



Geochemistry and mineralogy of subsurface till samples recovered from diamond drill hole R17-01, Rateria property (porphyry Cu±Mo), south-central British Columbia

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Front cover: Sample and core boxes from diamond drill hole R17-01. **Photo by T. Ferbey.**

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Abstract

Till geochemistry and mineralogy have the potential to detect buried porphyry Cu mineralization in drift-covered regions. The Guichon Creek batholith (Late Triassic) is a large (65 km by 30 km) texturally and compositionally zoned intrusive body in south-central British Columbia. It hosts the Highland Valley mine (calc-alkaline porphyry Cu-Mo±Au) and numerous other porphyry Cu±Mo mineral occurrences, including the Rateria porphyry Cu±Mo property (held by Happy Creek Minerals Ltd.). At the Rateria property, NQ diamond drill hole R17-01 reached bedrock at a depth of 146 m and till was intersected at two depth intervals: 90 to 111 m and 120 to 144 m below surface. Both till units contain clasts of local (intrusive felsic rocks) and exotic (volcanic rocks) derivation. Based on analysis of 14 samples, concentrations of ore and pathfinder elements in the silt plus clay sized fraction (<0.063 mm), and grain counts for ore and alteration minerals (0.25 – 2 mm), do not follow a specific trend, except for Cu which generally decreases with depth. The three highest Ag values in subsurface till samples from the Rateria drill hole exceed the values observed in regional surface till of the Highland Valley mine district. In addition, most Cu, As, Au, and all Pb, and Zn values are greater than background values for surface tills in the region. Chalcopyrite and gold grain counts for subsurface tills are within the range of nearby (<5 km) surface till samples. Samples with maximum elemental Cu and Au do not contain gold grains or copper-bearing minerals >0.25 mm. This suggests that the host mineral phases for these elements are predominantly in the fine fraction of till (<0.063 mm), possibly indicating post-glacial weathering of sand-sized mineral grains.

Keywords: Till geochemistry, till mineralogy, porphyry indicator minerals, calc-alkaline porphyry deposit, subsurface till, Highland Valley Copper mine

1. Introduction

Quesnel and Stikine terranes (Fig. 1) are prolific producers of porphyry mineralization (e.g., Nelson et al., 2013; Logan and Mihalyuk, 2014). However, prospective bedrock is commonly covered by glacial sediments, which challenges mineral exploration. Nonetheless, sampling subglacial tills, the predominant glacial sediment in these terranes, can help detect buried mineralization (Levson, 2001; Hashmi et al., 2015; Plouffe et al., 2016; Hickin and Plouffe, 2017). Subglacial till is the ideal sample medium for a till geochemical and mineralogical survey because it is commonly a first derivative of bedrock (Shilts, 1993; Lian and Hickin, 2017), has a predictable transport history, is deposited down-ice from its bedrock source and produces geochemical and mineralogical dispersal trains that extend across a broader area than their bedrock source (Levson, 2001).

Surface till samples (<2 m below surface) are typically collected in regional and orientation surveys, and may be supplemented by subsurface till samples (>2 m below surface) collected along road and stream cuts, and at mine sites (Levson, 2002; Ferbey and Levson, 2009; Hashmi et al., 2015; Plouffe and Ferbey, 2016). In British Columbia, sampling of semi-continuous vertical profiles from drilling is relatively rare. Notable exceptions include Levson (2002; Nak calc-alkaline porphyry Cu-Mo±Au prospect), Ferbey and Levson (2009; Huckleberry calc-alkaline porphyry Cu-Mo±Au mine), and Averill (2017; Blackwater-Davidson epithermal Au-Ag prospect). Herein we present results from another example, with core sampled from the Rateria property (porphyry Cu±Mo), 17 km southeast of the Highland Valley mine (calc-alkaline porphyry Cu-Mo±Au).

In June 2017, Happy Creek Minerals Ltd., completed an NQ

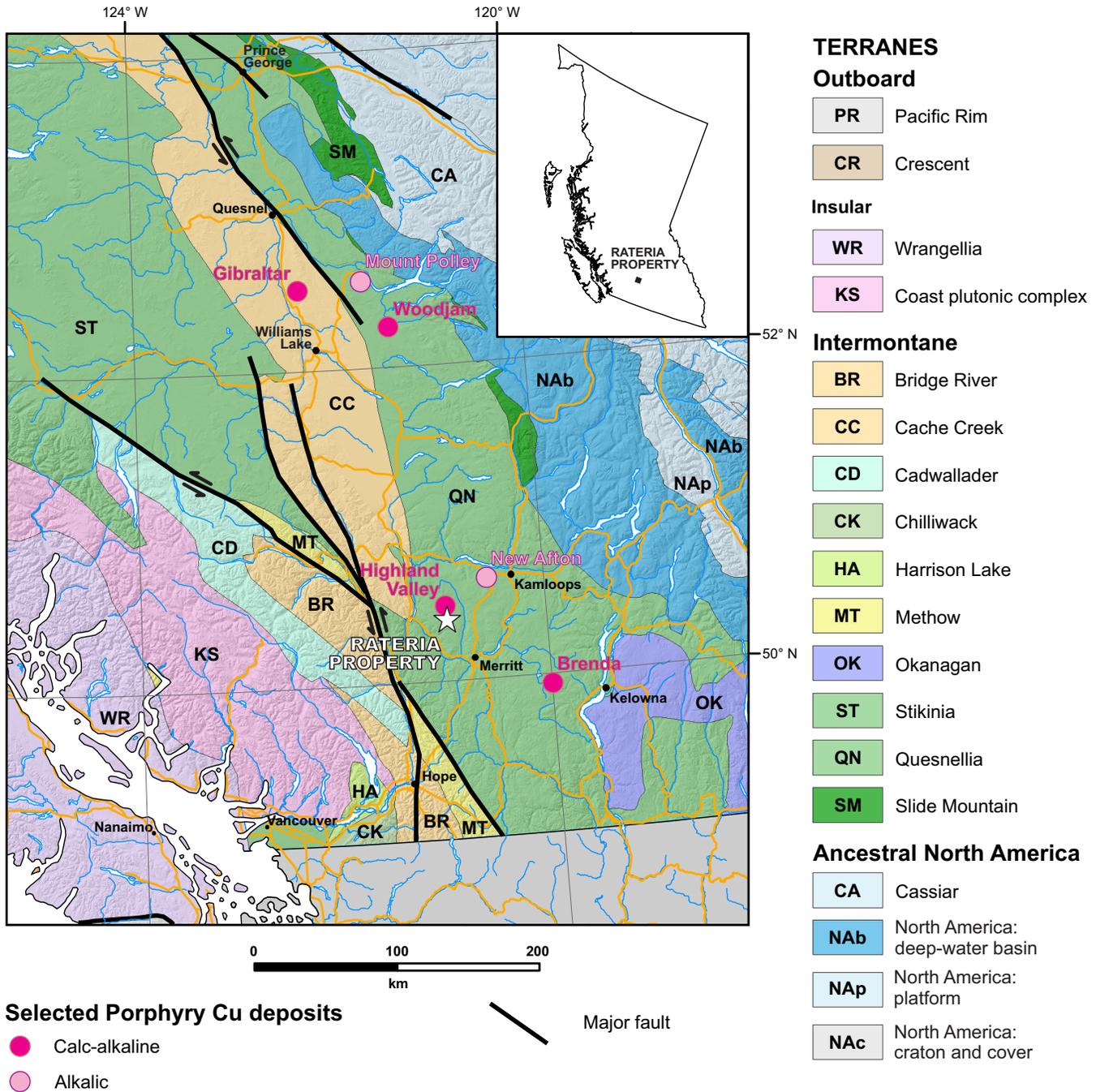


Fig. 1. Study area location. Diamond drill hole R17-01 was drilled in the southern part of Rateria property (white star). Terranes of the southern Canadian Cordillera after Nelson et al. (2013).

