Proven Approach to Mineral Exploration in Thick Surficial Deposits Applied to the Central Interior Copper-Gold Research Projects Area, Central British Columbia (Parts of NTS 093A, B, G, J, K, O)

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Introduction

Geoscience BC is undertaking a series of projects in the Central Interior Copper-Gold Research (CICGR) projects area, which occupies a large region in central British Columbia (BC) between the communities of Mackenzie and Williams Lake (Figure 1a). This region has significant mineral potential; however, exploration is hindered by extensive Quaternary sediment units that obscure bedrock. The objective of the CICGR projects is to investigate the potential for undiscovered mineral deposits buried beneath thick glacial sediments.

Drift prospecting using a comprehensive understanding of the surficial geology has been proven to reveal exploration targets where thick glacial sediments occur (e.g., Levson et al., 1994; Levson, 2001; Plouffe et al., 2001; Sacco et al., 2018). This paper contains a summary of the progress of a multiyear surficial exploration program targeting specific areas (surficial study areas; Figure 1a, b) within the larger CICGR projects area. The program is modelled after Geoscience BC's highly successful Targeting Resources through Exploration and Knowledge (TREK; e.g., Jackaman and Sacco, 2014; Jackaman et al., 2014, 2015; Sacco and Jackaman, 2015; Sacco et al., 2018) and Quesnellia Exploration Strategy (QUEST; e.g., Sacco et al., 2010; Ward et al., 2011, 2012, 2013) surficial exploration programs (Figure 1). The CICGR projects are generating high-quality baseline data integral to promoting and supporting successful mineral exploration in this challenging setting. Combined with data from the TREK (Jackaman et al., 2015) and QUEST (Ward et al., 2013) projects, the results of this study extend the coverage of directly comparable geochemical and mineralogical data and 1:50 000 scale surficial mapping to a large nearly continuous portion of central BC.

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The proven methodology applied in this program is designed to generate a geochemical and mineralogical database, and an understanding of the surficial geology necessary to collect and interpret these data, such that they can be integrated into and guide private-sector exploration. The scope of the program defines three objectives:

1) 1:50 000 scale surficial geology mapping;

2) comprehensive compilation of historical data and reanalysis of archived till survey samples; and

3) new and infill till geochemical and mineralogical surveys.

The surficial geology mapping provides an understanding of the drift composition, allowing optimal exploration methods to be selected. Interpretations of surficial geology were used to derive till sampling suitability (TSS) and drift thickness maps. The TSS maps identify areas well- and poorly suited to till sampling. The drift thickness maps provide depth to bedrock estimations that help guide bedrock mapping and prospecting programs, and identify areas where drill-supported sediment and/or bedrock sampling could be beneficial. Areas that are poorly suited to till sampling but have thick drift are good candidates for drill-supported sampling.

Archived samples with incomplete or outdated analytical information were reanalyzed as part of objective 2 and provide results that are compatible and comparable to the current provincial database. The results of the surficial mapping and data reconciliation were used to support the design and execution of subglacial till geochemistry and mineralogy sampling programs as part of objective 3. New data resulting from these programs will be combined with the reanalyzed sample data, significantly improving sample site densities across the project area, and reducing the analytical and genetic variability in the dataset, allowing for the generation of lower risk exploration targets.

