Surficial geochemical setting of the southern Carmacks-Minto copper belt

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Abstract

Preliminary surficial geological investigations of the southern Carmacks-Minto copper belt (NTS 115I/7) include material thicknesses, distribution and observations of thermal conditions. The Quaternary setting is discussed in relationship to material genesis and geomorphological processes operating on the landscape. Surficial material distribution is controlled by ice flow direction, prevailing wind direction and aspect-related differences in gravity and thermal-driven surficial processes.

Valley bottoms and north-facing slopes have moderate to thick surficial cover that include far-travelled sediments such as till, loess and glaciolacustrine sand. Drainage can be poor in these landscapes and permafrost is present in many areas. Valley bottoms contain thick Quaternary fill and are unsuitable for traditional soil surveys. North-facing slopes may provide good geochemical results if sampled carefully for first-order bedrock derivatives. Upland and south-facing slopes have thin to moderate surficial cover and can provide good conditions for traditional C-horizon soil sampling surveys. Windblown sand, silt and volcanic ash are deposited thickly, but unevenly, across the landscape. These sediments dilute surficial geochemical samples and are often incorporated into other materials through cryoturbation, and fluvial and gravitational reworking. Geochemical dilution by eolian materials is more significant near the Yukon River floodplain and in the central Carmacks-Minto copper belt.

Future surficial geochemical surveys should use a variety of methods suited to landscape characteristics and well-described surficial material characterizations. Applying surficial landscape models to existing soils data may also improve their utility for exploration. High quality surficial mapping is a critical part of surficial geochemical surveys and new products in this area will benefit from the use of airborne lidar.

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Introduction

Copper deposits extending from Carmacks Copper (Cu-Au-Ag; Yukon MINFILE 115I 008) to Minto (Cu-Au; Yukon MINFILE 115I 021 and 115I 022), and including the Stu prospect (Cu-Ag; Yukon MINFILE 115I 011), together form a northwest trending corridor known as the Minto or Carmacks copper belt (Fig. 1). Much of the existing mineralization in this region has been identified in landscape positions where surficial cover is absent or thin, typically on or near ridge tops. Exploration of landscapes characterized by thick surficial cover will require a better understanding of surficial materials distribution and genesis.

Challenges associated with surficial geochemical sampling in the region are well-known (Casselman, 2015; James, 2019; Paulter, 2015, 2016). Traditional soil sampling methods have had limited success at identifying known targets in areas of variable cover (Casselman, 2015) while applications of selective leach mobile metal ion and biological samples have had somewhat more success when used over thick cover (Paulter, 2016). Both methods require robust interpretations of surficial material distributions and careful sampling in the field. Existing surficial material and glacial limit maps (Jackson, 2000; Duk-Rodkin, 1999) lack the spatial resolution for property scale mineral exploration applications. This project aims to facilitate high-quality sediment surveys by describing the distribution and genesis of surficial materials in the southern part of the copper belt including the Carmacks Copper and Stu properties (also known as Carmacks and Carmacks North, respectively).

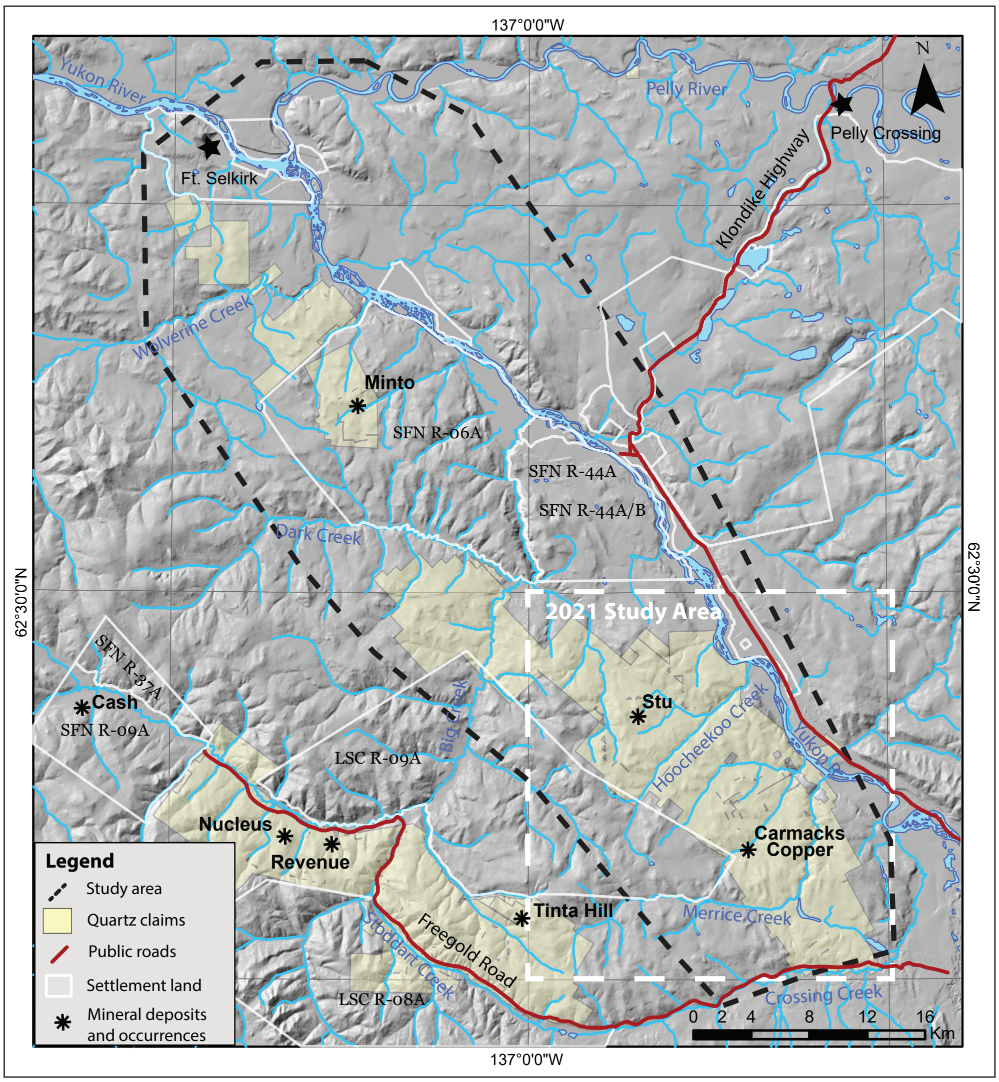

Figure 1. Land tenure, access and major features of the study area in central Yukon. Quartz claims are shown in yellow shaded polygons and settlement land is labeled by reserve block number and First Nation (LSC: Little Salmon Carmacks First Nation; SFN: Selkirk First Nation). Mineral deposits and significant occurrences are marked with an asterisks symbol.

Regional setting

Land tenure and development

The study area includes the Traditional Territories of the Selkirk and Little Salmon Carmacks First Nations. Land management is overseen by both First Nation governments as well as the Government of Yukon. Quartz claims cover much of the study area and, along with Selkirk First Nation settlement land, form a nearly continuous belt of tenured land from Crossing Creek to Fort Selkirk (Fig. 1). Road access to the southern part of the study area is via the seasonal publically maintained Freegold Road, as well as various privately maintained mining and exploration roads. The northern part of the study area has limited accessibility with the exception of the Minto mine which is serviced via barge and private roads from the Klondike Highway.

