moderate likelihood of slope instability.		Colluvial mantles on moderately steep slopes.	
IV	potentially unstable	permafrost	Expected to contain areas with a high likelihood of slope instability.	Expected to contain areas with a high likelihood of slope instability and/or moderate thermokarst subsidence or erosion.	Poorly drained colluvial mantles on moderately steep slopes; moderately steep colluvial complexes.	Any surficial unit thicker than a veneer with ice-moderate permafrost; poorly drained colluvial mantles on moderate slopes; imperfectly drained colluvial mantles on moderately steep slopes.
		no permafrost	Expected to contain areas with a high likelihood of slope instability.		Colluvial units on moderately steep to steep slopes.	
V	unstable	permafrost	Expected to contain areas with a very high likelihood of slope instability and/or thermokarst; may or may not exhibit evidence of previous slope failure and/or thermokarst.	Expected to contain areas with a very high likelihood of slope instability and/or major thermokarst subsidence or thermal erosion; typically exhibits evidence of previous slope failure and/or thermokarst.	Any unit with evidence of slope failure and/or thermokarst subsidence or thermal erosion.	Any unit with evidence of slope failure or ice-rich permafrost; poorly drained colluvial mantles on moderately steep slopes.
		no permafrost	Expected to contain areas with a very high likelihood of slope instability; typically exhibits evidence of previous slope failure.		Any unit with evidence of slope failure; typically occur on moderately steep to steep slopes.	

Applicable Hazard Category

Symbol	Class	Description
s	slope failure potential is dominant	Dominant hazard potential category related to gravity induced slope failure. May or may not include existing failures. Represents default category.
t	thermokarst potential is dominant	Dominant hazard potential category related to thermokarst subsidence or erosion. May or may not include existing failures.
b	both slope failure & thermokarst potential are co-dominant	Hazard potential category related to gravity induced slope failure and thermokarst subsidence or erosion. May or may not include existing failures.





Legend

ON-SITE SYMBOLS

- Pingo (collapsed)
- Pingo
- Thermokarst pond
- Tor
- Meander migration hazard
- Icing hazard
- Active layer detachment
- Debris slide
- Gully
- Retrogressive thaw flow
- Rock slide
- Slump
- Thermokarst gully
- Study area
- Palmer Environmental detailed field site and ID
- Road centreline (includes existing and proposed sections)
- Proposed mine facilities
- Waterbody
- ~30 m topographic contours

TERRAIN STABILITY CLASS

- No rating assigned (anthropogenic)
- I - Stable
- II - Generally stable
- III - Generally stable with isolated minor instability
- IV - Potentially unstable
- V - Unstable

APPLICABLE HAZARD CATEGORY

- Slope failure potential is dominant
- Thermokarst potential is dominant
- Slope failure and thermokarst potential are co-dominant

LABEL FORMAT

Unique polygon identifier

1
III,IV

Existing terrain stability class (current conditions)

Disturbed terrain stability class (following disturbance to ground conditions from road/facility construction without mitigation)

Refer to "Terrain Stability and Hazards Code Definitions" at beginning of map book for definitions of all terminology, and refer to Terrain map (Map 1) for complete terrain polygon labels (including drainage, permafrost and slope classes).

COFFEE GOLD PROJECT

Terrain Stability and Hazards

0 87.5 175 350 525 700 m

1:20,000

Original page size: 11.00 x 17.00 in

Base mapping from Geomatics Yukon and Natural Resources Canada
Terrain stability mapping completed by D. Sacco, C. Brown and R. McKillop using softcopy photo-interpretation systems at a view (zoom) scale of 1:10,000, following field reconnaissance conducted in association with J. Coates (Kryotek Arctic Innovation) in August 2015.