diamond drill hole (R17-01) in the southern part of their Rateria property to follow up on a low- to moderate-IP chargeability anomaly in inferred prospective rocks. Unconsolidated sediments from surface to the bedrock contact (0 to 146 m) were cored and placed in core boxes (Fig. 2). For this study, we took 14 samples from two massive, well-compacted diamicton horizons that we interpret as subglacial tills. These diamictons are similar to surface subglacial tills observed regionally (Ferbey et al., 2016). Below we present geochemical and mineral separation data from the drill-core samples, test

the variability of till composition with depth, and compare the composition of the drill core samples to regional surface till data sets presented by Plouffe and Ferbey (2016) and Ferbey et al. (2016).

2. Setting

The study area is 56 km southwest of Kamloops, British Columbia (Fig. 1) and is accessed by forestry roads. It falls within the Thompson Plateau, a physiographic subdivision of the Interior Plateau (Holland, 1976). It is a gently rolling upland



Fig. 2. Core boxes 1 through 17, from 0 m (top of photo) to 174 m (bottom of photo), for Happy Creek Minerals Ltd. diamond drill hole R17-01 (NQ size).

and, although bedrock outcrops discontinuously, it is most commonly mantled by thin (<2 m) to thick (>2 m) successions of Quaternary sediments.

The Rateria property is in the Highland Valley mine district, which is well-endowed with porphyry Cu deposits that are spatially and genetically related to the Guichon Creek batholith (Late Triassic; Fig. 3). Highland Valley mine has been in continuous operation since 1962 and, as of 2013, has processed 1615 million tonnes of ore grading 0.40% Cu and 0.010% Mo (Byrne et al., 2013). Numerous other porphyry Cu showings are related to the Guichon Creek batholith, including those at the Rateria property.

Happy Creek Minerals Ltd.'s diamond drill hole R17-01 is collared in retreat-phase, hummocky glaciofluvial deposits (Plouffe and Ferbey, 2015a; in press), adjacent to a series of sub-parallel meltwater channels that drained to the southeast. The Guichon Creek batholith is, for the most part, covered by variable thicknesses and facies of till that lie stratigraphically beneath the glaciofluvial sediments.

3. Bedrock geology

Late Triassic to Early Jurassic intrusions in Quesnel and Stikine volcanic arc terranes have potential to host porphyry Cu mineralization (e.g., Nelson et al., 2013; Logan and Mihalynuk, 2014). Most of this mineralization formed before these terranes accreted to ancestral North America. Deposit types include both calc-alkaline (e.g., Highland Valley, Gibraltar, and Brenda mines,) and alkalic (e.g., New Afton, Mount Polley, and Copper Mountain mines) varieties (Fig. 1).

The study area is underlain by the Guichon Creek batholith (Late Triassic; Fig. 3), a large (65 km by 30 km) texturally and compositionally zoned intrusive body with an older mafic marginal facies that changes laterally to a younger coarse-grained and porphyritic felsic interior (McMillan, 1985; Byrne et al., 2013). The younger felsic facies hosts the five porphyry Cu centres at Highland Valley mine (Valley, Lornex, Bethlehem, Highmont and JA); numerous other porphyry Cu±Mo mineral occurrences are spatially and genetically related to the larger batholith (Fig. 3). Adjacent to the batholith are upper Paleozoic and lower Mesozoic island arc volcanic, sedimentary, and intrusive rocks (Fig. 3; McMillan, 1978; McMillan et al., 2009).

Bedrock structure plays an important role in localizing zones of mineralization and alteration in the Highland Valley mine district, with high concentrations of copper and molybdenum occurring in, or directly adjacent to, veins, faults, and breccias (Bergey et al., 1971; McMillan, 1985; Casselman et al., 1995; Byrne et al., 2013). For example, some of the larger economic deposits are along major faults (e.g., Valley and Lornex along the Lornex fault and Bethlehem and Valley along the Highland Valley fault; Fig. 3). Some of these structures may have been active after the mineralizing event. For example, the Valley and Lornex porphyry centres are thought to represent a single deposit that was offset by the Lornex fault (Byrne et al., 2013).

The main ore minerals in the Highland Valley deposits are chalcopyrite, bornite, and molybdenite. Other hydrothermal metallic minerals, such as specular hematite, magnetite, and chalcocite, occur locally. Present in trace amounts are sphalerite, galena, tetrahedrite, pyrrhotite, enargite, and covellite. The main porphyry centres display variation in sulphide mineral assemblages. For example, molybdenite occurs at Valley, Lornex, Highmont, and JA but is absent at Bethlehem (Bergey et al., 1971; Casselman et al., 1995; Byrne et al., 2013). Other porphyry Cu mineral occurrences in the district contain similar sulphide mineral assemblages but can include other secondary copper minerals such as malachite.

