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British Columbia
Ministry of Energy and Mines

Canada

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Front cover: Typical subglacial till sample site, with large (9 to 15 kg) and small (1 to 2 kg) samples. Photo by. T. Ferbey

Back cover: Typical rolling terrain of Thompson Plateau. Photograph taken 7 km southeast of Highmont deposit. View is towards north. Photo by T. Ferbey

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Geochemical, mineralogical, and textural data from tills in the Highland Valley Copper mine area, south-central British Columbia

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Abstract
Although rocks of Quesnel terrane in the Intermontane Belt of south-central British Columbia have long-been known as prolific producers of porphyry mineralization, much of the bedrock in the region is covered by glacial sediments. Nonetheless, geochemical and mineralogical data, particularly from locally derived tills, can help detect deposits buried under Quaternary sediments. We collected till samples from 99 sites near the Highland Valley Copper mine for geochemical, indicator mineral, and grain size determinations to test the utility of the method at a site where the configuration and tenor of ore-grade porphyry Cu mineralization are known. Landform-scale features such as drumlins, flutings, crag-and-tails mapped on aerial photographs, outcrop-scale features such as striations, grooves, and rat tails measured in the field, and data from previous studies indicate a relatively simple regional Late Wisconsinan ice-flow history with generally southward sediment transport, making provenance determinations on subglacial tills relatively straightforward. Commonly a first derivative of bedrock, subglacial till is the ideal sample medium for till geochemical and mineralogical surveys. Most of our samples were taken from a regionally developed till facies interpreted as a subglacial till deposited by moving ice (well compacted, markedly fissile, massive, cobble-boulder diamicton with a relatively clay-rich matrix and abundant faceted and striated clasts). For comparison, we also collected from a more locally developed till facies interpreted as an ablation till (poorly compacted, non-fissile, massive cobble-boulder diamicton with a relatively clay-deficient matrix) that overlies the subglacial till. Quality assurance/quality control results indicate that, uncontrolled by analytical artefact, the geochemical and mineralogical results for the dataset presented herein are suitable for geological interpretations that will be considered in future publications.

Keywords: Till geochemistry, till mineralogy, porphyry indicator minerals, calc-alkaline porphyry deposit, Highland Valley Copper mine, subglacial till, basal till, Canadian Cordillera

1. Introduction

Although rocks of Quesnel terrane in the Intermontane Belt of south-central British Columbia (Fig. 1) have long-been known as prolific producers of porphyry mineralization, much of the bedrock in the region is covered by glacial sediments. Nonetheless, geochemical and mineralogical data, particularly from locally derived tills, can detect deposits buried under Quaternary sediments. To test the utility of the method in a region of known mineralization, we collected till samples from the Highland Valley Copper mine area (Fig. 2) for geochemical, indicator mineral, and grain size determinations. This report presents geochemical and mineralogical data from till samples collected in the Highland Valley Cu porphyry district in 2011 and 2012 (Plouffe and Ferbey, 2015a, 2016), and in 2015. These data complement regional till geochemical and mineralogical studies by Jackaman (2010), Plouffe et al. (2013a, b, 2016), and Plouffe and Ferbey (2015a).

We chose to study the Highland Valley Copper mine area because: 1) the configuration and tenor of ore-grade porphyry Cu mineralization are known; 2) at least part of the mineralized zones are covered by subglacial till of the last glaciation, and therefore were overridden by glaciers; 3) subglacial till is exposed; and 4) a high-density forestry road network enables truck access and efficient sampling. In addition to the Highland Valley study site, we also sampled near the Gibraltar (Cu-Mo porphyry) and Mount Polley (Cu-Au porphyry) mines, and the Woodjam prospect (Cu-Au±Mo porphyry; Fig. 1), the results of which are presented elsewhere (Plouffe and Ferbey, 2015a; 2016; Plouffe et al., 2016). The main objective of this orientation survey is to develop new exploration methods using till geochemistry and mineralogy to detect concealed porphyry Cu mineralization (Plouffe and Ferbey, 2015a).