Project number: 13103

Projection: UTM Zone 7
Datum: NAD 1983
Units: metre

Map 2

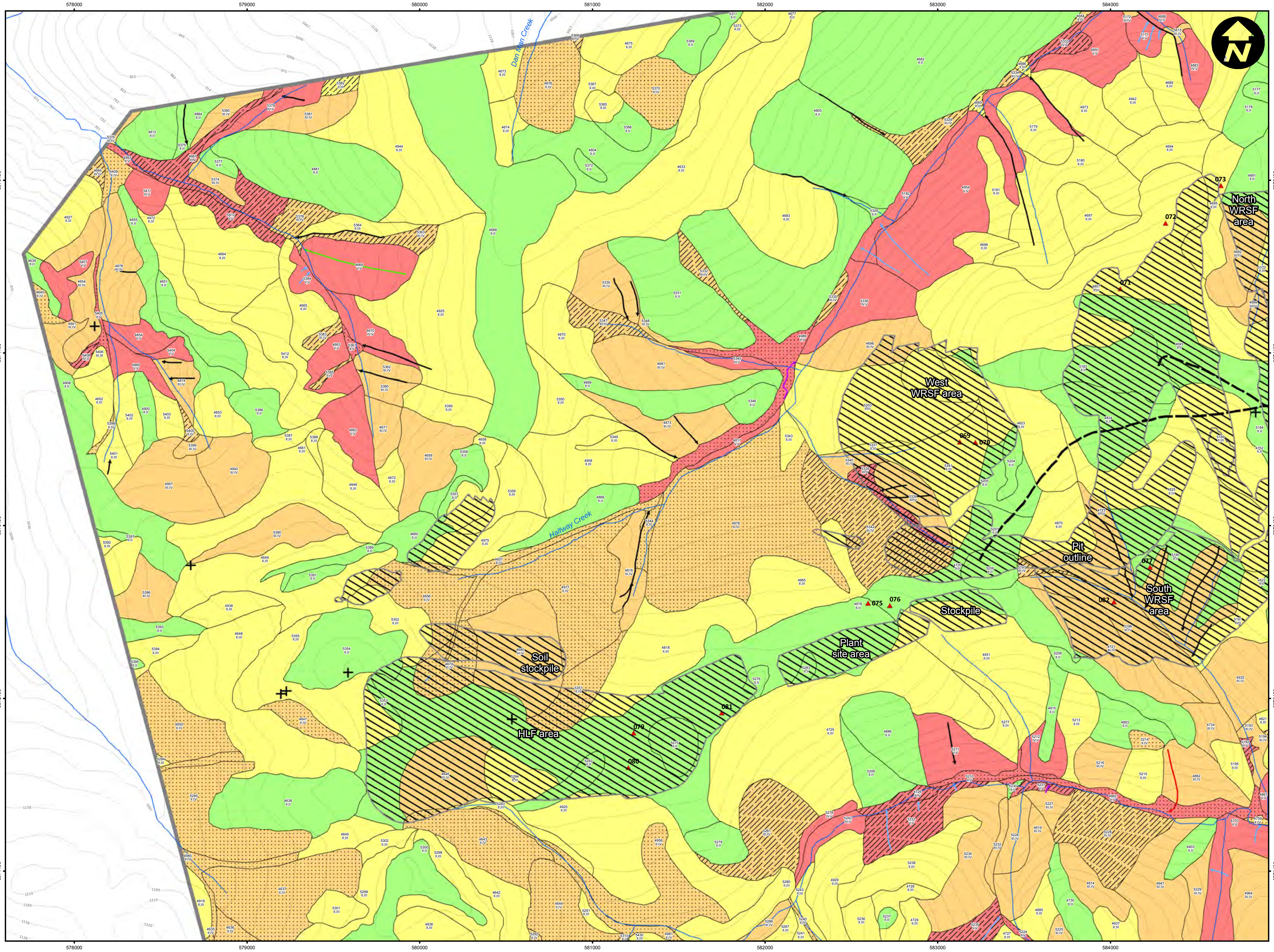
Sheet 31 of 33

KAMINAK GOLD CORPORATION

PALMER ENVIRONMENTAL CONSULTING GROUP INC.

Drawn by: CEB Checked by: RM 03/03/2016

Document Path: C:\Egnyte\Shared\Projects\Active\1310 - Kaminak Gold Corp\13103 - Coffee TSM\Programs\Mapping\Report figures\Terrain stability map\Terrain stability map_11x17_landscape.mxd



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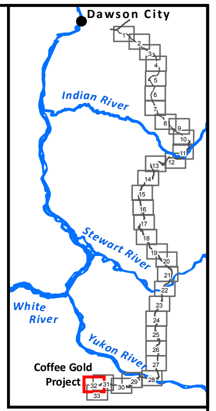

ON-SITE SYMBOLS

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TERRAIN STABILITY CLASS

- No rating assigned (anthropogenic)
- I - Stable
- II - Generally stable
- III - Generally stable with isolated minor instability
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- V - Unstable

APPLICABLE HAZARD CATEGORY

- Slope failure potential is dominant
- Thermokarst potential is dominant
- Slope failure and thermokarst potential are co-dominant

LABEL FORMAT

Unique polygon identifier: 1
III,IV
Existing terrain stability class (current conditions) (III); Disturbed terrain stability class (following disturbance to ground conditions from road/facility construction without mitigation) (IV)

Refer to "Terrain Stability and Hazards Code Definitions" at beginning of map book for definitions of all terminology, and refer to Terrain map (Map 1) for complete terrain polygon labels (including drainage, permafrost and slope classes).

COFFEE GOLD PROJECT

Terrain Stability and Hazards

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Base mapping from Geomatics Yukon and Natural Resources Canada
Terrain stability mapping completed by D. Sacco, C. Brown and R. McKillop using softcopy photo-interpretation systems at a view (zoom) scale of 1:10,000, following field reconnaissance conducted in association with J. Coates (Kryotek Arctic Innovation) in August 2015.