Pre-Quaternary geology

Located within the Yukon Plateau, the Carmacks-Minto copper belt lies east of the Dawson Range in an area of subdued relief west of the Teslin fault (Fig. 2). Bedrock geology in the region is primarily a series of Late Triassic to Early Jurassic Minto suite plutons that likely form a continuous batholith ~120 km long by ~15–20 km wide (Sack et al., 2020). The batholith likely

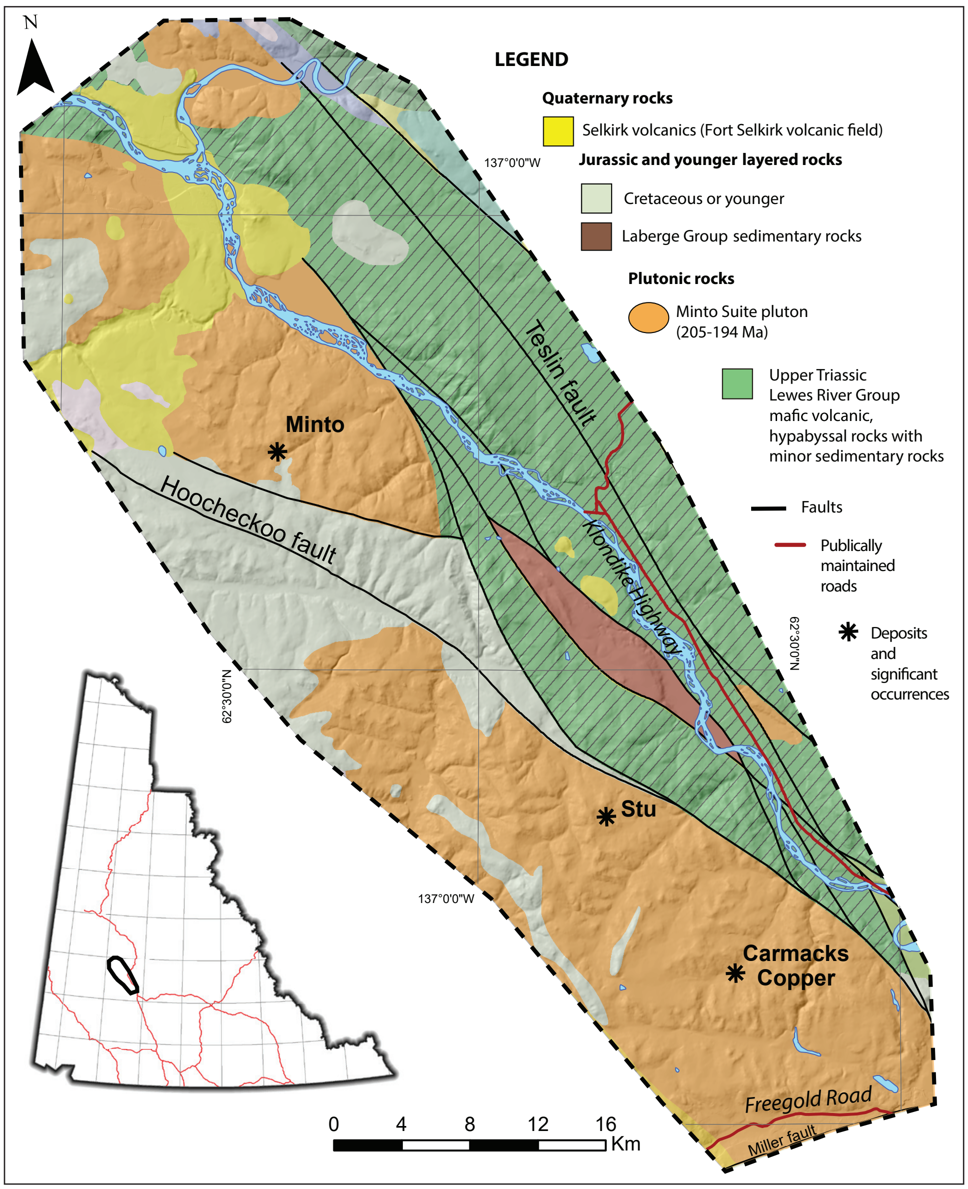

Figure 2. Simplified bedrock geology of the Minto-Carmacks copper belt. Geology from Yukon Geological Survey (2020a). Minto-Carmacks copper belt boundary from Sack and Colpron (2020). Occurrences from Yukon Geological Survey (2020b).

intruded metamorphic basement rocks of the Yukon-Tanana terrane and Late Triassic mafic volcanic rocks of the Povoas Formation. Copper (± gold and silver) deposits and occurrences within the copper belt are associated with Late Triassic to Early Jurassic rocks, the most economically significant of these are found as rafts within the plutons (Kovacs et *al*., 2020; Sack et *al*., 2020).

Mid-Cretaceous and older rocks are unconformably overlain by Late Cretaceous basalt and immature sedimentary rocks which were deposited on a deeply weathered erosional surface of considerable relief (Grond et *al*., 1984). Some volcanic rocks are highly prone to failure and complex kilometre-scale landslides are present in the southeastern part of the study area (Jackson, 2000). Although the Late Cretaceous landscape has remained largely intact through the Cenozoic, its overall physiography and surface expression has been modified by Quaternary volcanism and glaciation.

Quaternary geologic setting

The Carmacks copper belt has a complex Quaternary history that includes at least six periods of glaciation from two distinct sectors of the Cordilleran Ice Sheet. Glaciations occurred contemporaneously with volcanism in the Fort Selkirk volcanic field (Jackson et *al*., 1996, 2012) and both processes contributed to significant changes in fluvial drainage patterns in the region (Fig. 3; Huscroft et *al*., 2004).

Glaciation in central Yukon occurred via a complex of semi-independent topographically-controlled ice lobes that periodically coalesced to form the northern Cordilleran Ice Sheet (Duk-Rodkin et *al*., 2010; Jackson et *al*., 1991). The Selwyn Lobe advanced over the northern part of study area from the east while the Cassiar Lobe advanced from the southeast (Fig. 4; Bostock, 1936, 1966; Hughes et *al*., 1969; Jackson, 2000). The ice lobes became increasingly precipitation limited during the Quaternary (Ward et *al*., 2007) although they remained generally synchronous and in-step with global periods of ice advance and retreat.

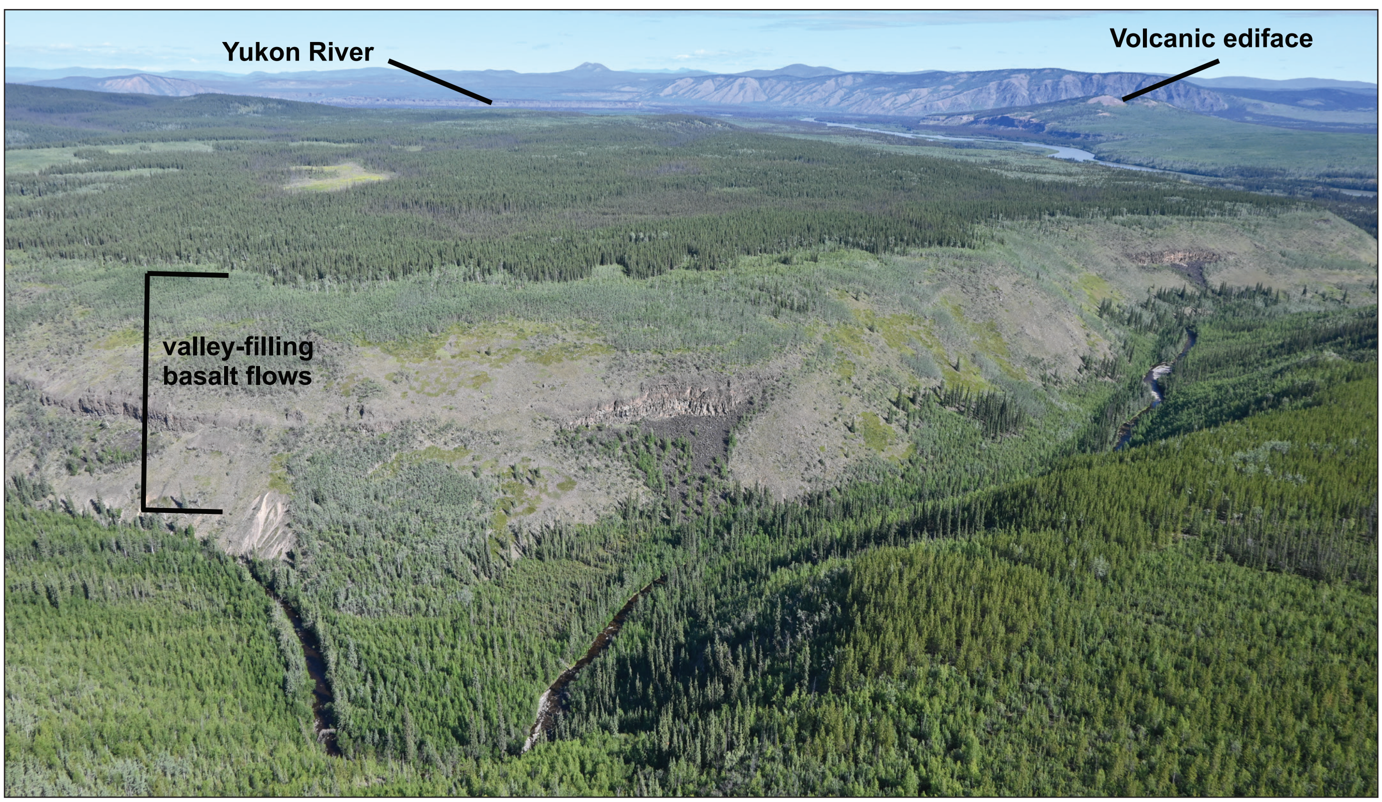

Figure 3. *View north across Wolverine Creek toward the Yukon River. Cenozoic volcanism filled valleys in the northern part of the study area and significantly altered earlier drainage systems.*