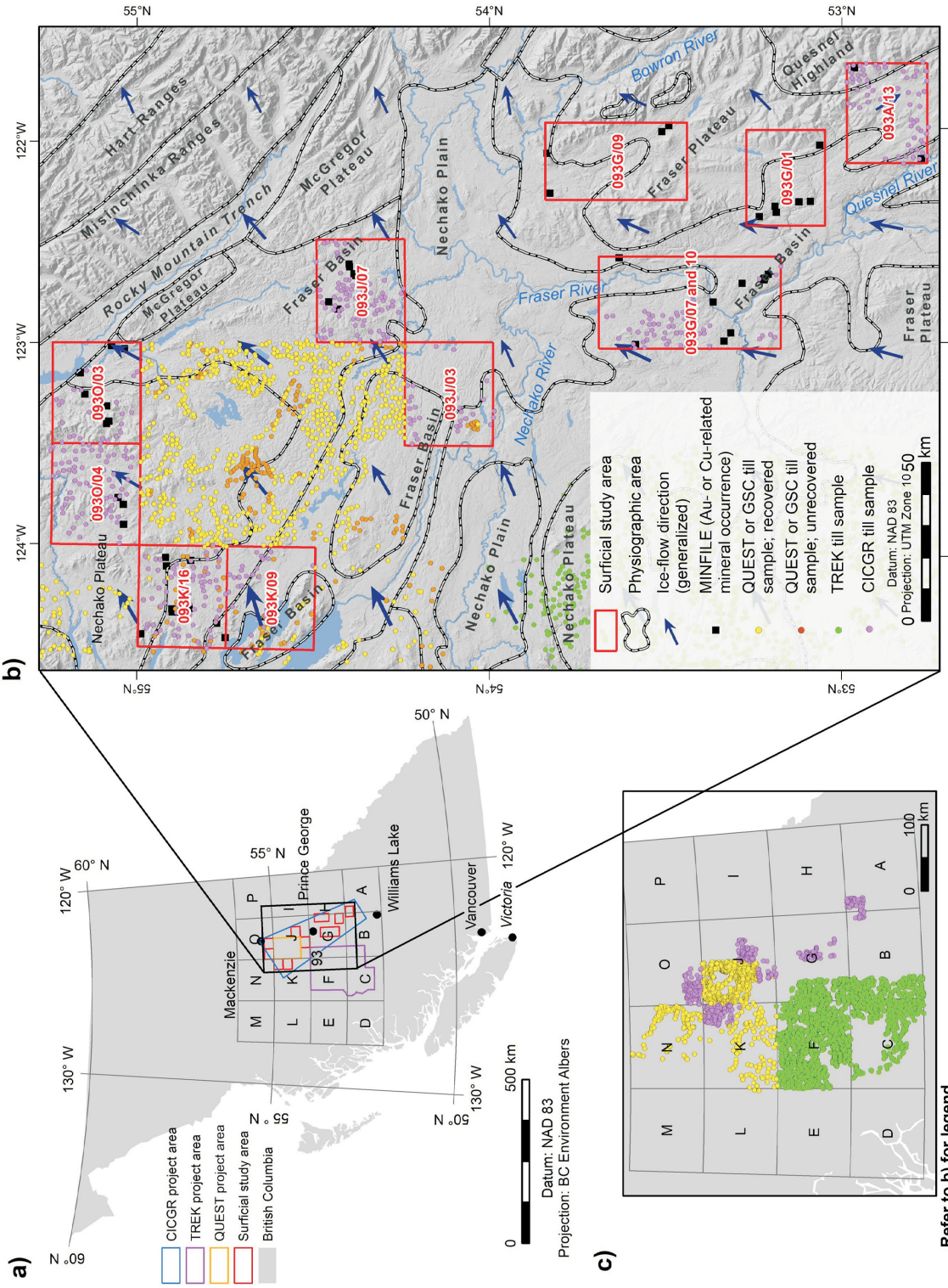

Figure 1. **a)** Location of Central Interior Copper-Gold Research (CICGR), Targeting Resources through Exploration and Knowledge (TREK) and Quesnellia Exploration Strategy (QUEST) projects areas. **b)** Surficial study areas; physiographic areas (Holland, 1976; Mathews, 1986); MINFILE occurrences (BC Geological Survey, 2020); locations of historical surface sediment samples proposed for reanalysis from QUEST (Ward et al., 2013) and Geological Survey of Canada (GSC) programs (Plouffe and Ballantyne, 1993; Plouffe, 1995; Plouffe and Williams, 1998); TREK till sample locations (Jackaman et al., 2015); and till samples collected during this study. **c)** Distribution of recovered historical till samples (yellow symbols) in central British Columbia, which will be reanalyzed to produce data comparable to existing data from the TREK project (green symbols) and this study (purple symbols).

Projects Area and Previous Work

The CICGR projects area occupies a large region in central BC between Mackenzie and Williams Lake. Within the CICGR projects area, the surficial exploration study areas include parts of NTS 093A, B, G, J, K and O and cover approximately 9700 km^2 (Figure 1). During the second year of the project, the area of the surficial exploration study was increased from 8600 to 9700 km^2, with the addition of 1100 km^2 dominantly in the NTS 093G/09 map area. There are 52 MINFILE mineral occurrences related to Au or Cu mineralization within the surficial study areas (BC Geological Survey, 2020), although significantly more occur within the larger CICGR projects area. The surficial study areas were determined based on three main criteria: 1) prospective geology; 2) avoidance of private land; and 3) applicability of till sampling. Surficial study area boundaries are based on the NTS map area boundaries, but some boundaries were adjusted to accommodate these criteria. For continuity of the till database, the compilation of historical till data and reanalysis of archived samples extends beyond the CICGR projects area to include the full extent of previous surveys (Figure 1).