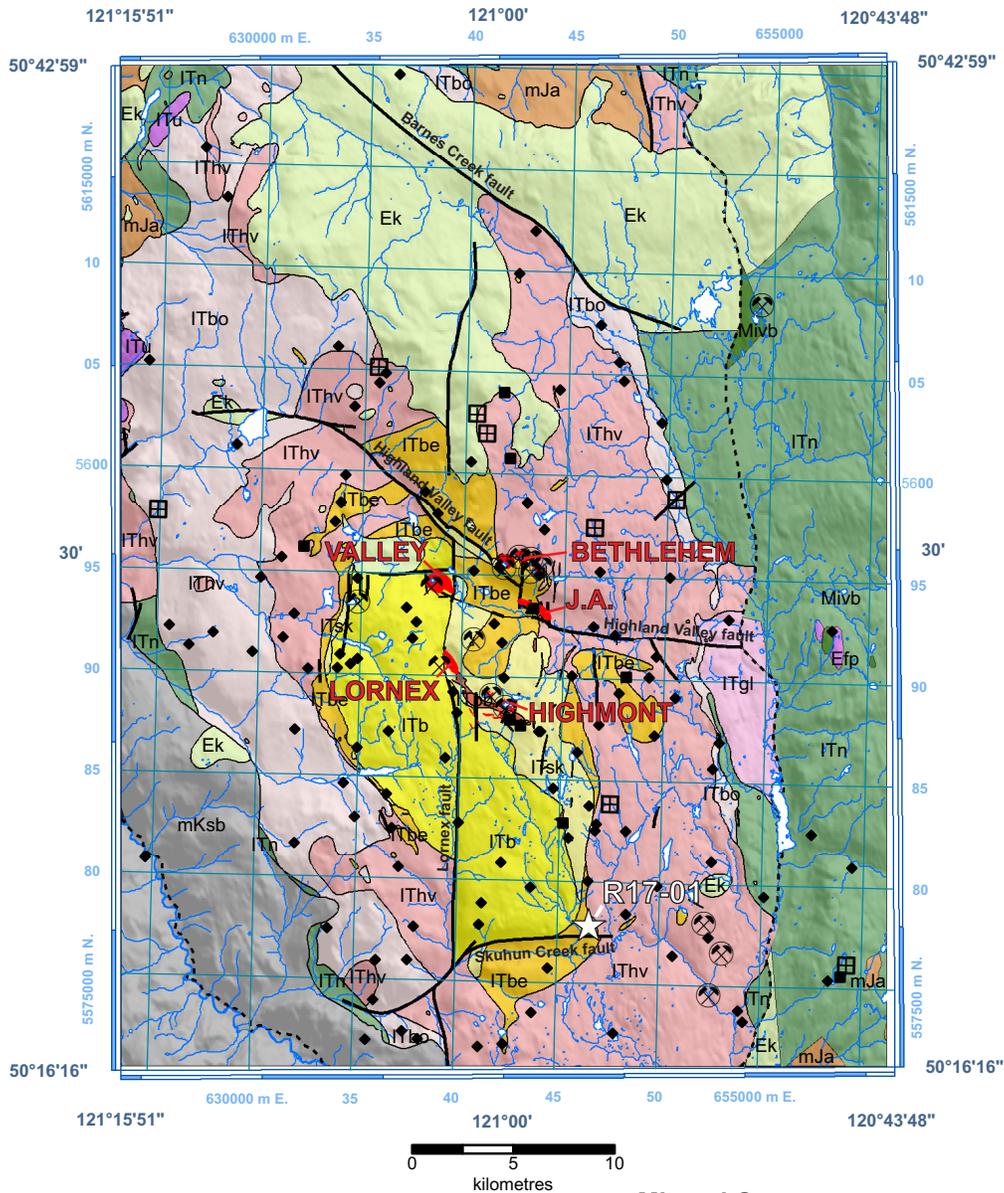
4. Quaternary geology

4.1 Ice-flow history and glacial transport

The study area was glaciated during the Late Wisconsinan (Clague and Ward, 2011). At the onset of glaciation, ice advanced out of alpine accumulation areas in the Coast and Cariboo mountains, eventually coalescing on the Interior Plateau to form the Cordilleran Ice Sheet. During the glacial maximum, one or more ice domes (or divides) formed in central British Columbia and ice flowed radially from their centres (Stumpf et al., 2000; Clague and Ward, 2011). Interpreting an area's ice-flow history is fundamental to determining the transport path of subglacial tills.

Ice-flow history details for the study area are presented in Ferbey et al. (2016), and are only summarized herein. Regionally, we recognize an early south to south-southeast ice flow and later flow to the southeast. We attribute the general southward flow to the development of an ice divide near 52°N (180 km

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Geology

Stratified Rocks

Eocene and Younger

Mivb *Unnamed volcanic rocks*

Ek *Kamloops Group*

Cretaceous

mKsb *Spences Bridge Group*

Jurassic

mJa *Ashcroft Formation*

Triassic

ITn *Nicola Group*

Intrusive Rocks

Eocene and Younger

Efp *Unnamed intrusive rocks*

Triassic - Guichon Creek Batholith and associated intrusions

ITgl *Gump Lake phase*

ITpb *post-Bethsaida phase*

ITb *Bethsaida phase*

ITsk *Skeena variety*

ITbe *Bethlehem phase*

IThv *Highland Valley phase*

ITbo *Border phase*

ITu *Undivided*

Mineral Occurrences

Producer

Past producer

Developed prospect

Prospect

Showing

Highland Valley District porphyry centre

Extent of McMillan et al. (2009) mapping

Fault

Fig. 3. Bedrock geology of the Guichon Creek batholith (McMillan, 1978; McMillan et al., 2009; Cui et al., 2015). Location of Highland Valley mine porphyry centres (red zones; Valley, Lornex, Bethlehem, Highmont, and JA), and Happy Creek Minerals Ltd. diamond drill hole R17-01 (white star), included.

to the north) during the Late Wisconsinan glacial maximum (Plouffe et al., 2016). The variation of ice movements from south to southeast recorded from glacial striations (see Fig. 4 of Ferbey et al., 2016) is related to the influence of topography at times when the Cordilleran Ice Sheet was thinner (e.g., pre and post-glacial maximum).

A simple ice-flow history will result in a simple transport path of subglacial tills. Linear, ribbon-shaped, dispersal trains reflecting a single phase of ice flow have been reported at the Galaxy property (alkalic porphyry Cu-Au) about 45 km east-northeast of Highland Valley mine (Kerr et al., 1993; Lett, 2011). Similar simple transport, predominantly towards the south-southeast, is expected for subglacial tills in the Highland Valley mine district (Ferbey et al., 2016; Plouffe and Ferbey, 2017).

4.2 Drill hole stratigraphy

The local Quaternary stratigraphy described here is based on recovery from Happy Creek Minerals Ltd.'s diamond drill hole R17-01 (Fig. 4), not surface exposures. R17-01 is an angled drill hole (-75° towards 270°) and so true depths were converted from apparent depths recorded on core boxes. Interpretations are limited by the diameter of the NQ drill core (48 mm), which is too small to observe some features required to interpret transport mechanism and depositional environment.

Depth to bedrock in R17-01 is significant (146 m) but not unique for the area. For example, exposures and drill hole logs at Highland Valley mine, 17 km northwest, show that depth to Late Triassic basement can be 160 m (Bobrowsky et al., 1993) to 300 m (McMillan, 1976) below surface. R17-01 is close to (<1 km) the Skuhun Creek fault, one of the major brittle structures running through the Highland Valley district (Fig. 3), but there is no lithological or structural indication of this fault in the drill hole.

4.2.1. Unit 1: 300 to 146 m below surface (bedrock)

Unit 1 is a variably altered (propylitic, sericitic, and potassic) granodiorite, likely belonging to Bethlehem phase of Guichon Creek batholith (Late Triassic; Fig. 4). Only the upper 30 m of the unit is described here (176 to 146 m) but logs provided by Happy Creek Minerals Ltd. show this same unmineralized unit extends to the bottom of the hole, to a depth of 300 m.

Competent granodiorite is overlain by weathered granodiorite over two depth intervals: 176 to 164 m and 151 to 146 m. The weathered granodiorite disaggregates along mineral grains and resembles a *grus*.

Well-sorted, laminated and coarsening upwards fine sand at 168 to 167 m, coarsening upwards silty very fine sand to medium sand with rare pebbles at 151.5 to 151 m, and silty and clayey very fine sand at 149 to 148 m might represent sediment injected into bedrock. Such injection features are a product of subglacial sediment being pushed or squeezed into weathered bedrock by weight of the over-riding glacier (Lian and Hickock, 2010). Alternatively, they could simply be passive sediment infill of joints or fractures. At 164 m, weathered granodiorite

is in sharp contact with 5 m of massive to cross-stratified, well sorted fine sand that coarsens upwards to a medium sand. This sandy horizon is similar to the overlying unit 2 (see below).

4.2.2. Unit 2: 146 to 144 m below surface (fluvial or lacustrine)

Unit 2 is predominantly a horizontally to cross-stratified, very fine sand to silt that fines upwards to a laminated silt and clay (Fig. 4). The lower contact with Unit 1 is sharp (Fig. 5). This unit was deposited in a lower energy environment, possibly fluvial or lacustrine.