Project number: 13103

Projection: UTM Zone 7
Datum: NAD 1983
Units: metre

KAMINAK GOLD CORPORATION

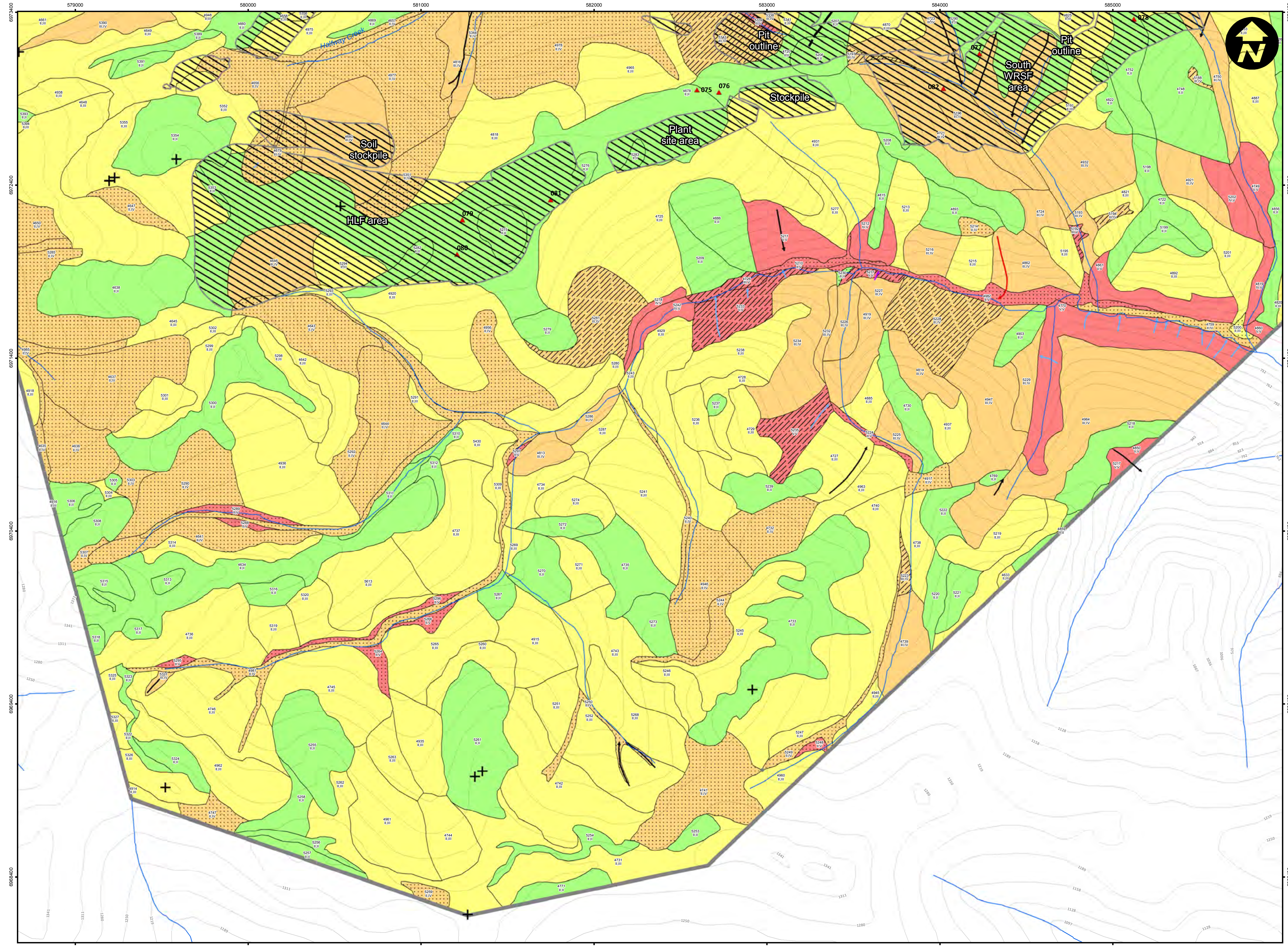
PALMER ENVIRONMENTAL CONSULTING GROUP INC.

Map 2

Sheet 32 of 33

Drawn by: CEB Checked by: RM 03/03/2016

Document Path: C:\Egnyte\Shared\Projects\Active\1310 - Kaminak Gold Corp\13103 - Coffee TSMPrograms\Mapping\Report figures\Terrain stability map\Terrain stability map_11x17_landscape.mxd



Legend

ON-SITE SYMBOLS

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- Tor
- Meander migration hazard
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- Debris slide
- Gully
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- Rock slide
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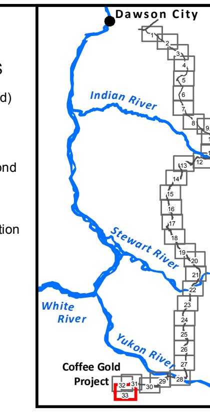
- Proposed mine facilities
- Waterbody
- ~30 m topographic contours

TERRAIN STABILITY CLASS

- No rating assigned (anthropogenic)
- I - Stable
- II - Generally stable
- III - Generally stable with isolated minor instability
- IV - Potentially unstable
- V - Unstable

APPLICABLE HAZARD CATEGORY

- Slope failure potential is dominant
- Thermokarst potential is dominant
- Slope failure and thermokarst potential are co-dominant



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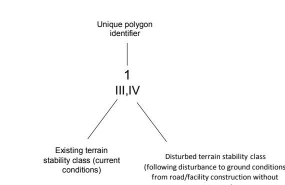


Refer to "Terrain Stability and Hazards Code Definitions" at beginning of map book for definitions of all terminology, and refer to Terrain map (Map 1) for complete terrain polygon labels (including drainage, permafrost and slope classes).

COFFEE GOLD PROJECT
Terrain Stability and Hazards

0 87.5 175 350 525 700 m — 1:20,000

Original page size: 11.00 x 17.00 in

Base mapping from Geomatics Yukon and Natural Resources Canada
Terrain stability mapping completed by D. Sacco, C. Brown and R. McKillop using softcopy photo-interpretation systems at a view (zoom) scale of 1:10,000, following field reconnaissance conducted in association with J. Coates (Kryotek Arctic Innovation) in August 2015.

Project number: 13103

Projection: UTM Zone 7
Datum: NAD 1983
Units: metre

Map 2

Sheet 33 of 33

KAMINAK GOLD CORPORATION

PALMER ENVIRONMENTAL CONSULTING GROUP INC.

Drawn by: CEB Checked by: RM 03/03/2016

Document Path: C:\Dynamics\Shared\Projects\Active\1310 - Kaminak Gold Corp\13103 - Coffee TSM\Programs\Mapping\Report figures\Terrain stability map\Terrain stability map_11x17_landscape.mxd