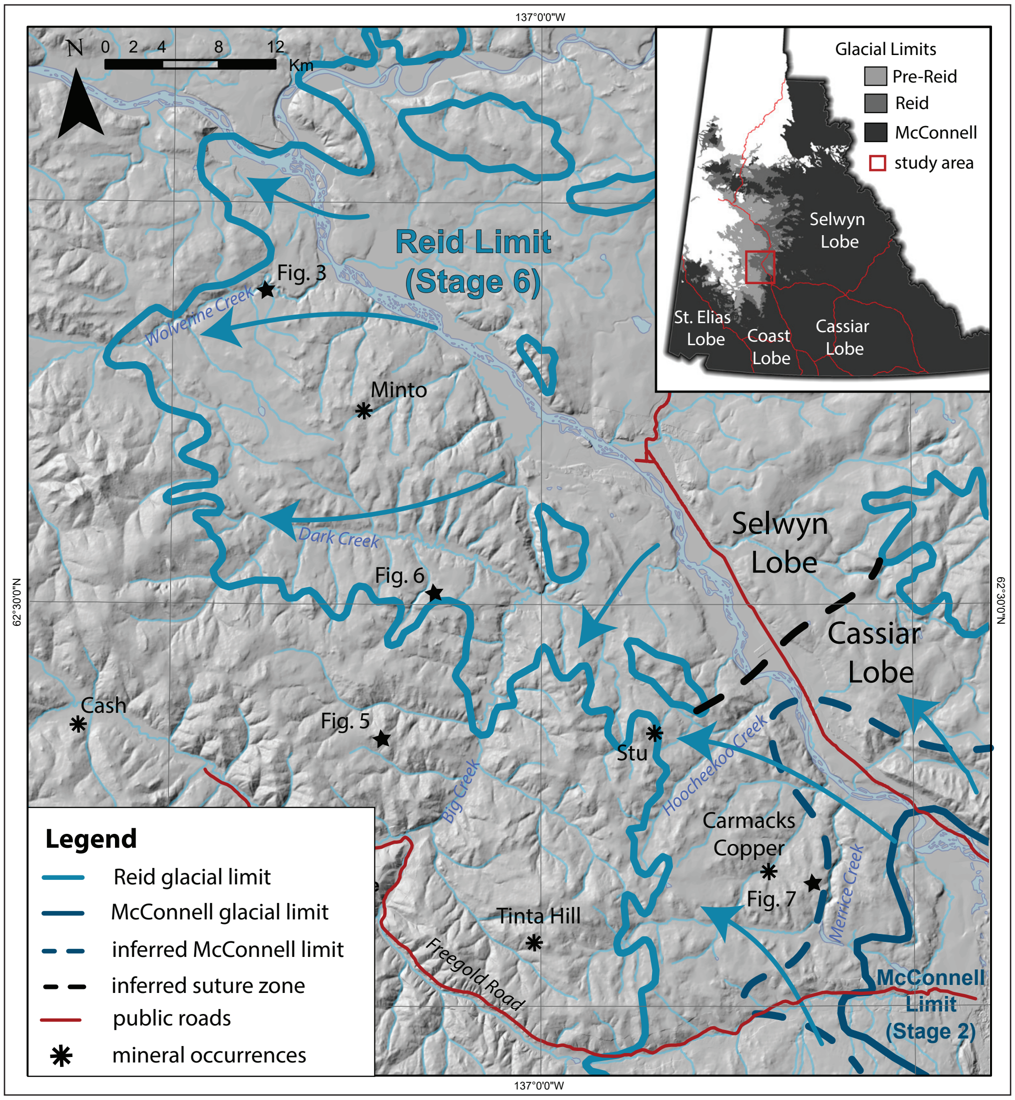

Figure 4. *Limits of the Selwyn and Cassiar lobes of the Cordilleran Ice Sheet during the Reid and McConnell glaciations (from Duk-Rodkin, 1999). A hypothetical suture zone between Selwyn and Cassiar lobe ice is represented by the black dashed line. A more extensive limit for the McConnell Glaciation indicated from new observations and mapping by Jackson (2000) is shown in dashed blue line along Merrice Creek.*

The chronology of Cordilleran glaciation in central Yukon is built from Selwyn Lobe records that include at least three "pre-Reid" advances between 2.1 Ma and 0.78 Ma (Jackson et *al.*, 1996, 2012; Nelson et *al.*, 2009; Westgate et *al.*, 2001). These glaciations were more extensive than later advances and extended beyond the study area (Duk-Rodkin et *al.*, 1999). Pre-Reid surfaces are difficult to distinguish from unglaciated terrain and are characterized by their absence of glaciogenic landforms and geomorphology reflective of dominantly fluvial regimes (Bond and Lipovsky, 2010). Uplands in pre-Reid terrain in the study area may have escaped glaciation altogether and are indistinguishable from unglaciated uplands of the eastern Dawson Range (Fig. 5).

The penultimate Reid Glaciation occurred ~140 000 years ago (Ward *et al.*, 2008; Preece et *al.*, 2011; Demuro et *al.*, 2012) and reached its maximum extent within the study area (Fig. 4). Landforms and limits associated with the Reid Glaciation are subdued and weathered, but still visible on the landscape (Fig. 6). Impoundment of east-flowing Yukon River tributaries including Merrice, Williams, Hoocheekoo, Big and Wolverine creeks likely occurred at the close of the Reid Glaciation and resulted in the creation of glacial lakes in these valleys.

The McConnell Glaciation was the least extensive advance of ice over the study area and reached its maximum extent near Merrice Creek (Fig. 4).