The Unit 1-Unit 2 stratigraphy is repeated: from 176 to 159 m and from 159 to 144 m, but the origin of this repetition remains uncertain. Taking into account the angled drill hole (-75° towards 270°), the repetition may reflect an irregular bedrock topography (Fig. 6a) or a slab of bedrock thrust by glaciotectionics (Fig. 6b).

4.2.3. Unit 3: 144 to 120 m below surface (subglacial till)

Unit 3 is a massive, pebble to boulder diamicton with a silty sand matrix (Fig. 4). Granule content is up to 25%. The lower 7 m of this unit contains predominantly intrusive clasts; the lowest 0.5 m contains monzodiorite clasts exclusively (Fig. 7). Clasts of exotic volcanic rocks are more abundant in the upper 17 m, reaching an estimated maximum of 60% (Fig. 8, Appendix 3). Some of the larger clasts in the lower part of unit 3 are striated. Boulders are more common in the upper part, with the largest recovered clast (>30 cm) occurring at 127 m. The lower contact with unit 2 is gradational over 20 cm.

Unit 3 is interpreted as subglacial till (Dreimanis, 1989) based on the massive nature of the sediment, and the presence of striated clasts and exotic lithologies. The lower gradational contact likely reflects the erosion and deformation of unit 2. As such, the contact zone resembles a subglacial traction till (Evans et al., 2006). Unit 3 was sampled for geochemical determinations and mineral separations. Samples 17TFE0002 and 17TFE0003 were collected from the lower, monomictic interval (with monzodiorite clasts; Figs. 4, 7) and samples 17TFE0004 to 17TFE0008 were collected from the upper, polymictic interval (with volcanic and intrusive clasts; Figs. 4, 8).

4.2.4. Unit 4: 120 to 111 m below surface (glacigenic debris flow; glaciofluvial or glaciolacustrine)

Unit 4 consists of interbedded massive, bouldery, silty-sand diamicton containing predominantly intrusive clasts and massive to laminated fine to coarse sand containing minor horizontally laminated silt and clay (Fig. 4). Diamicton interbeds are approximately 1.1 m thick; sandy beds are approximately 0.8 m thick. The lower contact of this unit is sharp. The diamictons have been interpreted as having been deposited by glacigenic debris flows (Levson and Rutter, 1989) that appear to have punctuated background glaciofluvial and/or standing water body sedimentation.

DRILL HOLE R17-01

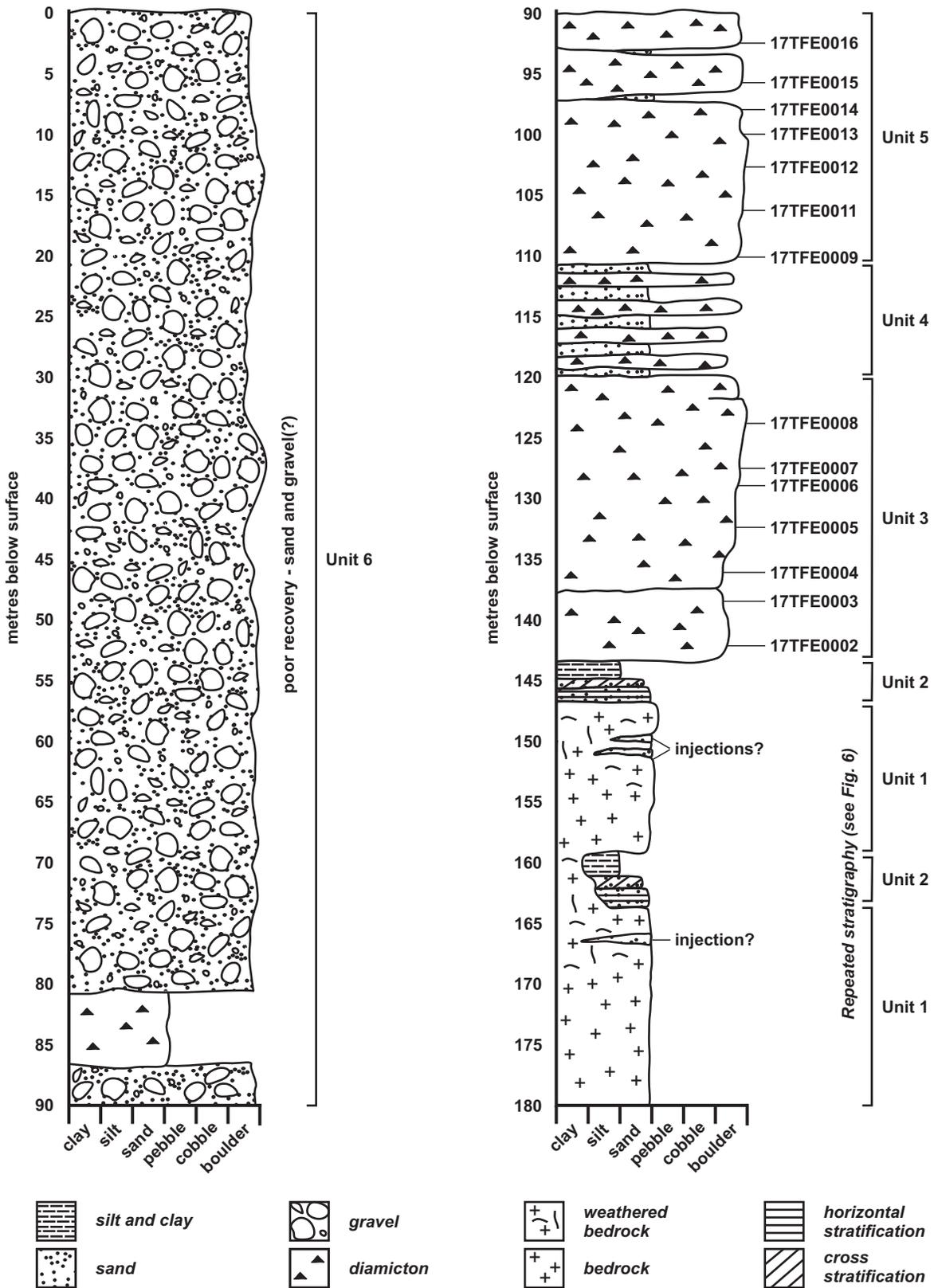


Fig. 4. Stratigraphic section from Happy Creek Minerals Ltd. diamond drill hole R17-01 (NQ size). Subsurface till sample locations are indicated.