Appendix C

Map 3 – Soil Erosion Potential

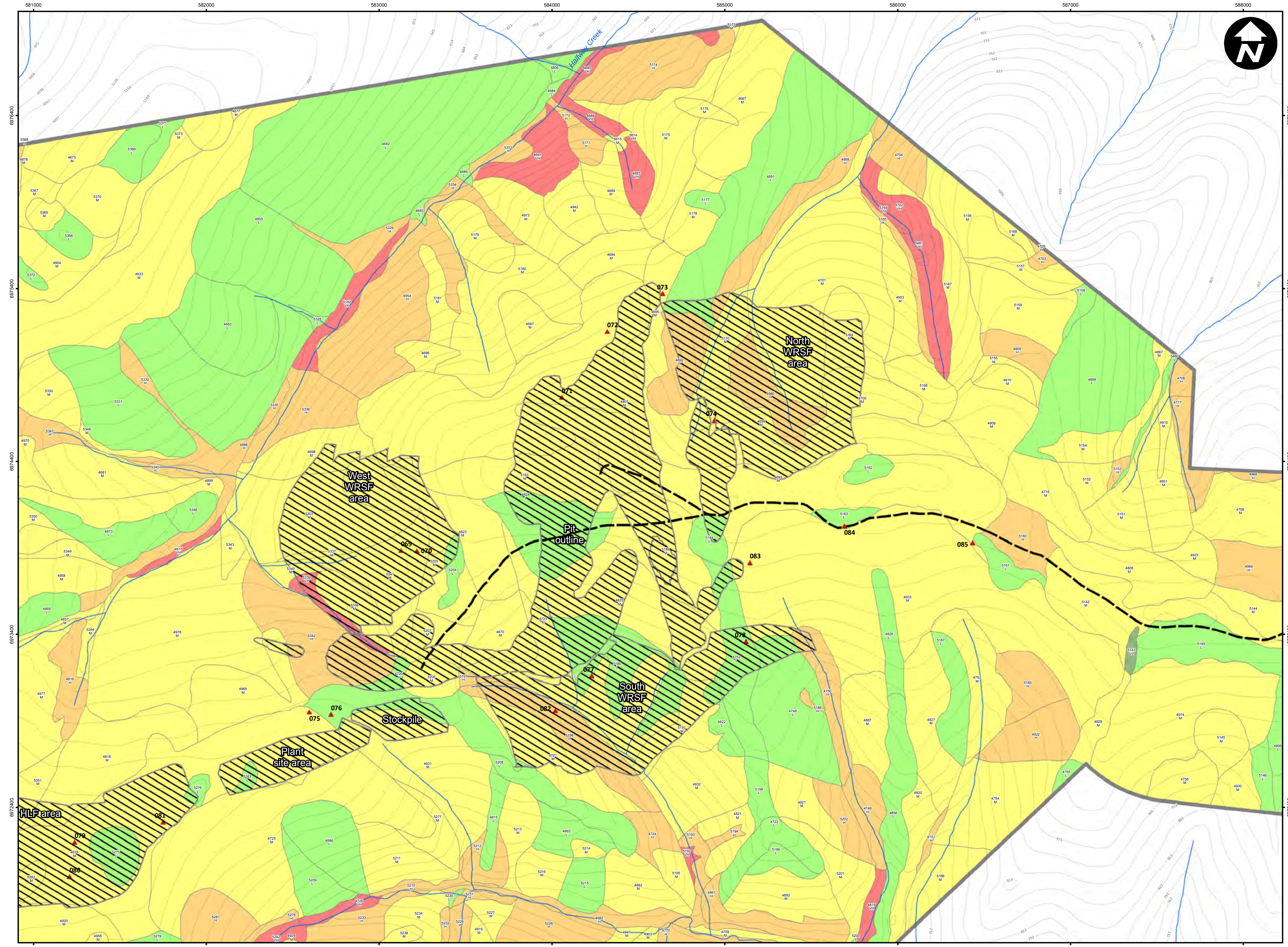
KAMINAK GOLD CORPORATION

Coffee Gold Project Soil Erosion Potential Map Code Definitions

PALMER ENVIRONMENTAL CONSULTING GROUP INC.

Soil Erosion Potential Class

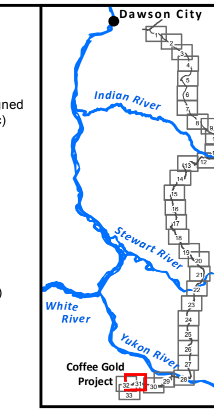
Symbol	Class	General criteria	Common terrain characteristics	Management implications
VL	very low	Increasing severity of pre-existing gullying Increasing ground ice content Increasing slope gradient Increasing silt and/or organic content	Bedrock; planar weathered bedrock; planar fluvial deposits without permafrost.	No or only very minor surface erosion within small areas of exposed soil on locally steeply sloping ground (e.g., creek banks); conventional surface runoff management appropriate.
L	low		Gently to moderately sloping weathered bedrock; gently to moderately sloping, permafrost free colluvial mantles; gently to moderately sloping, permafrost-free fluvial deposits.	Expect minor erosion of fine sediments along ditch lines, cut slopes and across disturbed soils; avoid channelling water toward more sensitive downslope units.
M	moderate		Planar to gently sloping organic material; gently to moderately sloping colluvial veneers with shallow or near-surface permafrost; gently sloping colluvial blankets with shallow or near-surface permafrost; moderately steep to steeply sloping, permafrost-free veneers and thin veneers; fluvial deposits with shallow or near-surface permafrost.	Expect moderate erosion when water is channelled down road surfaces or ditches (minor thermal erosion possible in areas of permafrost); plan for preventative and remedial actions in disturbed areas, including measures to minimize concentrated surface runoff in areas of permafrost and to trap sediments.
H	high		Moderately steeply sloping colluvial veneers; moderately to moderately steeply sloping colluvial blankets with shallow to near-surface permafrost; gently sloping colluvial complexes; ridgetop saddles with silt-rich colluvial veneer.	Significant erosion problems are expected when water is channelled onto or over exposed soil on these sites (moderate thermal erosion possible in areas of permafrost), particularly on cut slopes; plan for preventative and remedial actions in disturbed areas, including measures to minimize concentrated surface runoff in areas of permafrost and to trap sediments.
VH	very high		Steeply sloping colluvial mantles with shallow or near-surface permafrost; moderate to steeply sloping colluvial complexes.	Severe surface and gully erosion problems can be created when water is channelled onto or over these sites (major thermal erosion possible in areas of permafrost), particularly on cut slopes; erosion is commonly evident in natural conditions. If area not avoidable, minimize concentrated surface runoff in areas of permafrost, minimize extent and duration of soil exposure, and promptly stabilize soils with salvaged vegetation (e.g., moss) cover or appropriate erosion control measures.