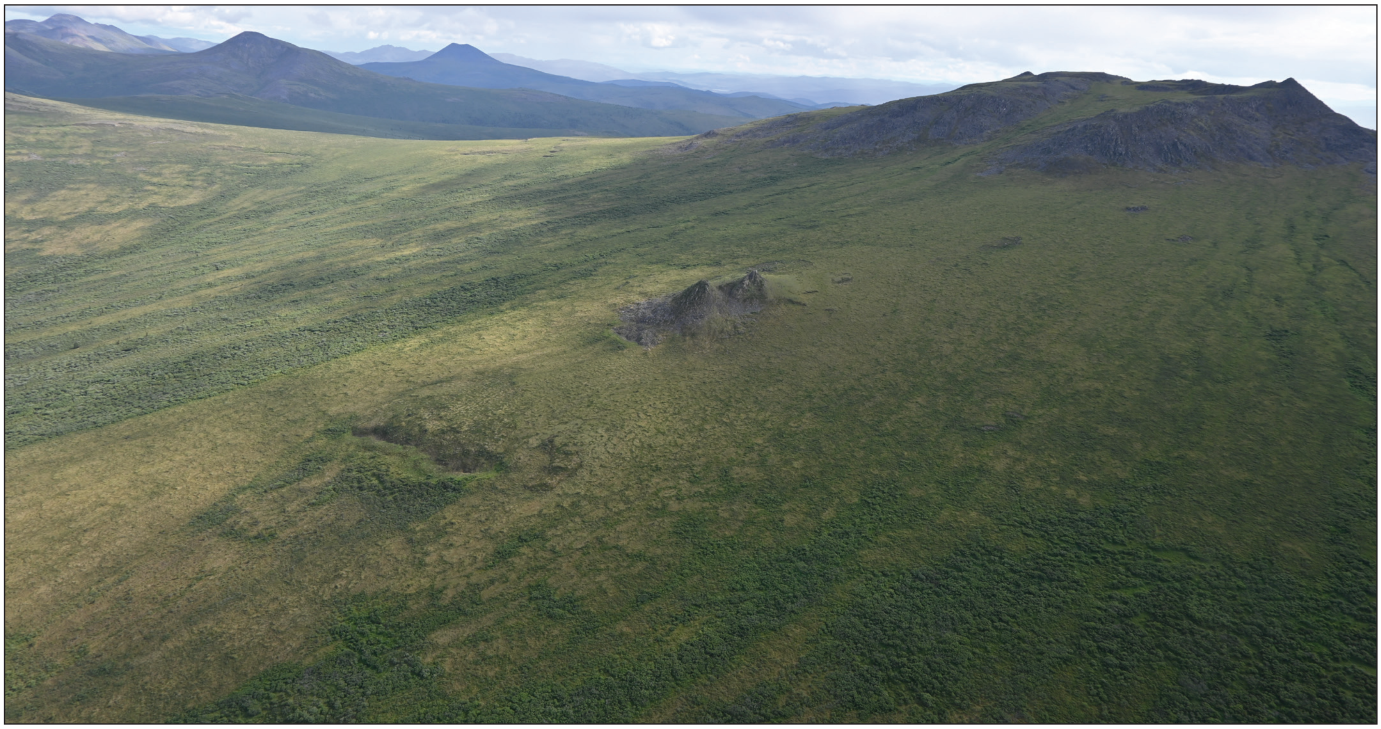

Figure 5. *Subdued terrain and thick blankets of weathered bedrock are characteristic of pre-Reid and unglaciated terrain in the study area. Upland surfaces that were glaciated during the pre-Reid glaciations are largely indistinguishable from unglaciated terrain*

Figure 6. *Erosional and depositional features associated with the Reid Glaciation are subdued, but still visible on the landscape. A Reid-aged moraine ridge is marked here with a dashed line.*

The McConnell Glaciation is thought to have advanced over central Yukon ~30 000 years ago (Matthews *et al.*, 1990; Jackson and Harington, 1991) and recession was likely underway ~15 000 years ago (Menounos *et al.*, 2017). High relief and sharply defined erosional (Fig. 7) and depositional landforms associated with the McConnell Glaciation are limited to areas southeast of Merrice Creek.

To the southwest of the study area, the St. Elias and Coast Mountain lobes of the Cordilleran Ice Sheet also had extensive advances during the Gladstone Glaciation (~60 000 years ago; Turner *et al.*, 2013; Ward *et al.*, 2007), however, this glaciation hasn't yet been recognized in areas glaciated by the Cassiar or Selwyn lobes. Additionally, mountainous areas of the eastern Dawson Range generated alpine glaciers during early Quaternary glaciations (LeBarge, 1995; Englehart *et al.*, 2016) that may have extended into some parts of the western study area.

Post-glacial landscape adjustment in the latest Pleistocene and Holocene is associated with eolian sedimentation and re-establishment of fluvial drainage systems. East-flowing drainages such as Merrice and Williams creeks may have been impounded by McConnell ice in the Yukon River valley, but would have rapidly incised through fine-grained sediments as deglaciation progressed. Eolian processes were active as glaciers receded and largely stabilized by vegetation ~9000 years ago (Wolfe *et al.*, 2011).

In the latest Holocene, White River Ash (volcanic tephra) was deposited ~1147 years ago over a broad swath of central Yukon (Clague *et al.*, 1995; Lerbekmo, 2008). It is distributed in a cone-shaped plume across the study area and mapped thicknesses range from more than 30 cm over Carmacks Copper to less than 5 cm at Wolverine Creek (Fig. 8; Lerbeckmo and Campbell, 1969). Field observations in the study area suggest the thickest accumulations are centered on the Stu property where primary ash-fall deposits of more than 30 cm are well-preserved on stable, flat, or shallow sloping surfaces. Other authors in the region have noted accumulations of up to a metre in depth (Casselman, 2015; Paulter, 2015) although these thicknesses may be related to resedimentation of these highly mobile materials.

Figure 7. *McConnell-aged erosional landforms such as this meltwater channel display greater relief than similar features in Reid-aged terrain.*

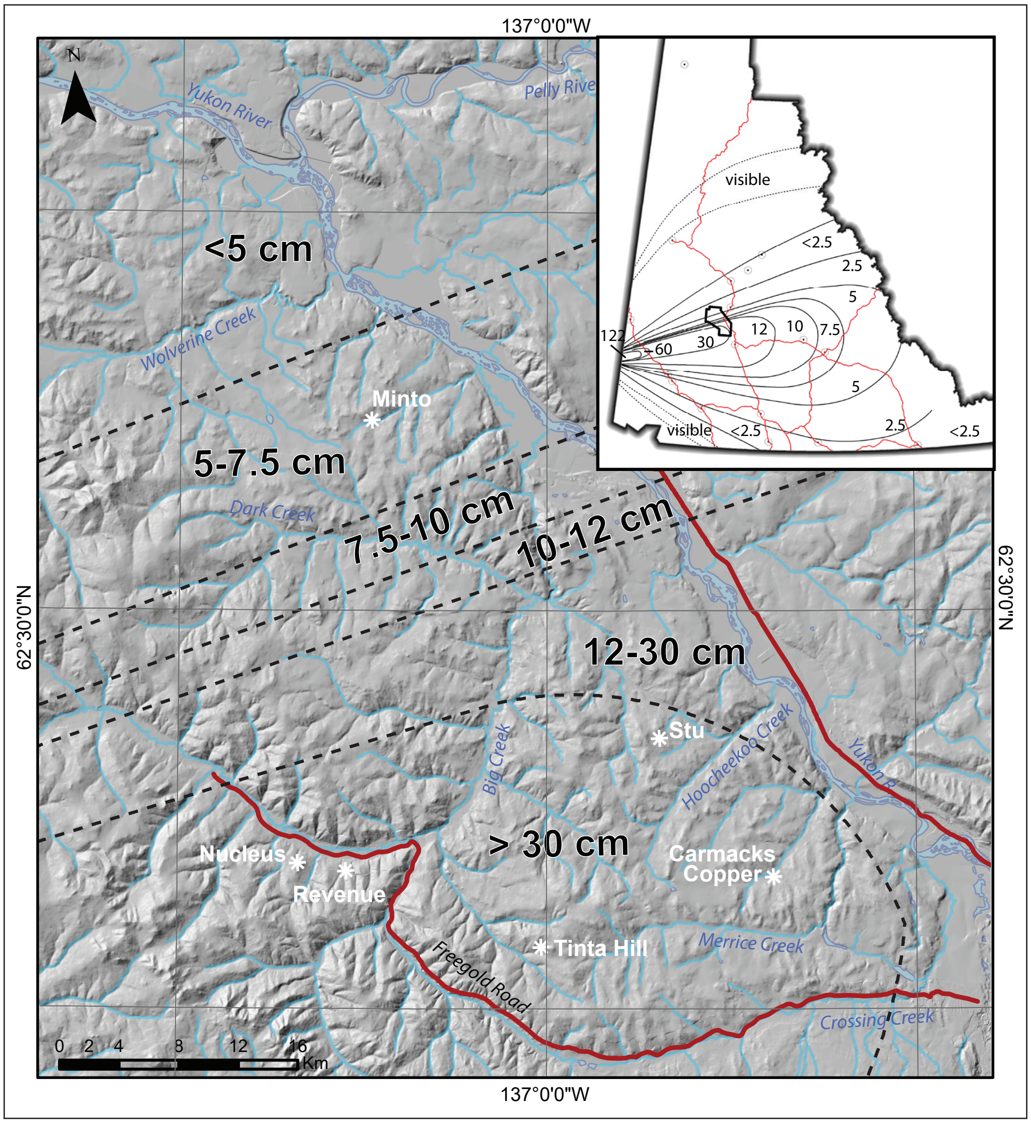

Figure 8. *Isopachs (cm) map of the east lobe of the White River Ash over the study area (from Mulliken et al., 2018). The study area coincides with an area of tightly spaced isopachs that mark a sharp decrease in thickness of ash north of the Stu claims. The southern part of the study area coincides with some of the thickest ash deposits in central Yukon.*

Surficial geochemical setting

In early stages of mineral exploration, surficial geochemical samples are commonly collected from soil parent materials (B or C-horizons) and stream sediments (silt-sized fraction). Less commonly, surveys of coarse-fraction stream sediments, A-horizon soils, and biological samples are undertaken (*i.e.*, Heberlein and Samson, 2010; Heberlein *et al.*, 2013). First-derivative surficial materials transported by gravity, water, or ice can be useful analogues for bedrock but are subject to varying degrees of dilution from other materials. The ideal medium has simple transport vectors and is evenly distributed across the landscape.