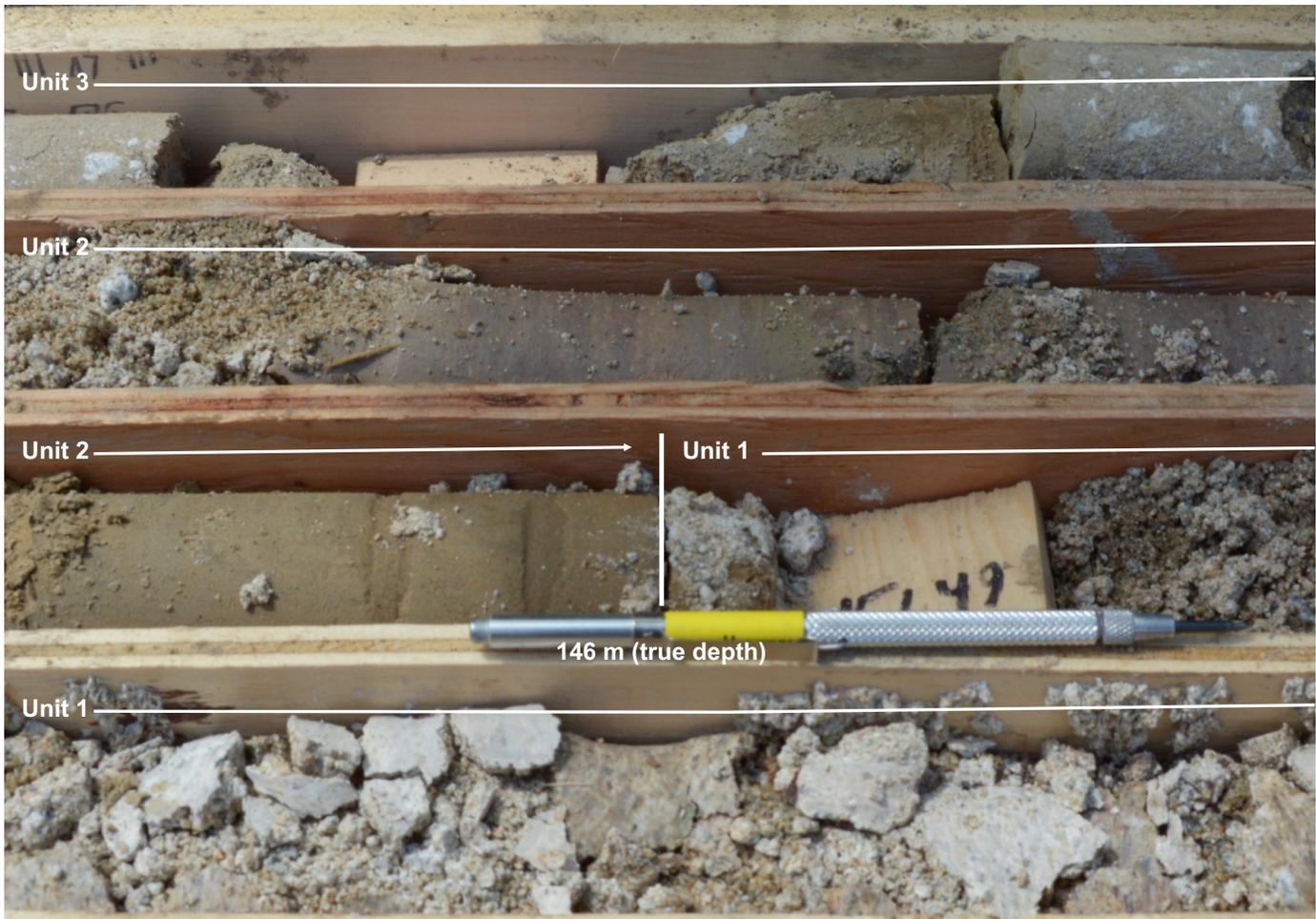


Fig. 5. Bedrock contact (Unit 1) with overlying unconsolidated sediments (Units 2 and 3), at 146 m below surface (true depth).

4.2.5. Unit 5: 111 to 90 m below surface (subglacial till)

Unit 5 is a massive boulder diamict with a silty sand matrix (Fig. 4). Most clasts (90%) are intrusive, 20 to 30% of which are monzodiorite (Fig. 9). A well-sorted fine sand lens appears at 97 m; a well-sorted coarse sand lens at 94 m. The lower contact of the unit is sharp. We interpret the diamict as a subglacial till (as defined by Dreimanis, 1989), and sampled it for geochemical determinations and mineral separations (17TFE0009 to 17TFE0016; Fig. 4).

4.2.6. Unit 6: 90 to 0 m below surface (glaciofluvial sands and gravels)

Unit 6 is the uppermost unit cored (Fig. 4). Recovery was poor, but it appears to be a sandy, pebbly to cobbly gravel, containing mainly intrusive clasts. Within this interval are local well sorted fine sand, silt and clay horizons. The lower contact of this unit is gradational. A massive pebbly diamict with a silty sand matrix and predominantly intrusive clasts occurs between 87 and 81 m. This diamict could be a till and reflect fluctuations at an ice margin (e.g., minor glacial retreat and readvance) during deglaciation. Alternatively, it could be a glacial debris flow produced by water-saturated debris

shedding off the front of a retreating glacier, or from a valley or channel side in an unstable paraglacial environment (Levson and Rutter, 1989).

Diamond drill hole R17-01 is collared in a hummocky glaciofluvial unit mapped by Plouffe and Ferbey (2015a; in press). Given the thickness of drill hole Unit 6 (at least 80 m), this map unit could include relatively deep paleo-channels or valleys.

4.2.7. Summary

In the absence of absolute chronology, organic-bearing sediments, soil development and deeply weathered sediments, we tentatively correlate the stratigraphic sequence of R17-01 to the Late Wisconsinan. Unit 2 most likely reflects fluvial or lacustrine pre-glacial sedimentation. Units 3 and 5, both interpreted as subglacial tills, intercalated with debris flows (unit 4) suggest a fluctuating ice front during glacier advance or retreat. During ice retreat, meltwater deposited the sand and gravel of unit 6 in contact with ice (buried ice) as reflected in the hummocky surface expression of the sediments.