Legend

SOIL EROSION POTENTIAL

- No rating assigned (anthropogenic)
- Very Low (VL)
- Low (L)
- Moderate (M)
- High (H)
- Very High (VH)



LABEL FORMAT

Unique polygon identifier
1
M
Soil erosion potential

- Study area
- Palmer Environmental detailed field site and ID
- Road centreline (includes existing and proposed sections)
- Proposed mine facilities
- Waterbody
- ~30 m topographic contour

Refer to "Soil Erosion Potential Code Definitions" at beginning of map book for definitions of all terminology, and refer to Terrain map (Map 1) for complete terrain polygon labels (including drainage, permafrost and slope classes).

COFFEE GOLD PROJECT
Soil Erosion Potential

0 87.5 175 350 525 700 m
1:20,000
Original page size: 11.00 x 17.00 in

Base mapping from Geomatics Yukon and Natural Resources Canada
Soil erosion potential mapping completed by D. Sacco, C. Brown and R. McKillop using softcopy photo-interpretation systems at a view (zoom) scale of 1:10,000, following field reconnaissance conducted in association with J. Coates (Kryotek Arctic Innovation) in August 2015.

Project number: 13103

Projection: UTM Zone 7
Datum: NAD 1983
Units: metre

Map 3

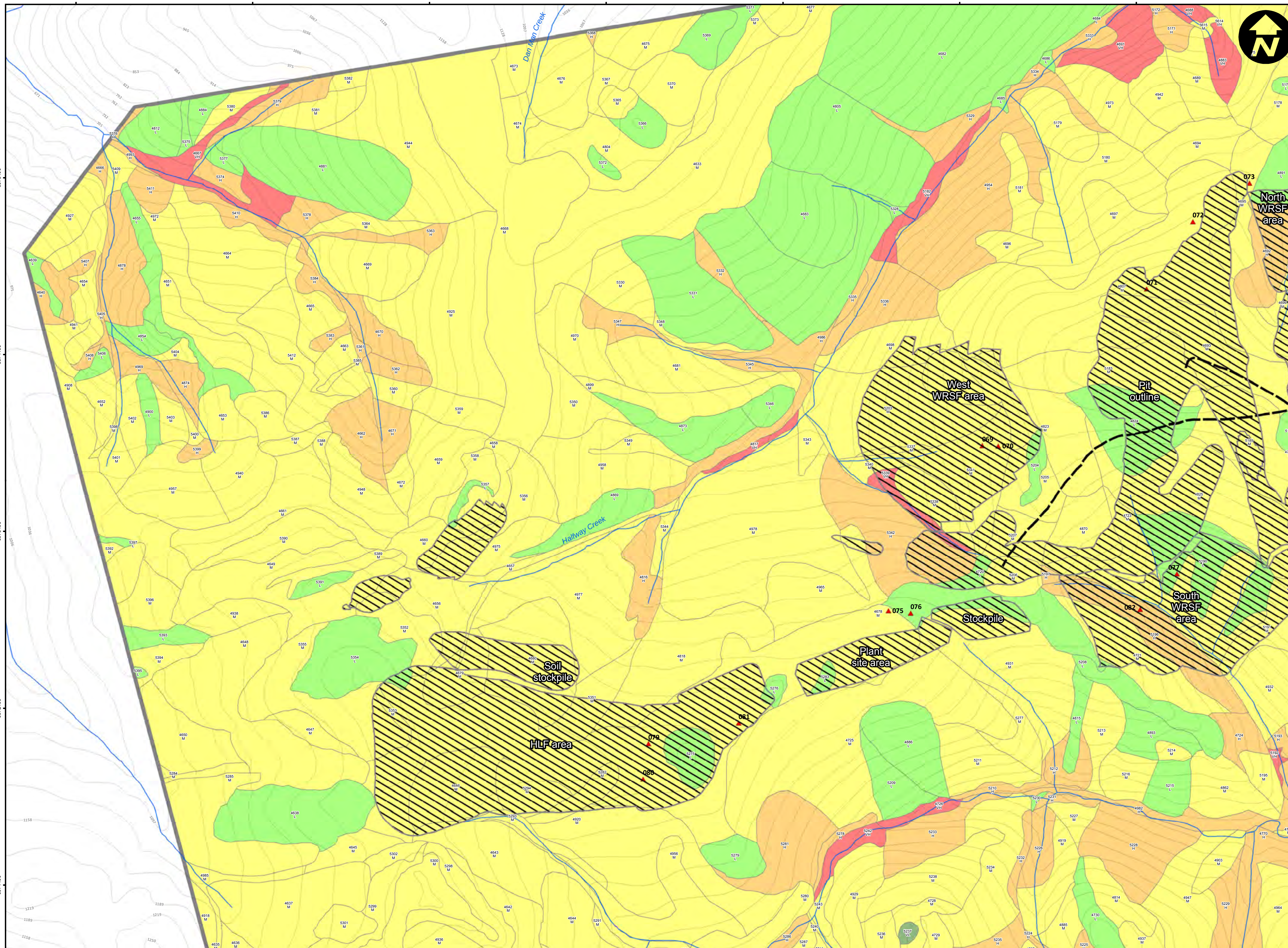
Sheet 31 of 33

KAMINAK GOLD CORPORATION

PALMER ENVIRONMENTAL CONSULTING GROUP INC.