The surficial study areas are within the Interior Plateau physiographic region and consist of parts of the Fraser Basin, Fraser Plateau, Nechako Plain, Nechako Plateau, Rocky Mountain Trench and Quesnel Highland (Holland, 1976; Mathews, 1986; Figure 1b). Bedrock exposures are commonly obscured by thick surficial deposits, composed dominantly of till, glaciolacustrine and glaciofluvial sediments. Surficial geology mapping has been conducted at various scales throughout the project area, providing an important regional context for the current, higher resolution interpretations. See Sacco et al. (2020) for a complete list of existing surficial geology mapping within the study areas.

The coalescence and subsequent divergence of glaciers in and around the northern part of the CICGR area during the last (Fraser) glaciation resulted in a complex surficial setting that has hindered exploration efforts. During the onset of the last glaciation, ice advancing from source areas north, south and west of the CICGR projects area coalesced, causing significant variations in ice flow and sediment transport and altered drainage systems resulting in the development of extensive glacial lakes (Clague, 1988; Plouffe, 1997; Sacco et al., 2017). Till was deposited in most areas during this glaciation; transport directions varied as the morphology of the ice sheet changed in relation to advance, climax and deglaciation. During deglaciation, ice retreated to the source areas leaving behind ablating ice masses in topographic lows. The retreating and stagnating ice altered drainage resulting in the deposition of large outwash deposits and the development of glacial Lake Fraser, a dynamic, time-transgressive body of water in which significant amounts of sediment accumulated. These thick sediment units obscure the underlying bedrock and till, which typically provide a basis for exploration, hindering the collection of high-quality surface sediment data. As a result, the CICGR area is underexplored and its mineral resources are largely unknown. Previous till sampling programs have been conducted in the northwestern part of the project area (Figure 1) and a description of past sampling programs relevant to the project is provided in Sacco et al. (2020).

Methods

The methodology for this program was adopted and improved from the previously completed TREK and QUEST projects. Surficial geology mapping was used to inform the reanalysis and genetic assessment of existing surface sediment samples and the planning and execution of the subsequent till sampling program. The till sampling program includes infill sampling in areas where the current density is insufficient and new sampling where no previous sampling has occurred. The new till sampling, combined with the reanalysis of archived samples, will culminate in a directly comparable till geochemical and mineralogical dataset for the surficial study areas.

Objective 1: Surficial Mapping and Till Sampling Suitability

Surficial geology mapping provides a basis for the collection and interpretation of surface sediment data. For this project, it identifies areas where subglacial till, the optimal surface sediment sample media for exploration, occurs at surface and provides the necessary framework to evaluate analytical results from historical and new surface sediment data. The surficial geology was interpreted at a scale of 1:50 000 from 1.5 m resolution satellite imagery converted into pseudo-stereo based on a digital elevation model (Natural Resources Canada, 2015). The stereo imagery enables the distinction of subtle patterns in topography and ground vegetation, which are diagnostic in interpreting the thicknesses and types of material and types of landforms in the shallow subsurface, and geomorphological processes that have affected the region.

The Geological Survey of Canada (GSC) mapping protocols (Deblonde et al., 2018) were chosen to maintain consistency with existing regional mapping by the GSC and similar scale mapping conducted by the BC Geological Survey (BCGS). Minor refinements were made to the mapping protocols to improve the accuracy of the TSS and drift thickness map products. Polygons were delineated based on surface material and expression, with an emphasis on identifying features that affect till sampling programs such as facies discrimination (e.g., subglacial till versus ablation till), geomorphological processes and important linear and point features (e.g., ice-flow indicators).

The TSS and drift thickness map products were derived from the surficial geology mapping (Figure 2). A multiclass TSS index, used to attribute each polygon, was based on the occurrence of subglacial till with consideration for any geomorphological processes that may have affected the material (e.g., reworking by meltwater, slope processes, etc.). The TSS is ultimately based on the proportion of subglacial till at the surface that is suitable for sampling. The drift thickness maps were derived using the expression and stratigraphic relationships of surficial map units, with a multiclass thickness index being used to symbolize mapped polygons following a similar approach as the TSS maps.