Regional geochemical survey (RGS) stream sediment data have been effective at identifying mineral occurrences in the study area, however, overall sample quality in the region is negatively affected by subdued relief, large catchment sizes, thick surficial cover, and organic scavenging (Mackie *et al.*, 2016, 2017). Infill sampling of large basins could produce targeted anomalies in areas of thick cover, particularly in the eastern part of the study area.

Stream silts are subject to dilution from abundant eolian materials on the landscape. One method that may be more resilient in these conditions is the examination of coarse-fraction heavy minerals in stream sediment samples. This technique has been successful at characterizing known minerals from the nearby Casino deposit and ongoing work on water chemistry may further support enhanced regional and targeted stream geochemical surveys (McClenaghan et *al.*, 2020).

Soil geochemistry quality depends on a wide number of site-specific factors including total soil depth, permafrost depth, surface organic thickness, loess thickness, transport distance, and type of geochemical anomaly (McKillop et *al.*, 2013). Existing soil sampling programs in the study area have had variable success (Casselman, 2015; James, 2019), but are generally under-used because of the complexity of the surficial setting. Understanding soil parent material genesis and distribution is a critical part of planning good surveys and reducing uncertainty in geochemical results.

Surficial materials distribution

Pre-Reid landscapes

Pre-Reid landscapes in the eastern part of the study area are dominated by weathered bedrock and colluvium. Glacial sediments deposited during pre-Reid glaciations have largely been moved downslope by gravity and have accumulated in valley bottoms and on stable topographic settings that have escaped erosion. Pre-Reid glacial sediments have been observed in borrow pit materials near Tinta Hill, and in deep excavations and drill core from tributaries to Big Creek. Pre-Reid landscapes and materials in the nearby McQuesten map sheet (NTS 115P) are discussed in detail in Bond and Lipovsky (2010).

Reid landscapes

Reid-aged landscapes comprise the surficial setting for existing mineral deposits and significant occurrences in the Carmacks-Minto copper belt, and as such, are addressed in detail here. The rounded uplands, shallow hillslopes, and broad, flat valley bottoms of the upper Merrice (Fig. 9) and Williams creek valleys make useful analogues for a number of similar drainages in the region. In order to illustrate the distribution of surficial sediments in the southern part of the copper belt, idealized valley profiles were constructed for characteristic landscape positions (Figs. 10c, 12a, 13a and 14d). Idealized distributions are based on observations from soil pits, road cuts, trenches and drill core in Williams, Nancy Lee and Hoocheekoo valleys.

Figure 9. *View down (east) upper Merrice Creek from Tinta Hill. The gentle topography and flat valley floor is typical of many east-flowing tributaries to the Yukon River in the study area.*

Valley bottoms

Broad, flat valley bottoms are common in many east-flowing tributaries to the Yukon River, and reflect Quaternary infilling of formerly v-shaped fluvial drainages (Fig. 10a,b). Impoundment of Yukon River tributaries during the Reid Glaciation (and possibly the McConnell as well) resulted in glaciolacustrine deposits in many valley bottoms. These materials range from fine silt to coarse sand and are often associated with deltas and other shoreline deposits preserved ~2 to 20 m above the modern valley floor (Fig. 11). Glaciolacustrine and deltaic landforms are better exposed along the base of south-facing hillslopes and may be partially buried by eolian sediments at the base of north-facing hillslopes (Fig. 10c). Fine-grained glaciolacustrine and glaciofluvial or deltaic materials can be challenging to distinguish from eolian sand deposits and may, in part, be sources for these materials.

Valley bottom sediments are generally not exposed in the study area, but drilling at Carmacks Copper suggests up to 80 m of unconsolidated sediments beneath the modern valley floor (Fig. 10c). Valley filling sediments commonly comprise glacial, glaciofluvial, lacustrine and fluvial sediments, but may also include pre-Quaternary sedimentary and volcanic materials. Permafrost is common in valley bottoms where poor drainage contributes to saturated conditions and thick organic cover.

It is not recommended that traditional parent-material soil samples be collected in valley bottom settings in the southern Carmacks-Minto copper belt. Bedrock may be close to (or at) surface in some areas, but valley bottom landscapes lack the even distribution and simple transport vectors required to generate high quality geochemical results. Existing samples collected

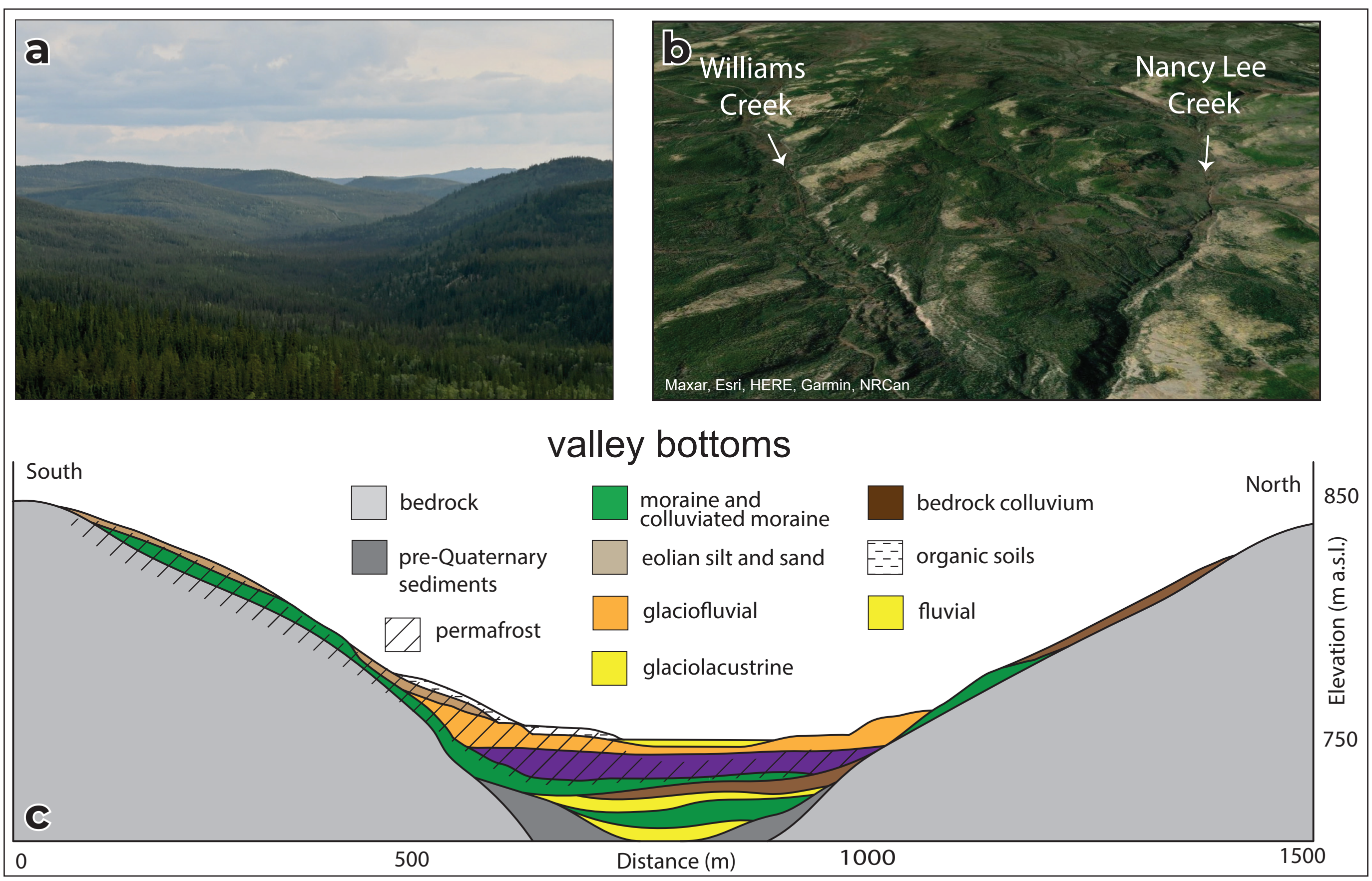

Figure 10. ***(a)*** *View west up Williams Creek from near its confluence with the Yukon River.* ***(b)*** *View west over Williams and Nancy Lee creeks (image from ArcGIS Earth).* ***(c)*** *Idealized cross valley profile of Williams Creek from observations of east-flowing drainages between the Carmacks Copper and Stu properties. Hypothetical valley fill comprises a range of glacial and non-glacial materials. Eolian deposits (including ash) are present on most surfaces.*