Drawn by: CEB Checked by: RM 03/03/2016

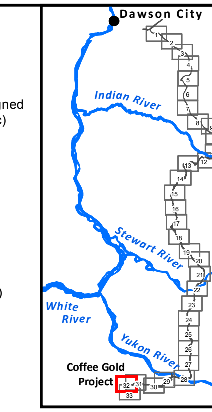
Document Path: C:\Egnyte\Shared\Projects\Active\1310 - Kaminak Gold Corp\13103 - Coffee TSM\Programs\Mapping\Report figures\Erosion potential map\Erosion potential map_11x17_landscape.mxd



Legend

SOIL EROSION POTENTIAL

- No rating assigned (anthropogenic)
- Very Low (VL)
- Low (L)
- Moderate (M)
- High (H)
- Very High (VH)



- Study area
- Palmer Environmental detailed field site and ID
- Road centreline (includes existing and proposed sections)
- Proposed mine facilities
- Waterbody
- ~30 m topographic contour

LABEL FORMAT

Unique polygon identifier

1

M

Soil erosion potential

Refer to "Soil Erosion Potential Code Definitions" at beginning of map book for definitions of all terminology, and refer to Terrain map (Map 1) for complete terrain polygon labels (including drainage, permafrost and slope classes).

COFFEE GOLD PROJECT

Soil Erosion Potential

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1:20,000

Original page size: 11.00 x 17.00 in

Base mapping from Geomatics Yukon and Natural Resources Canada
Soil erosion potential mapping completed by D. Sacco, C. Brown and R. McKillop using softcopy photo-interpretation systems at a view (zoom) scale of 1:10,000, following field reconnaissance conducted in association with J. Coates (Kryotek Arctic Innovation) in August 2015.

Project number: 13103

Projection: UTM Zone 7
Datum: NAD 1983
Units: metre

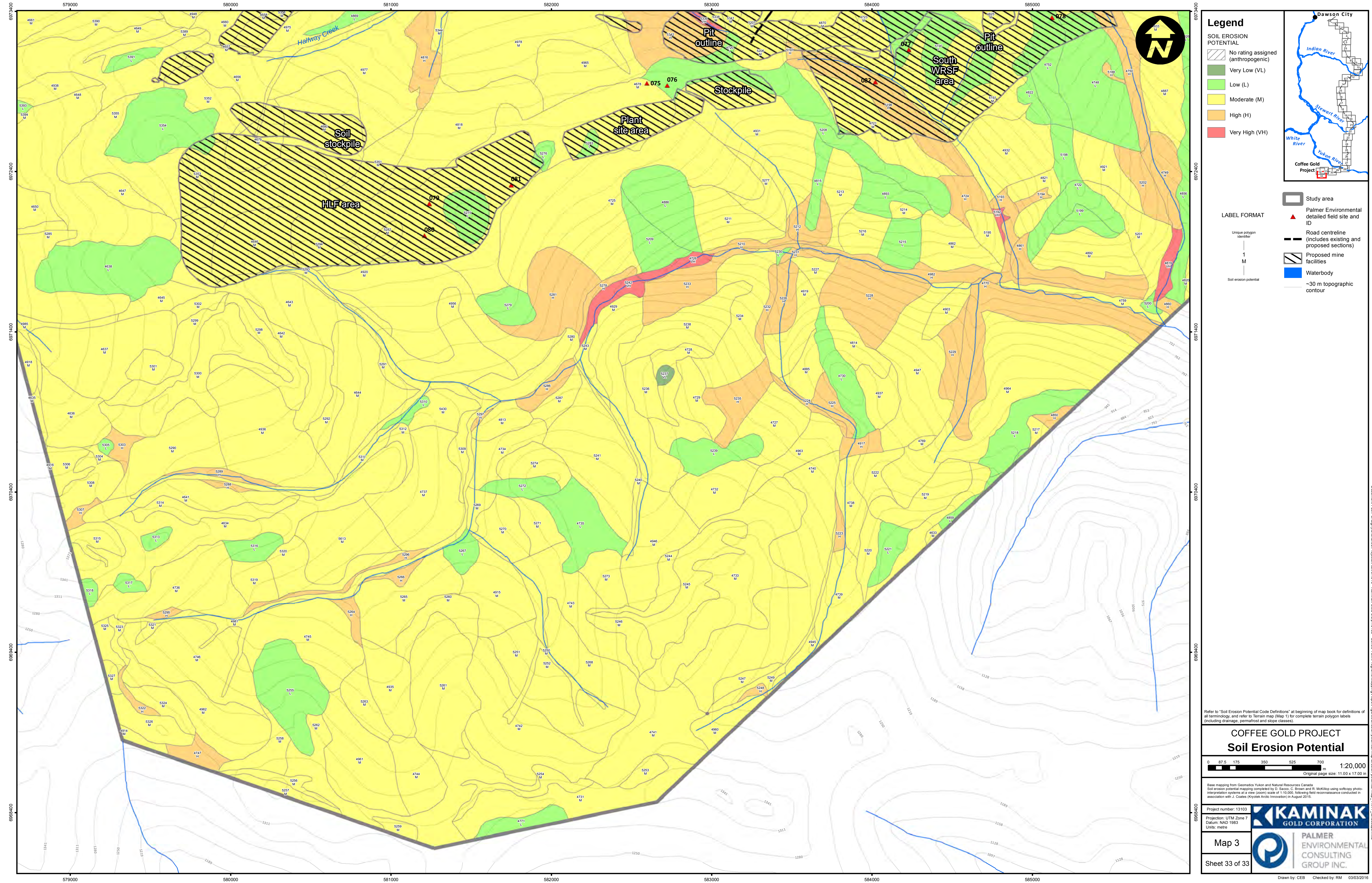
Map 3

Sheet 32 of 33

KAMINAK GOLD CORPORATION

PALMER ENVIRONMENTAL CONSULTING GROUP INC.