Objective 2: Compilation of Historical Data and Reanalysis of Archive Samples

The reanalysis of till samples archived from previous regional geochemical surveys is a cost-effective method of significantly upgrading the utility of the associated geochemical datasets. Maintaining the integrity and function of a regional geochemical database is a challenge when the analytical information being compiled is acquired from surveys conducted in different years. Many of these historic projects were completed in the 1990s when sampling protocols were less strict, and a considerable amount of the original results were generated using analytical methods that are now outdated.

Each of the archived samples is attributed with a genetic category based primarily on the original sample notes, where available, or the new surficial interpretations and observations made during fieldwork. A genetic category for each sample will be included in the final data compilation. Archive sample material was sent to Bureau Veritas Minerals (Vancouver, BC) for analysis of the silt plus clay–size (<0.063 mm) fraction to elevate these datasets to current standards. Analytical packages include an ultra-trace analysis by inductively coupled plasma–mass spectrometry (ICP-MS) for 53 elements following aqua-regia digestion, and major and minor elements by inductively coupled plasma–emission spectrometry (ICP-ES) following lithium metaborate-tetraborate fusion and dilute acid digestion. Prior to analysis by the laboratory, analytical duplicate and control reference samples were inserted into the sample sequence to monitor and assess the accuracy and precision of the new analytical results. The reanalysis by modern laboratory techniques combined with the genetic interpretations of these samples create a high-quality dataset that is comprehensive and directly comparable to the standard of current provincial datasets used to support exploration and environmental assessments.

Objective 3: Till Geochemical and Mineralogical Survey

The till geochemical and mineralogical survey began during year two of the program. Subglacial till is the primary target because it is a first derivative of bedrock (Schilts, 1993), is predictably transported in the direction of ice flow and provides a larger anomaly than the original bedrock source (Levson, 2001). Target sample media must be correctly identified to limit variability within the dataset and ensure contrasts in the dataset (i.e., anomalies) are related to mineralization rather than material genesis. The surficial geology and TSS mapping provided the foundation to plan and collect suitable subglacial till samples at ~2 km spacing. The survey was conducted to established standards to produce high-quality field and analytical results that are consistent with and comparable to the existing provincial till geochemical database.

At each sample site, two 1–2 kg subglacial till samples were collected from the C horizon for geochemical analysis and 50 clasts of large pebble- to small cobble-size were collected for lithological analysis. At approximately every other site, a 10–12 kg bulk subglacial till sample was collected for mineralogical analysis. Sacco et al. (2020) detail the field sampling protocols used in the till geochemical and mineralogical survey.

The subglacial till samples for geochemical analysis were shipped to Bureau Veritas Minerals, where they will be dried, have an archive generated, and processed to produce clay-size (0.002 mm) and silt plus clay–size (<0.063 mm) fraction splits. Both fractions will be analyzed for minor and trace elements by an ultra-trace aqua-regia digestion (0.5 g) ICP-MS package for 53 elements and by instrumental neutron activation analysis (INAA) for total gold plus 34 elements. Major and minor elements will be determined by ICP-ES following a lithium metaborate-tetraborate fusion and dilute acid digestion. This analytical package will include loss-on-ignition by weight difference after ignition at 1000ºC, plus total carbon and sulphur by LECO analysis. The LECO analysis converts carbon and sulphur forms in a sample into CO_2 and SO_2 by combustion in an induction furnace. The concentrations of CO_2 and SO_2 are measured by infrared absorption and thermal conductivity to determine total concentrations of carbon and sulphur. Quality control for analytical determinations will include the use of field duplicates, analytical duplicates, reference standards and blanks, based on established protocols (Spirito et al., 2011).

Clast lithologies will be grouped into broad categories that reflect the main lithologies of local bedrock to provide insight on the direction and distance of glacial transport. The bulk till samples were sent to Overburden Drilling Management Limited (Ottawa, Ontario) and processed for gold grain concentrates (<2.0 mm) and heavy and medium mineral concentrates (0.25–2.0 mm) using a combination of gravity tables and heavy liquids. Concentrates will be visually picked for gold and porphyry-copper–indicator minerals.