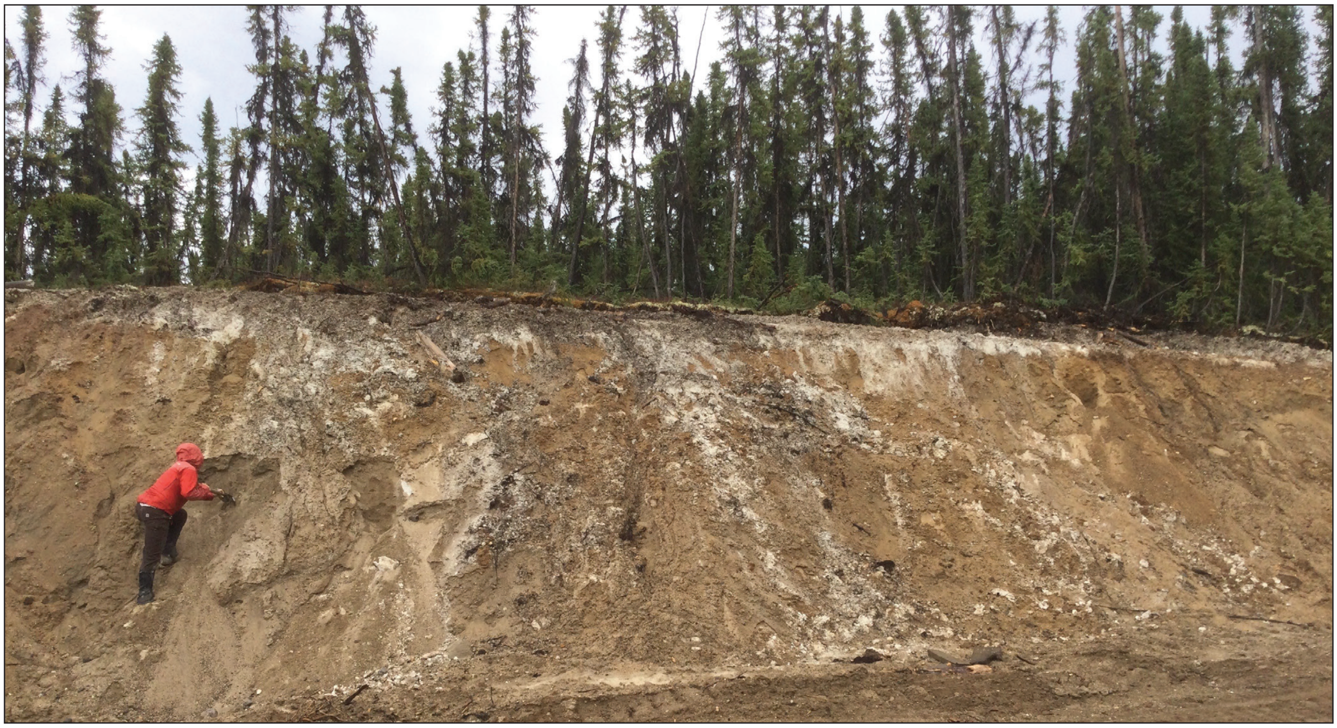

Figure 11. *Sandy glaciolacustrine or deltaic sediments form a flat terrace on this north-facing slope ~10 m above the modern valley floor.*

using traditional soil sampling methods are unlikely to accurately reflect underlying bedrock in valley bottom settings.

North-facing hillslopes

North-facing slopes are characterized by cold thermal conditions and relatively intact surficial materials (Fig. 12a). Moraine (till) is found in both blankets (>1 m thick) and veneers on higher positions on valley sides and commonly comprises a sandy cobble diamict with a silt-rich matrix. Till preservation is discontinuous on hillslopes and can fill topographic depressions where it reaches observed thicknesses of at least 2.5 m.

Moraine exposed in a north-facing trench above Williams Creek (Fig. 12b) can be subdivided based on texture, lithology and degree of compaction into three diamict units: a lower mixed facies containing local bedrock (unit 3 on Fig. 12c); a silty compact facies of non-local materials (unit 4); and a modified, loose upper facies of predominantly non-local materials (unit 5). Copper values from each unit are generally representative of transport distance. High copper in mixed bedrock and till at the lower contact of unit 2 (3220 ppm Cu) and bedrock-enriched till in unit 3 (700 ppm Cu) contrast with low copper values in overlying silty, compact, and far-travelled materials of units 4 and 5 (38.3 and 38.8 ppm Cu). Slightly elevated copper values in unit 6 (108.5 ppm Cu) are likely related to the incorporation of upslope bedrock materials into this unit.

Eolian sand deposits are most common near glacial limits where prolonged katabatic winds developed sand sheets, dunes and blankets. These landforms and materials are best preserved on leeward (north-northwest facing) slopes and in hollows and depressions (Fig. 12e). Eolian deposits are thickest near the Yukon River valley and around other floodplain sources of sand and silt. Windblown sand and silt deposits are derived from both proximal and distal sources, are well-homogenized, and record cooler, windier, glacial and periglacial conditions (Muhs, 2017). Ice-rich organic materials are common at the bottom of north-facing hillslopes (Fig. 12d).

North-facing hillslopes can be challenging settings for surficial geochemical sampling. Highly-transported glacial and eolian materials are poor proxies for bedrock and may accumulate in thicknesses that make traditional sampling impractical. Existing samples from these areas should be used with caution unless parent materials are clearly documented. Shallow auger drills would be useful for new surveys where glacial or eolian materials are preserved in thicknesses that limit hand sampling. It isn't clear how permafrost may affect partial-leach mobile metal applications, but its widespread presence should be taken into account in these sampling programs.

South-facing hillslopes

South-facing hillslopes are warmer and drier than north-facing slopes in the study area. Gravity-driven processes dominate south-facing slopes and much of the surficial cover has been moved into lower slope and valley bottom positions on the landscape (Fig. 13). Silt-enriched weathered bedrock and weathered bedrock colluvium are common on middle and upper slope positions (Fig. 13b).

South-facing hillslopes provide many good settings for surficial geochemical sampling. Care should be taken to avoid thick surficial cover, confirm bedrock parent materials, and recognize silt-enrichment at the top of the soil profile. On some south-facing slopes, ongoing