Drawn by: CEB Checked by: RM 03/03/2016



Refer to "Soil Erosion Potential Code Definitions" at beginning of map book for definitions of all terminology, and refer to Terrain map (Map 1) for complete terrain polygon labels (including drainage, permafrost and slope classes).

COFFEE GOLD PROJECT

Soil Erosion Potential

0 87.5 175 350 525 700 m — 1:20,000

Original page size: 11.00 x 17.00 in

Base mapping from Geomatics Yukon and Natural Resources Canada
Soil erosion potential mapping completed by D. Sacco, C. Brown and R. McKillop using softcopy photo-interpretation systems at a view (zoom) scale of 1:10,000, following field reconnaissance conducted in association with J. Coates (Kryotek Arctic Innovation) in August 2015.

Project number: 13103

Projection: UTM Zone 7
Datum: NAD 1983
Units: metre

Map 3

Sheet 33 of 33

KAMINAK GOLD CORPORATION

PALMER ENVIRONMENTAL CONSULTING GROUP INC.

Drawn by: CEB Checked by: RM 03/03/2016

Appendix D

Terrain, Terrain Stability and Soils Field Data (Excel file submitted separately)

An electronic copy of this file has been provided with the digital version of the Project Proposal. The digital file is an Excel spreadsheet and contains 3 tabs as described below:

1. Site Tab - 98 rows (including header rows) and 25 columns describing general site conditions at each assessed location;
2. Terrain Tab - 98 rows (including header rows) and 10 columns describing terrain hazards and processes at each assessed location; and
3. Permafrost Tab - 98 rows (including header rows) and 8 columns describing permafrost conditions at each assessed location.

This document is available in digitial version only.

Appendix E

Tetra Tech EBA Technical Memo: Road Design Considerations in Areas of Permafrost

TETRA TECH EBA

TECHNICAL MEMO

ISSUED FOR REVIEW

To:	Robin McKillop, P. Geo.	**Date:**	March 3, 2016
c:	K. Jones, P. Eng., VP Arctic Development	**Memo No.:**	3
From:	V. Roujanski, P. Geol.	**File:**	704-ENG.EARC03004-01
Subject:	Geotechnical Considerations for Road Design in Areas Underlain by Permafrost		

This 'Issued for Review' document is provided solely for the purpose of client review and presents our interim findings and recommendations to date. Our usable findings and recommendations are provided only through an 'Issued for Use' document, which will be issued subsequent to this review. Final design should not be undertaken based on the interim recommendations made herein. Once our report is issued for use, the 'Issued for Review' document should be either returned to Tetra Tech EBA or destroyed.

1.0 INTRODUCTION

Tetra Tech EBA Inc. (Tetra Tech EBA) is pleased to submit this Memo to Palmer Environmental Consulting Group (PECG) regarding geotechnical considerations for the proposed all-season access road design in areas underlain by permafrost.

The proposed Kaminak access road route runs approximately 214 km from the Klondike Highway junction (Bear Creek) near Dawson City southward to the Coffee Property mine area.

2.0 PERMAFROST ALONG THE PROPOSED KAMINAK ROAD ALIGNMENT AND IN THE MINE AREA

2.1 Permafrost Distribution, Temperatures, Ice Content, and Related Geohazards

According to the Permafrost Map of Canada (Heginbottom, 1995) the proposed Kaminak road alignment is located within the zone of extensive discontinuous permafrost, in which 50 to 90% of the area is expected to be underlain by permafrost. Our calculations of permafrost distribution within the 200 m-wide proposed road corridor using ArcGIS technology show that approximately 56% of **the corridor area** is underlain by permafrost (9% - by very ice-rich permafrost, 12% - by permafrost with visible excess ice, and 17% - by predominantly ice-poor permafrost). Approximately 18% of **the corridor are**a is covered by placer tailings deposits and may include pockets of ice-rich material buried by the tailings and where the ground thermal regime was affected by mining. Approximately 44% of **the corridor area** is therefore estimated to be permafrost-free.

Permafrost thicknesses were measured with thermistor cables at the south end of the proposed access road, within the Coffee Mine area. The results are highly variable, ranging from approximately 30 m to 165 m thick.

Active layer thickness varies spatially and temporally. In areas with thicker insulating organic cover, it is usually thin (approximately 0.3 m to 0.6 m), whereas it can be several metres thick within partially exposed bedrock or within coarse surficial material with a high clast content.

At the south end of the proposed Kaminak road alignment, within the Coffee Mine area, permafrost temperatures were measured with thermistor cables, as well as with temperature sensors on vibrating wire piezometers. At the

Tetra Tech EBA Inc.
14940 - 123 Avenue
Edmonton, AB T5V 1B4 CANADA
Tel 780.451.2121 Fax 780.454.5688

depth of zero seasonal temperature variation, ground temperatures range from -0.6ºC to -2ºC. The permafrost classification for the road within the Coffee Mine area is thus "warm".

Ground ice content (percent by volume) of the perennially frozen surficial materials along the proposed road alignment is highly variable, i.e. ground ice that is predominantly:

- not visible (Nf, Nbn, Nbe): This is generally ice-poor permafrost;
- visible excess ice (Vx, Vc, Vr, Vs): This moderately to ice-rich permafrost is well-bonded but rarely includes large ground ice bodies; or
- forming significant accumulations, such as ice wedges and other massive ice bodies: This is very ice-rich permafrost.