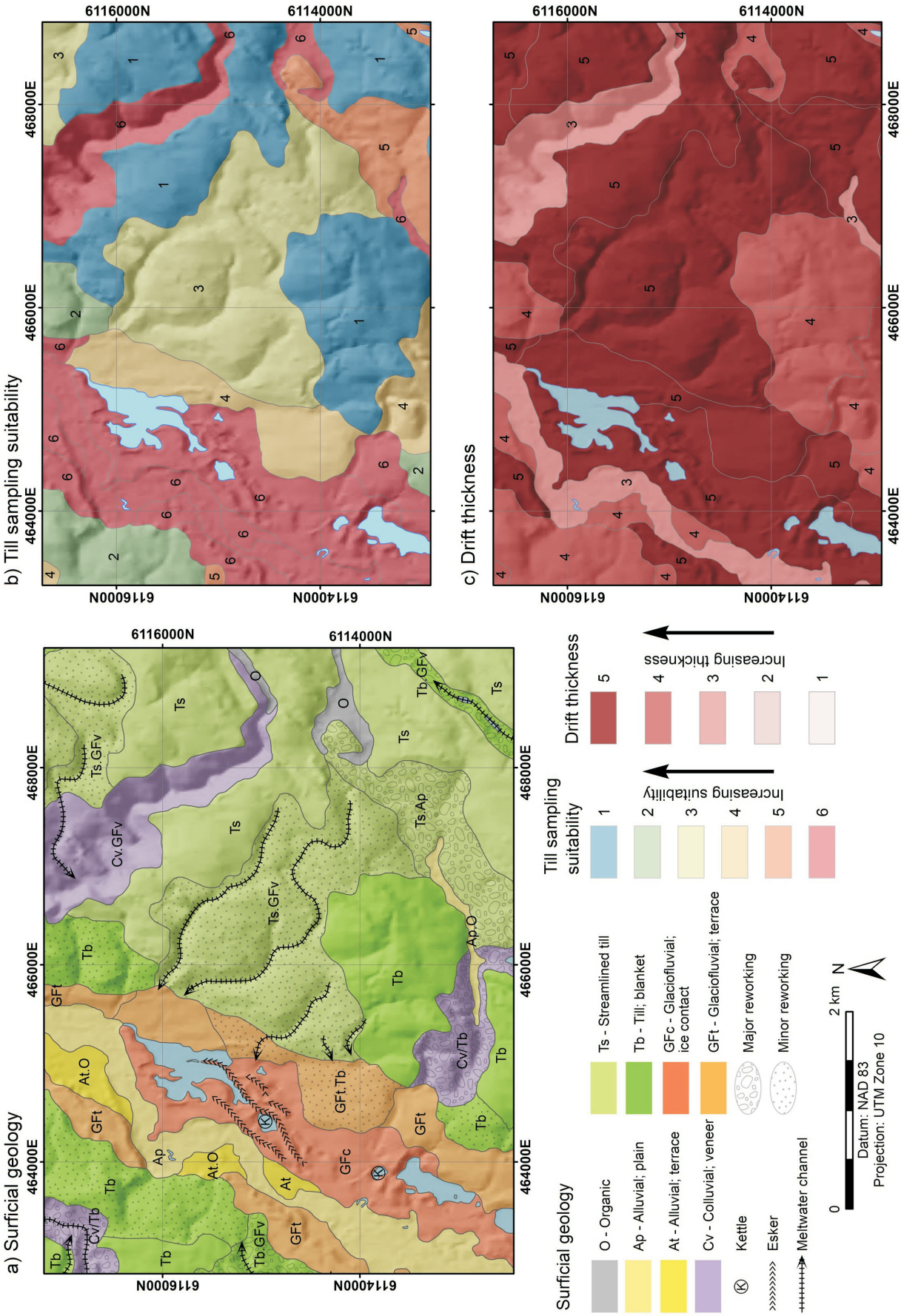

Figure 2. Examples of **a)** surficial geology, **b)** derived till sampling suitability and **c)** drift thickness mapping in the Central Interior Copper-Gold Research surficial study areas.