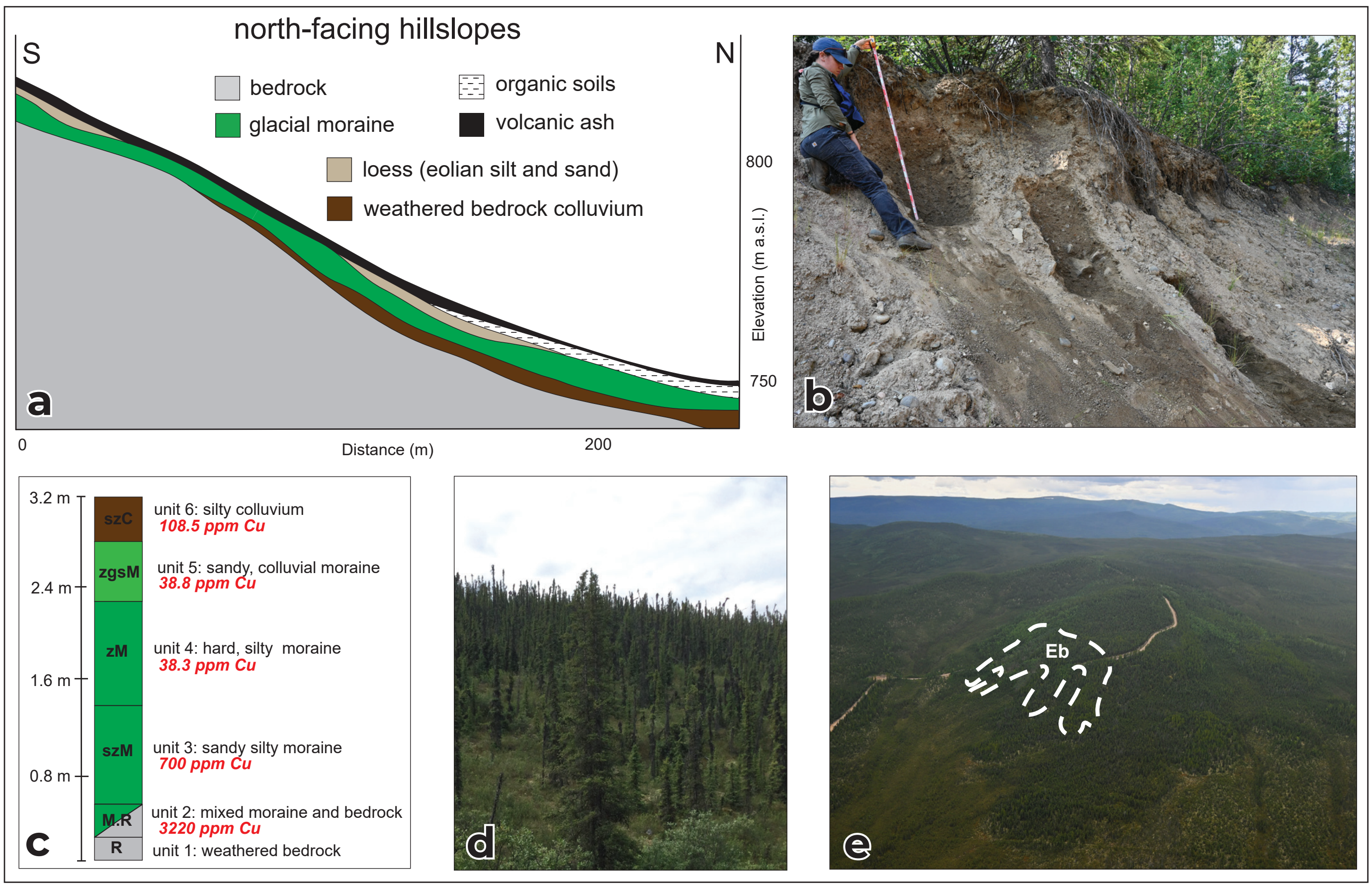

Figure 12. (a) *Idealized valley profile of a north-facing hillslope in the study area. Blankets and veneers of till are preserved above bedrock, weathered bedrock, and colluvium on most surfaces. Eolian silt, sand, and ash is well-preserved and may be overlain by, or interbedded with, ice-rich organic materials. Permafrost is not shown, but is present on most north-facing slopes.* **(b)** *Moraine exposed in a ~3 m deep trench above Williams Creek.* **(c)** *Stratigraphic profile of the units exposed in* **(b)** *with results from silt-fraction geochemistry.* **(d)** *Permafrost is common on north-facing slopes and can be associated with thick organic soils and stunted forest.* **(e)** *This sandy eolian blanket was deposited on a northwest-facing slope above Williams Creek. Cold soils and thick vegetation likely helped preserve these sediments.*

weathering of exposed bedrock has generated thin veneers of weathered bedrock colluvium that can obscure underlying extra-basinal sediments (Fig. 13c). These materials may be good representations of upslope bedrock if sampled correctly, but could confound the results of programs focusing on A-horizon or biological samples.

Upland surfaces

Flat to gently sloping upland surfaces are commonly characterized by bedrock or weathered bedrock variably overlain by windblown silt (loess) and ash (Fig. 14). With background or lower than background metal values (Preece et al., 2014), windblown ash can mask underlying mineralized soils when incorporated into geochemical samples. This dilution of soil samples is well-known and primary ash fall is easily recognizable in the field. Similarly, numerous publications have discussed the poor suitability of loess for geochemical sampling in the Dawson Range, and their findings apply to this study area as well (McKillop, 2013; Bond and Lipovsky, 2011).

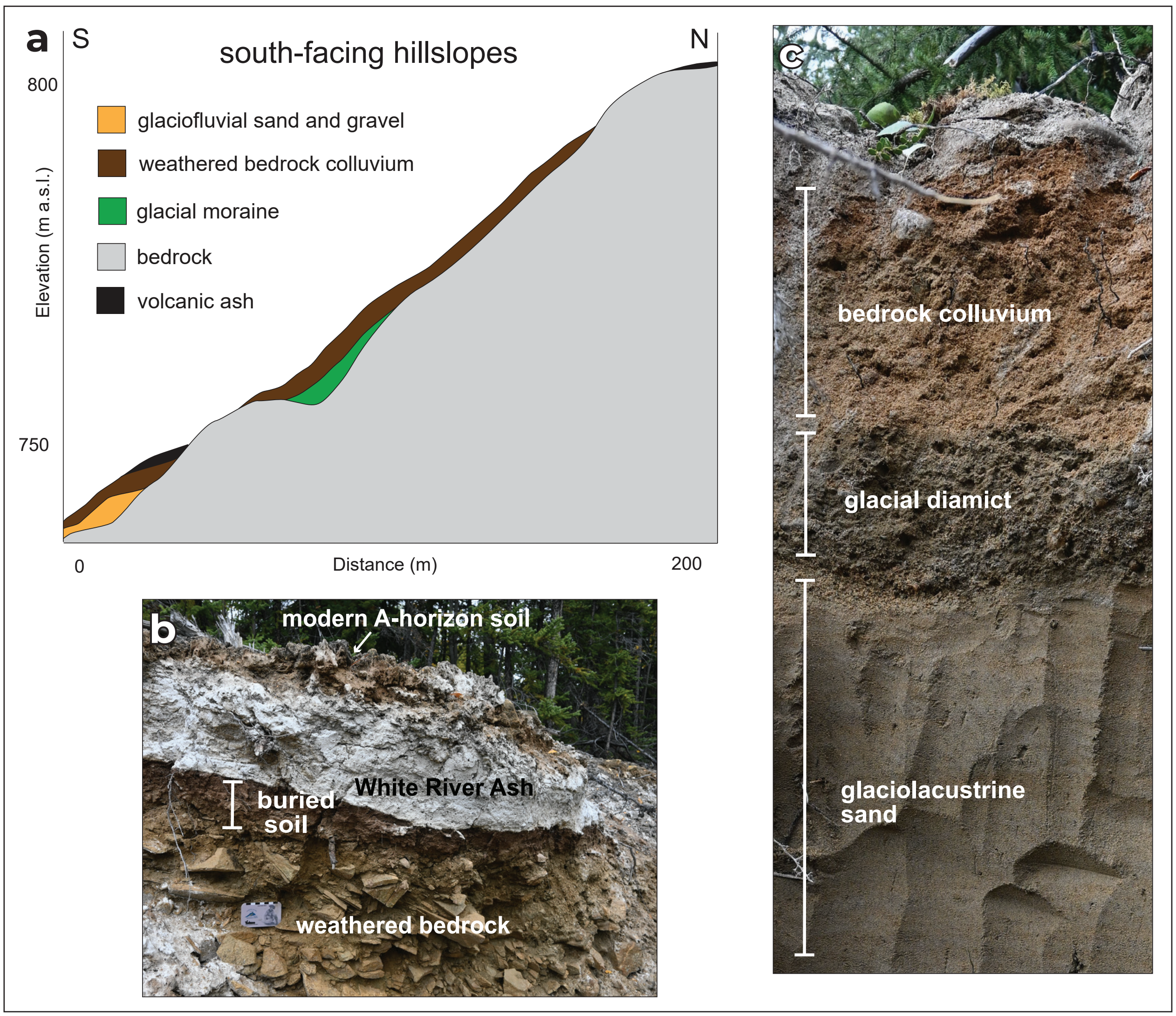

***Figure 13. (a)** Idealized valley profile of a south-facing hillslope in the study area. Upper slopes are characterized by thin surficial cover and abundant bedrock, weathered bedrock, and weathered bedrock colluvium. **(b)** White River Ash is preserved above a well-developed soil in local weathered bedrock materials. **(c)** A veneer of weathered granite bedrock overlies till and glaciolacustrine sediments on this south-facing section near the bottom of a hillslope on Nancy Lee Creek.*