Warm permafrost temperatures along the proposed road alignment mean that areas underlain by ice-rich perennially frozen ground are sensitive to any kind of natural or manmade disturbance. As a consequence, one of the permafrost-related geohazards within the project area is thermokarst, which could be triggered by construction activities or by natural processes, such as forest fires. Development of thermokarst can be accompanied by thermal erosion, subsidence, and mass wasting of thawing ice-rich organic and fine-grained mineral soils.

2.2 Permafrost and Geotechnical Considerations for Road Design and Construction

Although every effort was made to avoid areas of thaw-sensitive perennially frozen soils when selecting the proposed road route, in some cases this was not possible and some sections of the selected road alignment cross areas underlain by warm ice-rich permafrost as shown on the Map of Permafrost Distribution Along Proposed Kaminak Road Alignment (Roujanski and McCuaig, 2016). Approximately 14 km of the 214 km-long road is founded on very ice-rich permafrost and approximately 24 km – on ice-rich permafrost. Road construction in such areas can cause a change in heat exchange at the ground surface and a change in the existing thermal regime of the ground. This may lead to thaw degradation of ice-rich permafrost in the subgrade, i.e. gradual melting of ground ice beneath the road. The resulting differential settlement may cause sharp dips in the road surface, progressively widening cracks and, less commonly, sinkholes where massive ice bodies previously existed. Thawing and settlement may continue for years until the ice has melted, thawing has stopped, or road fill bridges the resulting voids (Andersland and Ladanyi, 2004).

Within the areas of active or recent placer mining in the valley bottoms, the proposed alignment often follows existing mining access roads or crosses extensive areas covered by placer mining tailings. The ice-rich material within these disturbed sections has been mostly removed and the road maintenance costs are expected to be low. However, pockets of the ice-rich material may exist and will require special consideration for design.

In general, there are two approaches for the design of roads in permafrost areas (Johnston, 1981; Crory, 1991, McGregor et al., 2010):

1. **Passive Approach**: Provide full thermal protection to maintain permafrost in its frozen condition; or
2. **Active Approach**: Provide for limited thaw penetration into the underlying subgrade where preservation of permafrost is not possible or practicable and the consequences of thaw are allowed for in the design.

Both approaches may be employed on any appreciable length of the proposed road alignment.

A passive approach should be employed along those sections of the proposed road alignment that cross areas underlain by ice-rich permafrost, such as bottoms of creek valleys infilled with perennially frozen very ice-rich silt (loess), interbedded with, and/or overlain by, organic material, known as "black muck". Geotechnical considerations for the road design within such sections are as follows:

- Cuts and ditches are avoided wherever possible;
- Movement of equipment used for clearing the Right-of-Way (ROW) should be controlled or prohibited to keep the terrain disturbance to a minimum and to preserve the organic mat;
- The snow cover is carefully removed before construction of the embankment in a winter operation to reduce settlement of the fill during the thaw period;
- The embankment should be constructed by the end dumping method so that the vegetation cover will not be damaged by hauling equipment;
- High fills and sideslope alignments are avoided wherever possible;
- For conceptual design purposes, embankment thickness should be at least 2.0 m, placed on heavy weight, non-woven geotextile, to protect the subgrade from thawing;
- Flat horizontal and vertical curves and gradients not exceeding 8% are highly desirable;
- Drainage should be controlled to prevent water ponding along the toe of the embankment. This will allow the thermal regime of the frozen subgrade to be maintained. If runoff water must be collected and channelized, it should be done at a reasonable distance from the embankment (>10 m); and
- Snow accumulation should be prevented on the lee side of higher sections of the road embankment to maintain thermal regime of the frozen subgrade.

Basic principles for thermal design of embankments to preserve the permafrost include the following (McGregor et al., 2010):

- Favourable thermal conditions should be imposed and maintained underneath the structural core of the embankment; and
- Thermal design is required to ensure raised or at least maintained permafrost levels beneath the core of the embankment.

3.0 CONCLUSIONS

The proposed Kaminak access road route runs approximately 214 km across the zone of extensive discontinuous permafrost, in which approximately 21% of **the corridor area** is underlain by ice-rich to very ice-rich permafrost. Approximately 14 km of the 214 km-long road founded on very ice-rich permafrost and approximately 24 km – on ice-rich permafrost. Sections of the proposed alignment crossing thaw sensitive permafrost terrain will require special geotechnical considerations.

These include adequate thermal protection of ice-rich permafrost in the subgrade by avoiding cuts and ditching, minimizing terrain disturbance during clearing ROW, preserving the insulating organic mat, using special road construction methods (the end dumping), removing snow, and drainage control along the embankment.

4.0 REFERENCES

Andersland, O.B. and Ladanyi, B. 2004. *Frozen Ground Engineering, 2nd ed*., John Wiley & Sons, Hoboken, New Jersey.

Crory, F.E., 1991. Construction Guidelines for Oil and Gas Exploration in Northern Alaska. U.S. Army Cold Regions Research and Engineering Laboratory CRREL Report 91-21.

Heginbottom, J.A. (compiler). 1995. *Canada Permafrost.* Canada Centre for Mapping, Geomatics Canada and Geological Survey of Canada, Map MCR 4177, scale 1:7,500,000.

Johnston, G.H., ed. 1981. *Permafrost Engineering Design and Construction.* Toronto: John Wiley & Sons.

McGregor, R., Hayley, D.W., Wilkins, G., Hoeve, E., Grozic, E., Roujanski, V., and Jansen, A. 2010. *Guidelines for Development and Management of Transportation Infrastructure in Permafrost Regions.* Transportation Association of Canada.

Roujanski, V.E. and McCuaig, S. 2016. Map of Permafrost Distribution Along Proposed Kaminak Road Alignment (15 sheets), Scale 1:15 000, Tetra Tech EBA, Submitted to Kaminak Gold Corporation.