Progress and Future Work

Approximately 700 till samples that were collected in the 1990s as part of a GSC regional till sampling program (Plouffe and Ballantyne, 1993; Plouffe, 1995; Plouffe and Williams, 1998) and 825 samples collected in the late 2000s as part of Geoscience BC's QUEST project (Ward et al., 2013) have been proposed for reanalysis. In co-operation with the GSC, 288 representative 2 g splits of the silt plus clay–size (<0.063 mm) fraction of archive sample material and 672 original unprocessed character splits were retrieved from the storage facilities in Ottawa. The reanalysis of these 960 historic samples using modern laboratory techniques has been completed, creating an updated, higher quality dataset. Upon finalization of the surficial geology mapping, genetic attributions for the analyzed samples will be added to the database. Table 1 and Figure 1 indicate the historical sample sources and their recovery status. Recovery of the remaining archived samples proposed for reanalysis will be attempted during year three of this multiyear project; however, the current reanalysis results may be released sooner.

The 2020 field program focused on till sample collection and field verification of the surficial geology mapping, however, progress was slowed due to the effects of the COVID-19 pandemic. Adhering to WorkSafeBC safety guidelines created logistical challenges that extended beyond normal field program issues related to weather and mechanical breakdowns. Most notably, maintaining small working group bubbles was required to reduce the risk of crew exposure and community spread of COVID-19. The limited availability of basic services such as appropriate lodging and air travel were restricted, which limited accommodation and travel options, subsequently increasing the time required to move field crews. In addition, a decision was made to prioritize sample collection over field verification of the surficial interpretations. As a result, sample collection rates were slightly lower than anticipated but field verification was significantly curtailed.

To date, 456 new till samples have been collected in the CICGR project area (Figure 1). Adequate sample density has been attained within NTS map areas 093J/03 and 07, 093K/09 and 16, and 093O/03 and 04. The study areas that are mostly within 093A/13 and 093G/07 and 10 were partially sampled but require additional sampling to attain the ideal sampling density and distribution. Future sampling will address undersampled areas in 093A/13 and 093G/07 and 10, and in 093G/01 and 09, which have not been sampled yet.

The 2020 samples have been sent to Bureau Veritas Minerals and Overburden Drilling Management Limited for geochemical and mineralogical analysis, respectively. The geochemical, mineralogical and pebble data from the new samples will be evaluated and compiled before they are released as digital databases, which will include all analytical results, quality control data, and results from the reanalyzed historic samples.

Surficial geology mapping was finalized for NTS map areas 093J/07 and 03, 093K/09 and 16 and 093O/03 and 04, during the second year of the program. Preliminary surficial geology interpretations have also been completed for the remaining study areas. These preliminary interpretations will be finalized using field observations collected during the 2021 sampling program.

Till sampling suitability (Table 2) and drift thickness categories (Table 3) were finalized and attributed to the surficial geology polygons. In the CICGR area, TSS is most heavily influenced by the distribution of glacial lake sediments and ablation till. These glacial lake and stagnating ice deposits are also generally associated with thicker drift as they tend to accumulate in large depressions (i.e., Fraser Basin around Prince George) and within valley fill sequences. As a result, the areas that are poorly suited to surface till sampling due to overlying glaciolacustrine and ablation till deposits are well-suited to subsurface drill-supported sampling. Drill-supported sampling has the potential to provide till and bedrock samples, and stratigraphic information, which can inform the evaluation of surface sediment exploration data and provide information about groundwater and sediment aquifer potential.

Table 1. Sources and status of archive sample compilation for the Central Interior Copper-Gold Research projects area, northeastern British Columbia.

Report	Year	Recovered (n)	Pending recovery (n)	Archived fraction	NTS map area
Geoscience BC Report 2013-15 (Ward et al., 2013)	2013	672	153	Unprocessed	093J/03, 05, 06, 10–14
GSC Open File 2593 (Plouffe and Ballantyne, 1993)	1990, 1991	225	63	0.063 mm	093K/01–08, 10–12, 15, 16; 093N/01, 02, 06–11
GSC Open File 3194 (Plouffe, 1995)	1992, 1993, 1994	53	353	0.063 mm/ unprocessed	093K/01–10, 12, 14–16; 093L/01, 08; 093N/02–12, 14–16; 093O/05, 12
GSC Open File 3687 (Plouffe and Williams, 1998)	1997	2	0	0.063 mm	093K/04
Unpublished	1997, 1999	8	2	0.063 mm	093K/O9, 15; 093N/02, 03, 06, 11

Abbreviation: GSC, Geological Survey of Canada

Table 2. Till sampling suitability classifications for the Central Interior Copper-Gold Research projects area.