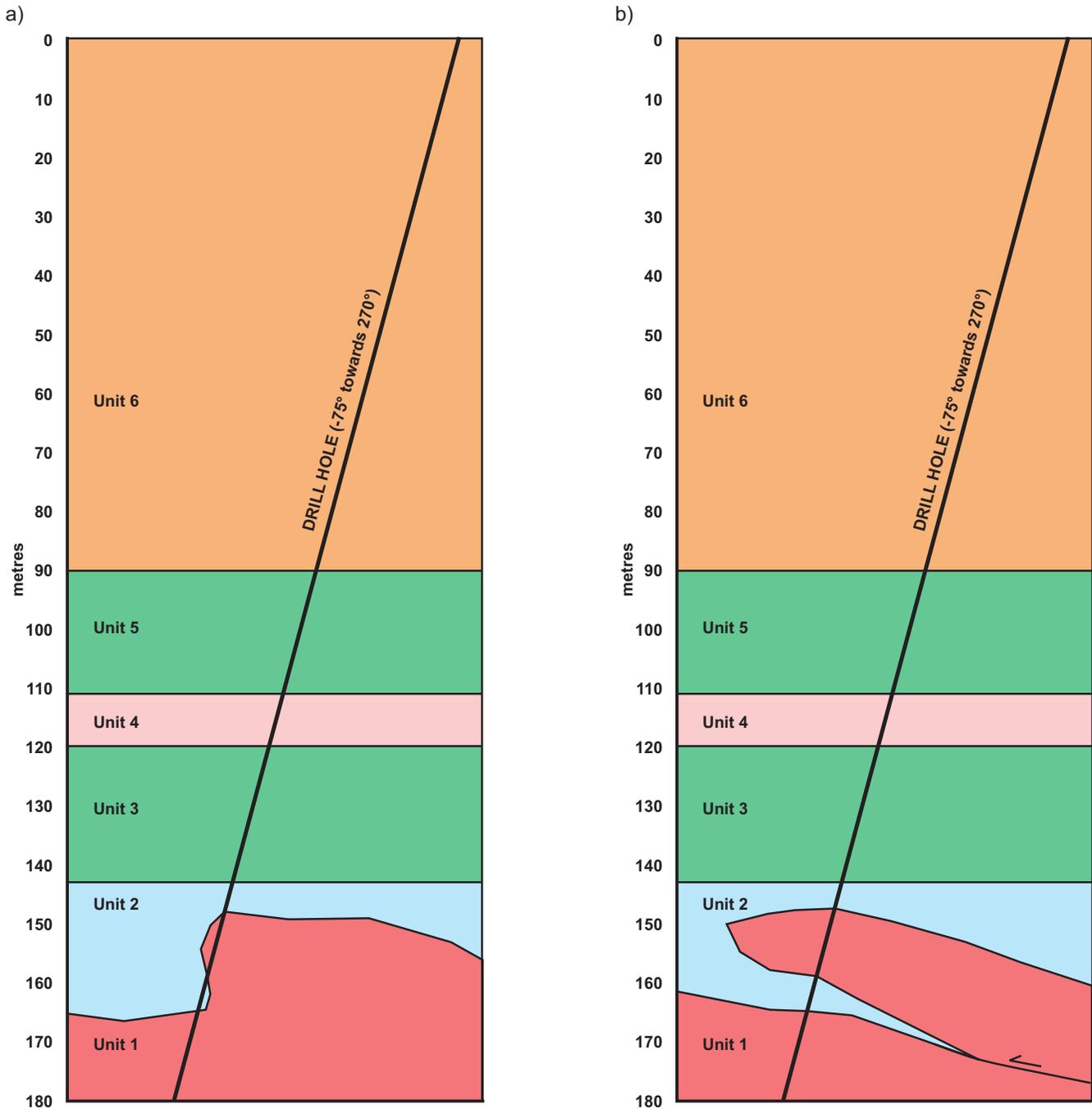


Fig. 6. Two explanations for repeated stratigraphy (Units 1 and 2). **a)** Irregular bedrock topography is pierced, Unit 2 re-encountered, and bedrock re-entered. **b)** Glacially thrust slab of bedrock pierced, Unit 2 re-encountered, and bedrock re-entered.



Fig. 7. Lower unit 3, monomictic diamicton with only monzodiorite clasts.



Fig. 8. Upper unit 3, monomictic diamicton with granitic and volcanic clasts.



Fig. 9. Unit 5, massive diamicton with mainly (up to 90%) intrusive clasts and local exotic volcanic clasts. Note monzodiorite boulder in top row.

5. Till sampling

Ferbey et al. (2016) presented till matrix geochemistry and mineralogy for surface samples in the Highland Valley mine district. Till composition clearly reflects mineralization at Highland Valley mine, and at other mineral occurrences in the district. Here, we supplement these data with 14 samples collected at 2 to 4 m depth intervals from the drill core (Fig. 4). With the exception of size, the samples were collected following procedures used by Ferbey et al. (2016), which are outlined in Spirito et al. (2011), McClenaghan et al. (2013), and Plouffe et al. (2013). Ferbey et al. (2016) used two surface till sample sizes: 2 to 3 kg for geochemical analyses and 10 to 15 kg for heavy mineral analyses. Samples collected for this project weighed from 2 to 3 kg, as limited by the size of drill cores, and this material was used for both matrix geochemistry and mineral separations (Fig. 10).

6. Laboratory methods

Laboratory methods used for this study were identical to those used by Ferbey et al. (2016), allowing data to be directly integrated or compared. Overburden Drilling Management (Ottawa, ON) first sieved 100 g of silt plus clay sized material (<0.063 mm) for geochemical analyses conducted at Bureau Veritas Commodities Canada (Vancouver, BC; Fig. 11). Material left over was recombined with the original bulk sample and then run through a mineral processing circuit at Overburden Drilling Management (Fig. 12). The following details these geochemical and mineralogical analyses.



Fig. 10. Example of sample collection and sample size (sample 17TFE002).

6.1 Geochemical analyses

Geochemical analyses were completed on the silt plus clay-sized (<0.063 mm) fraction at Bureau Veritas. Analyses completed were: 1) 0.2 g aliquot digested with lithium metaborate/tetraborate, fused at 980°C, dissolved in 5% HNO₃ (lithium-fusion), and then analyzed by inductively coupled plasma emission spectrometry and mass spectrometry (ICP-ES and ICP-MS); 2) 30 g aliquot diluted in a hydrochloric and nitric acid solution (ratio 1:1, modified aqua regia) and

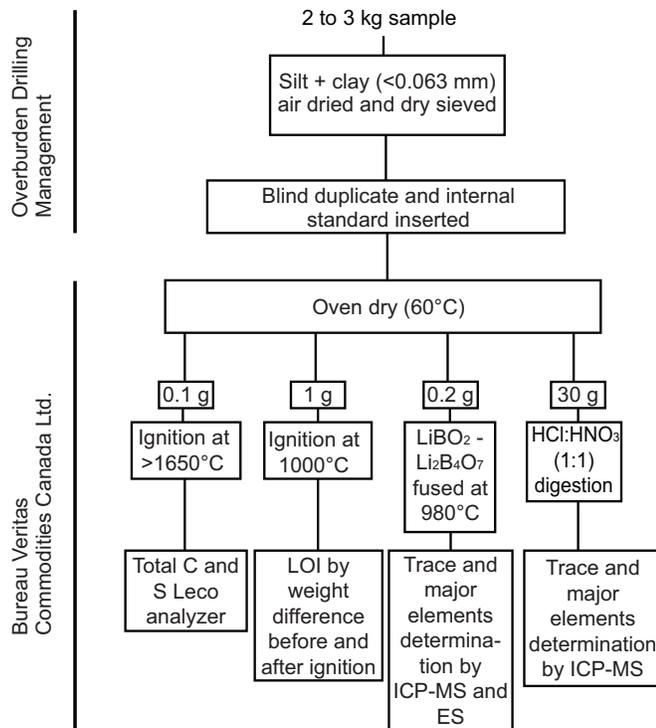


Fig. 11. Sample processing and geochemical analyses flow chart (modified from Plouffe and Ferbey, 2015b). Laboratory responsibilities shown on left.

analyzed by ICP-MS; 3) 0.1 g aliquot ignited at $>1650^{\circ}\text{C}$ in a Leco analyzer for total carbon and sulphur determination; and 4) loss on ignition (LOI) was determined on 1 g aliquot by weight difference after ignition at 1000°C (Fig. 11). Large aliquots (30 g) were submitted for analyses by ICP-MS to reduce the gold nugget effect (Harris, 1982; Stanley, 2008). This was done to increase analytical precision by reducing the effect of heterogeneously distributed gold grains in the silt-size fraction.

Geochemical data, including detection limits, are presented in Appendices 1 (modified aqua regia) and 2 (lithium-fusion). Included are worksheets (see QA_QC_listing) that lists blind (analytical) duplicates and analytical standard samples.