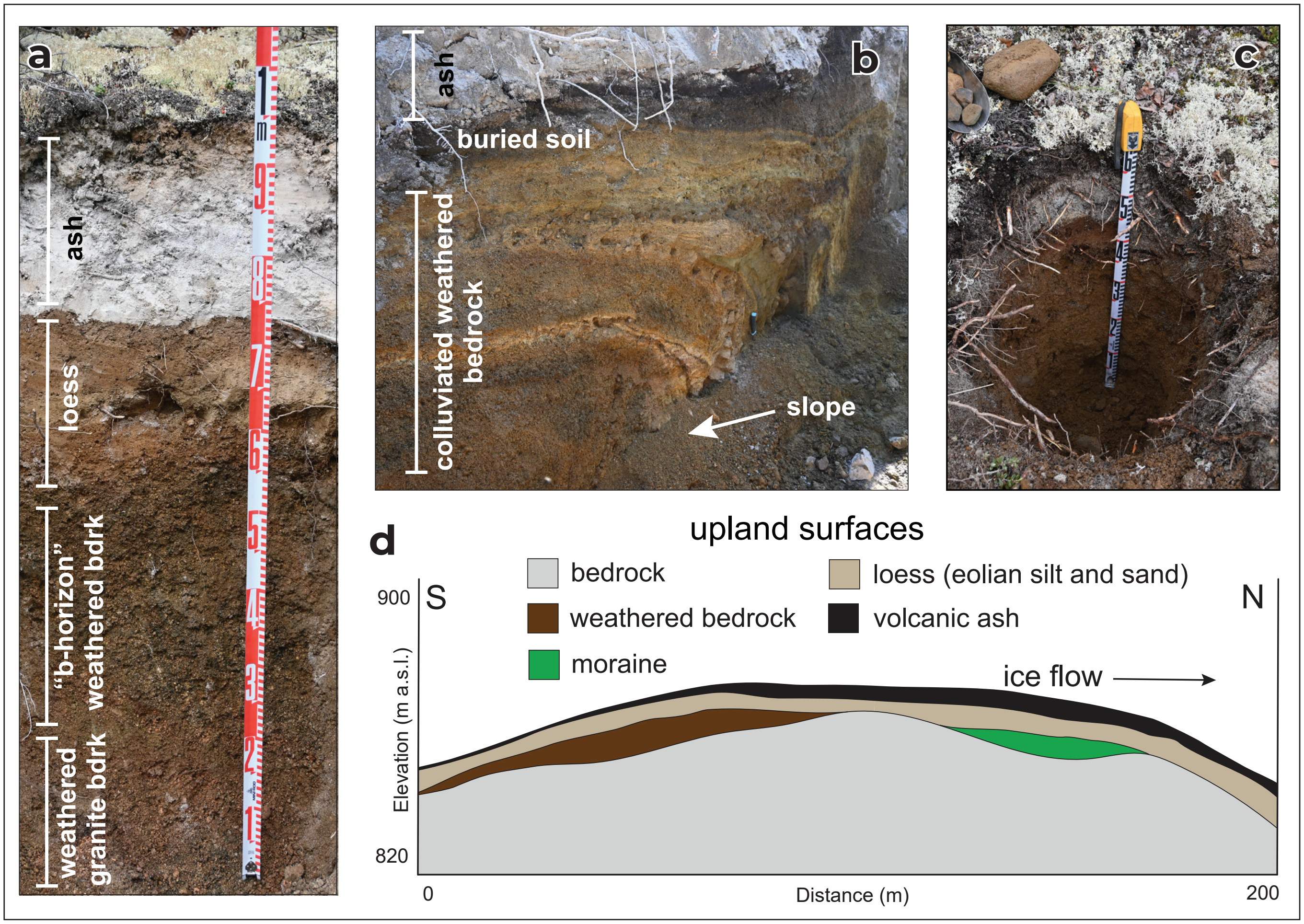

***Figure 14. (a)** The stratigraphy seen in this road cut is common on upland surfaces that have seen limited erosion. Granite bedrock and weathered granite bedrock are overlain by windblown silt (loess) and ash. **(b)** Weathered bedrock in this trench on the Stu property is creeping downslope (toward the left). Deeply weathered and fractured bedrock is overlain by a well-developed paleosol and thick accumulations of White River Ash. **(c)** A typical soil pit on a Reid-aged upland surface is characterized by ash (~10–15 cm) and loess (~20 cm) overlying silty, oxidized, pebble-cobble glacial diamict. **(d)** Upland surfaces preserve relatively thin (<1 m) in situ accumulations of weathered bedrock and eolian sediments.*

Intact weathered bedrock and moderately transported weathered bedrock are ideal surficial geochemical materials and analytical results for these medium are straight-forward to interpret. While windblown materials are generally thin on upland surfaces, they may accumulate in topographic swales or other protected areas. Loess can also be incorporated into parent materials through cryoturbation and have a significant impact on geochemical results (Bond and Sanborn, 2006). Regardless, both loess and volcanic ash are easy to identify and avoid in flat to gently sloping upland environments.

McConnell landscapes

McConnell-aged landscapes have a limited extent in the study area and are primarily restricted to the Yukon River valley and areas south of Merrice Creek (Fig. 4). Materials associated with McConnell glaciation are generally thicker and more continuous than glacial deposits associated with earlier glaciations. Detailed descriptions of McConnell-aged materials are available in Cronmiller (2020) for the nearby Carmacks area.

Indicator mineral analysis

Fieldwork in 2021 included sampling for indicator minerals from both bedrock and stream sediment sources. Drill core samples containing a range of mineralized and unmineralized rocks from the Minto and Carmacks deposits have been submitted to Overburden Drilling Management for indicator mineral characterization. The results of these samples will be compared to five stream sediment samples collected from upstream and downstream of the Carmacks deposit on Williams Creek and tributaries. Preliminary results will be reported at a later date, and follow-up sampling and analysis may be undertaken.

Conclusions

Assessment reports for the Carmacks-Minto copper belt routinely report that <10% of the landscape is suitable for traditional prospecting. The remaining 90% of the landscape requires dealing with surficial geology. Understanding the genesis and distribution of these materials will inevitably improve exploration results.

When used with an understanding of surficial materials, traditional soil sampling has been shown to work well in this region (James, 2019). Identifying areas of thick cover is essential to leveling results and obtaining reliable samples with the least amount of time and effort. Windblown silt and ash are variably deposited across the study area and have the potential to significantly dilute surficial geochemical samples. Traditional soils will need to be supported by alternative sampling programs (*i.e.*, shallow drilling or selective leach geochemistry) over areas of thick surficial cover. The landscape model presented here can also be used to evaluate existing soil geochemistry data and highlight areas that may require targeted sampling through alternative methods. Ultimately, it may be useful to level data according to topographic position in order to minimize the diluting effects of thick surficial cover.

Although general genetic processes and distributions are discussed here, property-scale surficial mapping is a critical base layer for designing and interpreting surficial geochemical surveys. Given the subdued geomorphology, pervasive eolian cover and dense vegetation, any future mapping should be based on stereo-photography coupled with high-resolution airborne lidar. Ongoing work in the region will focus on updating glacial limits, expanding our knowledge of the surficial geology, and testing the utility of stream sediment indicator minerals for ongoing exploration.

Acknowledements

Little Salmon Carmacks and Selkirk First Nations are thanked for sharing access to their Traditional Territories in order for this work to be completed. Granite Creek Copper provided camp and logistical support for fieldwork on their Carmacks and Carmacks North properties. Debbie James and Owen Peer were gracious hosts and provided invaluable property-scale geological knowledge. Conversations with Jeff Bond, Scott Casselman, Maurice Colpron, Nicolette Kovacs, Povilas Grigutis and Jacob Longridge contributed significantly to our understanding of regional and property-scale geology. Emily Halle and Jesse Halle are also thanked for supporting logistical aspects of this work, providing local expertise, and sharing deep "overburden" core from the Freegold Mountain project. A review of this manuscript by Jeff Bond added breadth and depth to the paper, and Jeff is thanked for his contribution. Karen MacFarlane's careful and thoughtful editing is very much appreciated.

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