Till sampling suitability class	Description	Implications for exploration
1	All subglacial till	Most surface sediment is composed of till and suitable for sampling; minor amounts of other materials may occur even where not indicated in map unit.
2	Dominantly subglacial till or all subglacial till with minor reworking	Till is the dominant surficial material, or greater than half of the map unit is in situ subglacial till. Most of the map unit is suitable for surface till sampling.
3	Lesser amounts of subglacial till or dominantly subglacial till with minor reworking	In situ subglacial till comprises less than half of the map unit. Focus on high ground and down-ice from bedrock outcrops to increase the probability of finding till suitable for sampling at surface.
4	Lesser amounts of till with minor reworking or all till with major reworking	Suitable till for sampling likely occurs at surface in a small proportion of map unit. Focus on high ground and down-ice from bedrock outcrops to increase the probability of finding till suitable for sampling at surface; machine-supported sampling may be beneficial.
5	Till is dominant material with major reworking	Map unit dominantly composed of reworked till at surface, which is not suitable for sampling, and other materials. Till suitable for sampling is most likely to occur on high ground, but will be very limited in extent; machine-supported sampling is recommended.
6	Minor till with major reworking or no till	Unlikely to locate suitable till for sampling at surface within map unit; machine-supported sampling is recommended.

Table 3. Drift thickness classifications for the Central Interior Copper-Gold Research projects area.

Drift thickness class	Description	Implications for exploration
1	Bedrock is the dominant material exposed at surface; majority of overlying sediment is interpreted to be less than 2 m thick.	Bedrock occurs at surface or can be accessed with hand tools in most areas; optimal target for bedrock mapping and sampling; till in these units is commonly weathered and may not be suitable for mineral exploration samples.
2	Bedrock is the secondary surficial material; more than 50% of unit is interpreted to be overlain by sediment up to 2 m thick.	Bedrock is exposed at surface on topographic highs and can be accessed in hand-dug pits in most areas; good target for bedrock mapping and sampling; weathered till is common; composition of in situ till reflective of local bedrock.
3	Veneer is identified as the dominant surface expression with minimal bedrock outcrop; most bedrock in this unit is overlain by up to 2 m of sediment.	Bedrock outcrop is limited, but may be accessible with hand tools on topographic highs, along steep slopes, and where meltwater has removed sediment; bedrock likely accessible with an excavator; till composition typically reflects local bedrock.
4	Blankets greater than 2 m thick are dominant; sediment generally forms mantles that follow bedrock topography and thin on topographic highs.	Bedrock outcrop is rare and will likely only occur on topographic highs; bedrock may be accessible using excavator; till composition reflective of more distal bedrock sources.
5	Ablation till and large constructional glaciofluvial landforms that typically overlie subglacial till blankets.	Drill likely needed to access bedrock; underlying till is likely representative of more distal bedrock sources.
6	Thick glaciolacustrine or glaciofluvial deposits that form the upper surface of valley fill sequences or infill large depressions; commonly underlain by till and/or advance-stage glacial sediments.	Drill needed to access bedrock; potential for complex stratigraphy must be considered during drill-supported sediment sampling.

The finalized surficial mapping products and reanalysis results are planned for release in early 2021. The mapping release will include georeferenced PDF map sets of surficial geology, TSS and drift thickness. All mapping files will be provided in Esri geodatabase and shapefile format, embedded with appropriate GSC symbology codes such that users can easily import and symbolize these data to assist with their own exploration activities. The data release will include the analytical results from the archive samples and all quality assurance–quality control material.

Conclusions

The integration of surficial mapping and results of surface sediment sample analyses into a comprehensive dataset contributes to the ongoing development of a province-wide, regional exploration database. Survey methods conform to strict specifications; compiled information is comprehensive, compatible and reproducible; and the package complements a wide range of other ongoing geoscience initiatives and exploration activities. The project results, combined with data from the earlier Targeting Resources through Exploration and Knowledge (TREK) and QUEST projects, extend the coverage of comprehensive geochemical and mineralogical data to a larger portion of central British Columbia, and will promote increased awareness in a highly prospective region, assist in the identification of new exploration targets and support follow-up activities. In addition, these results will highlight specific areas where till sampling with hand tools cannot be used to determine mineral potential and different exploration techniques may be required.

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