6.2 Indicator mineral processing and identification

Heavy mineral concentrates were produced at Overburden Drilling Management. An archive split was not taken before heavy mineral separation and the entire sample was processed. Samples were first wet sieved to <2 mm and pre-concentrated on a shaking table. Clasts in the >2 mm fraction were classified and their amount estimated into four broad classes (volcanic or sedimentary, granitic, carbonate, and others). Heavy mineral concentrates obtained from the shaking table were panned in a small container (micro panning) and observed under a binocular microscope to determine the number of gold grains and their size. Based on morphology, gold grains were classified as reshaped, modified, or pristine as defined by DiLabio

(1990). Gold concentration in the heavy mineral concentrates (calculated ppb) was then estimated based on the number of gold grains, their size, and the total weight of the concentrate following a calculation outlined in Averill and Zimmerman (1986) and Averill (1988). Gold grains were returned to the shaking table concentrate, which was then separated into mid- (>2.8 to 3.2) and high- (>3.2) density fractions using methylene iodide diluted with acetone to the correct specific gravity.

Magnetic minerals were removed from both density separates with a hand magnet. Non-ferromagnetic density fractions were sieved to 0.25 to 0.5 mm, 0.5 to 1 mm, and 1 to 2 mm fractions. The >3.2 SG, 0.25 to 0.5 mm separate was subjected to a paramagnetic separation using a Carpc® magnetic separator set at 0.6, 0.8, and 1 amp to help mineral identification (McClenaghan, 2011; Plouffe et al., 2013). All size and density fractions were examined for indicator minerals using a binocular microscope. Minerals were identified based on color, crystal habit, luster, cleavage, and surface textures. For some grains, optical identification was verified with a scanning electron microscope (SEM). The percentage of green epidote was estimated from the 0.25 to 0.5 mm, SG >3.2 , and 0.8 to 1.0 amp fraction as reported in Plouffe and Ferbey (2015b; 2016), Plouffe et al. (2016) and Ferbey et al. (2016). The unmodified laboratory reports produced by Overburden Drilling Management are included in Appendix 3.

7. Quality assurance/quality control measures

Quality assurance/quality control (QA/QC) results indicate that geochemical results obtained as part of this project are suitable for geological interpretation and are not a product of analytical artefact. Interpretations of QA/QC geochemical data are detailed below. Due to limited sample size (2-3 kg), duplicate samples were not submitted for heavy mineral analyses.

7.1. Geochemical analyses

A blind duplicate (analytical duplicate) and internal standard were inserted in the sample suite sent for geochemical analysis to estimate data precision and accuracy. Field duplicates were not collected given the small amount of available drill core material. One blind duplicate was prepared by splitting a routine sample following procedures outlined in Spirito et al. (2011) and McClenaghan et al. (2013) and was used to evaluate analytical variability. The internal standard, BCGS Till 2013, was inserted in the sample suite to evaluate analytical accuracy. Estimates for analytical precision and accuracy are provided in Appendices 1 and 2.

7.1.1. Blind duplicate

Analytical precision for all porphyry Cu commodity and pathfinder elements in the blind duplicate, determined by modified aqua regia ICP-MS, is $<15\%$ RSD, a value considered acceptable for geologic interpretation (Abzalov, 2008; Appendix 1). A precision value $>15\%$ RSD for W (20% RSD) is attributed to a determination close to detection limit.

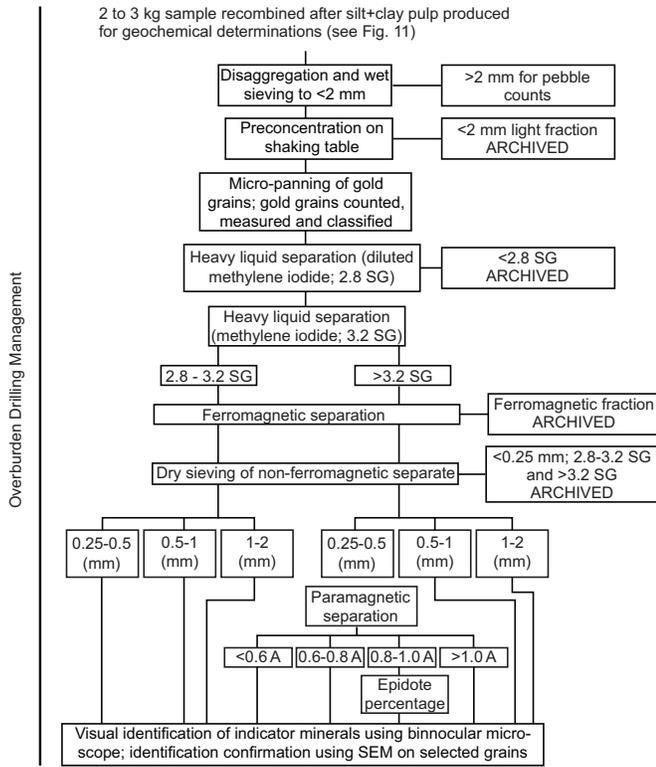


Fig. 12. Indicator mineral processing and identification flow chart (modified from Plouffe and Ferbey, 2016).

Analytical precision for total determinations by lithium borate fusion ICP-ES/MS are similarly high for all analytes associated with porphyry Cu mineralization except W (Appendix 2). However, given the small number of geochemical analyses reported here, including a single blind duplicate, the reader is referred to Ferbey et al. (2016) and Plouffe and Ferbey (2016) for a thorough evaluation of analytical precision typically encountered in the analytical methods applied herein.

7.1.2. Internal standard

Many elements analyzed on the BCGS Till 2013 standard by modified aqua regia ICP-MS and lithium borate fusion ICP-ES/MS, are within two standard deviations of the recommended value for a given element (Lynch, 1996; Appendix 1). This indicates that analytical determinations in this study are accurate for most elements. Notable exceptions include some porphyry Cu commodity (e.g., Cu, Au) and pathfinder elements (e.g., Zn, Ni, As, Hg), where analytical determinations are higher than recommended values. These elevated values could be related to a different (stronger) aqua regia digestion used for determinations presented here.

8. Results

Samples from the two till units fail to display significant multi-elemental enrichment. Maximum trace element values occur in different samples, in different till horizons (Table 1). For example, maximum Cu (484 ppm) and Zn (74 ppm) occur at 92 m below surface (17TFE0016), maximum Au (8.9 ppb) at 104 m (17TFE0012), maximum Ag (1085 ppb) and W (0.8 ppm) at 130 m (17TFE0006), and maximum Mo (2.33 ppm), As (27.2 ppm) and Sb (0.92 ppb) occur at 142 m (17TFE0002). Although copper values display an overall increase upsection, other commodity and pathfinder elements do not. No particular till unit or bed uniquely carries a porphyry Cu signature. Rather, elevated elemental values occur throughout the sample profile. Samples with maximum Cu and Au concentrations do not contain native copper, copper sulphide, oxide, or carbonate-hydroxide, or gold grains (Table 2; Appendix 3) suggesting that these elements are predominantly tied in mineral phases in the silt and clay fraction, possibly produced by post-glacial weathering of sand-sized grains.

The distribution of elevated grain counts for selected ore and alteration minerals is similarly dispersed throughout the sample profile (Table 2). An exception might be maximum chalcopyrite (7 grains in the 0.25 to 0.5 mm and one grain in the

Table 1. Selected commodity and pathfinder element determinations by aqua regia ICP-MS. Maximum values shown in red.

Sample	Depth (m)	Unit	Mo (ppm)	Cu (ppm)	Pb (ppm)	Zn (ppm)	Ag (ppb)	As (ppm)	Au (ppb)	Sb (ppm)	Hg (ppb)
17TFE0016	92	5	0.71	484.03	4.20	73.6	710	3.4	3.1	0.26	21
17TFE0015	96	5	0.71	322.35	4.72	73.6	238	4.9	2.3	0.35	29
17TFE0014	98	5	0.60	268.69	4.14	69.5	259	4.4	2.4	0.29	22
17TFE0013	100	5	0.77	224.44	3.34	63.0	82	4.4	3.3	0.32	13
17TFE0012	104	5	0.53	260.11	3.36	62.3	110	3.6	8.9	0.31	17
17TFE0011	106	5	0.81	211.46	3.66	60.3	82	4.6	4.4	0.37	19
17TFE0009	110	5	0.69	251.53	3.84	67.8	65	4.0	2.7	0.29	16
17TFE0008	125	3 (upper)	0.41	321.94	4.09	62.2	89	2.8	2.7	0.19	18
17TFE0007	127	3 (upper)	0.34	318.39	4.49	66.6	687	2.7	6.9	0.23	18
17TFE0006	130	3 (upper)	0.38	297.00	4.47	64.2	1085	3.1	6.5	0.23	25
17TFE0005	132	3 (upper)	0.49	153.50	4.28	64.3	152	3.4	4.1	0.22	11
17TFE0004	136	3 (upper)	0.52	133.52	4.61	62.5	77	3.6	5.0	0.19	13
17TFE0003	138	3 (lower)	0.47	103.30	4.82	60.2	135	3.1	5.4	0.23	24
17TFE0002	142	3 (lower)	2.33	147.43	3.77	56.4	204	27.2	3.2	0.92	12

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Table 2. Selected ore and alteration mineral grain counts. Epidote values are percent estimates of green epidote in the 0.25 to 0.5 mm, 0.8 to 1.0 amp, fraction. Values for other minerals are total grains recovered from bulk sample; pyrite grain counts are estimates. See Appendix 3 for size and density fraction details for these other minerals. Maximum values shown in red. * plus one chalcopyrite grain in the 0.5-1 mm fraction (Appendix 3).

Sample	Depth (m)	Unit	Table feed (kg)	Gold	Chalcopyrite	Galena	Pyrite	Arsenopyrite	Jarosite	Epidote (%)
17TFE-0016	92	5	1.5	0	0	0	10	0	0	70
17TFE-0015	96	5	1.7	0	0	0	10	10	0	85
17TFE-0014	98	5	2.0	1	0	0	20	0	0	80
17TFE-0013	100	5	1.8	0	1	0	10	0	0	85
17TFE-0012	104	5	1.4	0	0	0	10	0	0	85
17TFE-0011	106	5	0.9	0	1	0	0	0	0	90
17TFE-0009	110	5	1.5	1	0	0	5	0	0	80
17TFE-0008	125	3 (upper)	2.1	0	7*	0	0	0	0	70
17TFE-0007	127	3 (upper)	1.8	3	1	0	0	0	3	50
17TFE-0006	130	3 (upper)	2.1	0	0	1	10	2	2	50
17TFE-0005	132	3 (upper)	1.5	0	0	0	10	0	1	60
17TFE-0004	136	3 (upper)	1.8	1	0	0	20	0	0	80
17TFE-0003	138	3 (lower)	1.8	2	0	2	20	0	2	60
17TFE-0002	142	3 (lower)	1.9	2	0	0	20	0	0	70

0.5 to 1 mm fraction) and gold (3 grains) counts in two different samples in the upper 2 m of Unit 3 (125 to 127 m). Although these same samples do have the second highest trace element Cu (321 ppm) and Au (7 ppb) values (Table 1), maximum Cu and Au values occur in the upper half of Unit 5 (as mentioned above). Green epidote grain counts also vary throughout the sample profile, with the mean of Unit 5 counts (82%) being almost 20% greater than those in Unit 3 (63%).

Most Cu, As, Au, and all Pb, Zn, Ag concentrations in samples from units 3 and 5 (Table 3) are greater than the median values of surface till samples in the Highland Valley district reported by Ferbey et al. (2016). The three highest Ag concentrations (687, 710 and 1085 ppb) in units 3 and 5 exceed the maximum values observed in regional surface till samples (Ferbey et al., 2016). Normalized chalcopyrite grain counts in four drill hole samples (5 to 33 grains/10 kg) and gold grain counts in six samples (5 to 17 grains/10kg) are within the range of mineral counts observed in nearby (< 5 km) surface till samples (0 to 49 chalcopyrite grains/10 kg and 1 to 39 gold grains/10 kg) (Ferbey et al., 2016; see Figs. 3 and 4 of Plouffe and Ferbey, 2017, and data in Plouffe and Ferbey, 2016).

Diamonds 0.25 to 1 mm in size were recovered from each subsurface till sample collected. We interpret the diamonds

to be derived from the drill bit. Diamond grain counts range from 1 to 24 in the 0.25 to 0.5 mm and from 0 to 8 in the 0.5 to 1 mm size fractions (Appendix 3). Grains are euhedral and consistently yellow (Fig. 13). It is common for diamonds to be recovered from sediments obtained from diamond drill cores (McMartin and McClenaghan, 2001; Spirito et al., 2011).



Fig. 13. Synthetic diamonds recovered from sample 17TFE0002. These are contamination from diamond drill bit and were recovered from each of 14 samples collected.

Table 3. Selected commodity and pathfinder element determinations by aqua regia ICP-MS for surface samples collected within Highland Valley mine district (Ferbey et al., 2016).

	Mo (ppm)	Cu (ppm)	Pb (ppm)	Zn (ppm)	Ag (ppb)	As (ppm)	Au (ppb)	Sb (ppm)	Hg (ppb)
Minimum	0.48	37.04	1.65	18.1	3	1.2	BD	0.11	BD
Maximum	28.87	1706.97	216.20	122.4	559	39.4	60.1	4.97	211
Mean	2.13	239.10	5.58	48.6	55	4.1	3.6	0.38	37
Median	1.13	178.09	3.27	48.7	36	3.6	2.9	0.30	30

BD=below detection

9. Conclusion

Quality assurance/quality control results indicate that the geochemical and mineralogical datasets from subglacial tills presented here are suitable for geological interpretations. No particular till unit or specific till horizon in NQ diamond drill core R17-01 at the Rateria porphyry Cu±Mo property (Happy Creek Minerals Ltd.) carries a strong porphyry Cu signature. Concentrations of commodity and pathfinder elements, and grain counts for ore and alteration minerals lack systematic stratigraphic variation, except possibly Cu, which generally decreases with depth. Samples with maximum elemental Cu and Au do not contain copper-bearing minerals or gold grains, suggesting that these metals are tied in fine-grained (silt and clay) mineral phases. Discrepancies between commodity element values and grain counts for typical ore minerals could also be due to in-situ, post-glacial weathering of sand-sized minerals.

The methods used to produce the data from subsurface tills at the Rateria property are the same as those used for surface samples from the Highland Valley mine district (Ferbey et al., 2016) and so are comparable and can be integrated. The three highest Ag concentrations in the Rateria samples exceed the values observed in regional surface till. In addition, most Cu, As, Au, and all Pb, Zn, Ag, values are greater than background values for surface tills of the Highland Valley mine district. Chalcopyrite and gold grain counts for subsurface tills at Rateria are within the range of nearby (<5 km) surface till samples. Results from this study will contribute to our ability to detect concealed Cu-porphyry mineralization based on till geochemistry and mineralogy.

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