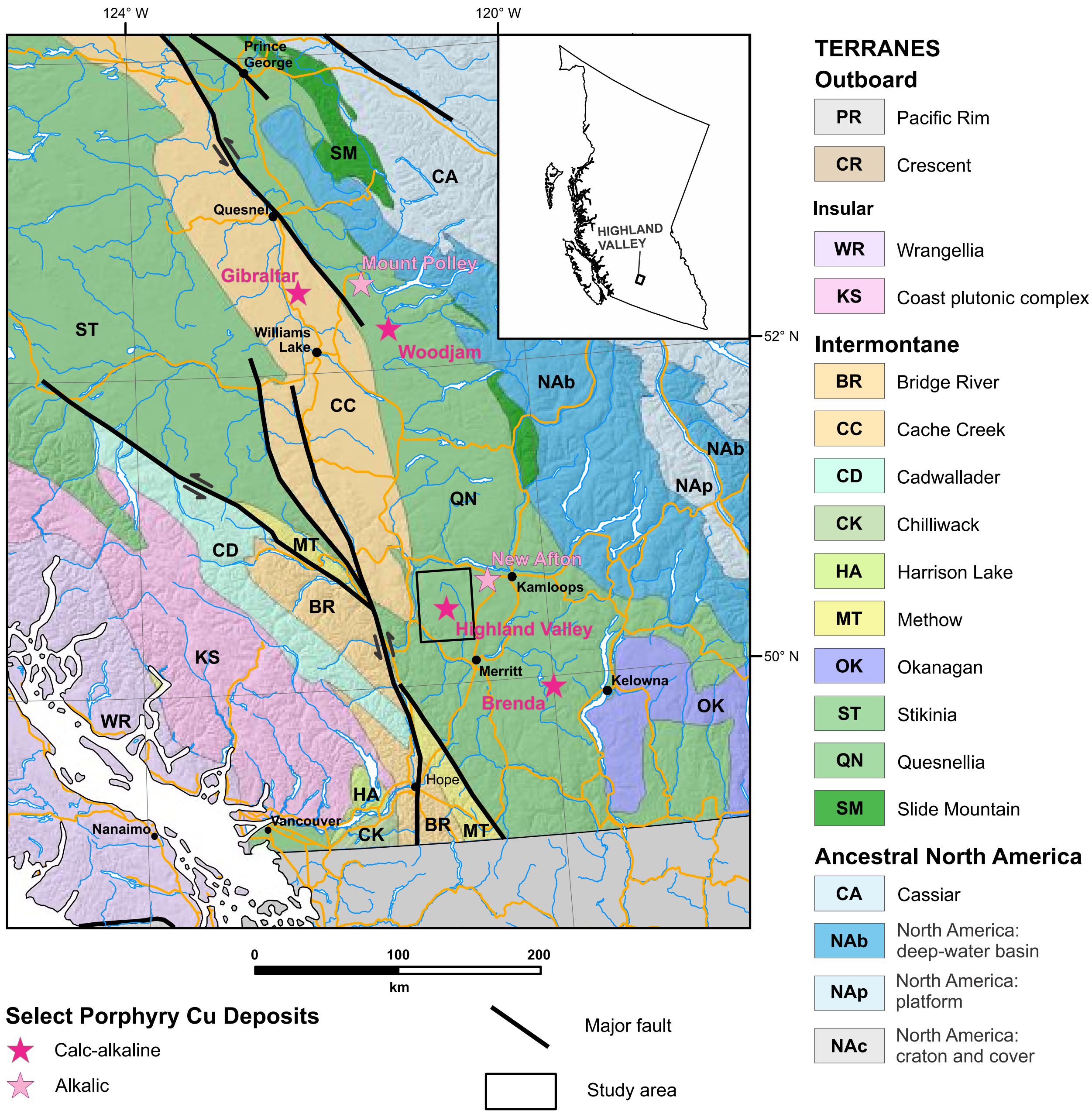

Fig. 1. Study area location. Terranes of the southern Canadian Cordillera after Nelson et al. (2013).

2. Study area and physiography

The Highland Valley mine area is 54 km southwest of Kamloops, British Columbia (Fig. 1). The mine site is accessed by Highway 97C, and the larger study area by a dense network of forestry roads. The study area is in the Thompson Plateau, a physiographic subdivision of the Interior Plateau (Holland, 1976). The plateau is a gently rolling upland; bedrock is generally mantled by thin (<2 m) to thick (>2 m) sequences of Quaternary sediments (Fig. 2). In areas of thicker sediment cover, bedrock can be found at the stoss (up ice flow) ends of crag and tail ridges and locally, in deep road cuts. In areas of thin drift, which are less extensive, bedrock commonly outcrops (Plouffe and Ferbey, 2015b).

3. Bedrock geology and the Highland Valley Copper mine

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 docked with ancestral North America. Deposit types include both calc-alkaline (e.g., Highland Valley mine, Woodjam prospect and Brenda mine) and alkalic (e.g., New Afton and Mount Polley mines) varieties (Fig. 1). Logan and Mihalynuk (2014) considered that mineralized trends within the arcs (Cu-Au±Ag-Mo) are related to the effects of slab subduction and slab tears.

Fig. 2. Typical rolling terrain of Thompson Plateau. Photograph taken 7 km southeast of Highmont deposit (see Fig. 3). View is towards north.

Mineralization at the Highland Valley porphyry Cu mine is in calc-alkaline rocks of the Guichon Creek batholith (Late Triassic; Fig. 3), part of Quesnel terrane, which consists of upper Paleozoic and lower Mesozoic island arc volcanic, sedimentary, and intrusive rocks (Fig. 1; McMillan, 1978; McMillan et al., 2009). The batholith is texturally and compositionally zoned, 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 five porphyry Cu centres at Highland Valley Copper mine (Valley, Lornex, Bethlehem, Highmont and JA) are spatially associated with this younger felsic facies (Fig. 3).

Bedrock structure plays an important role in localizing zones of mineralization and alteration, 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). Major structures in the area include the Lornex (north trending) and the Highland Valley, Skuhun and Barnes Creek faults (northwest trending; Fig. 3). The Valley and Lornex porphyry centres are thought to represent a single intrusion that was offset by the Lornex fault (Byrne et al., 2013).

The main ore minerals at Highland Valley mine are chalcopyrite, bornite, and molybdenite. Other hydrothermal metallic minerals, such as specular hematite, magnetite, and chalcocite, are local. 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).

The 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). In December 2012, proven and probable reserves were estimated at 697 million tonnes at 0.29 % Cu and 0.008% Mo (Byrne et al., 2013). The Guichon Creek batholith is host to numerous other porphyry Cu±Mo mineral occurrences (Fig. 3). These typically contain sulphide mineral assemblages similar to mineralized zones at Highland Valley, but can include other secondary copper minerals such as malachite.

4. Quaternary geology

4.1 Ice-flow history and glacial transport

The Highland Valley mine area was glaciated during the Late Wisconsinan (Clague and Ward, 2013). At the onset of

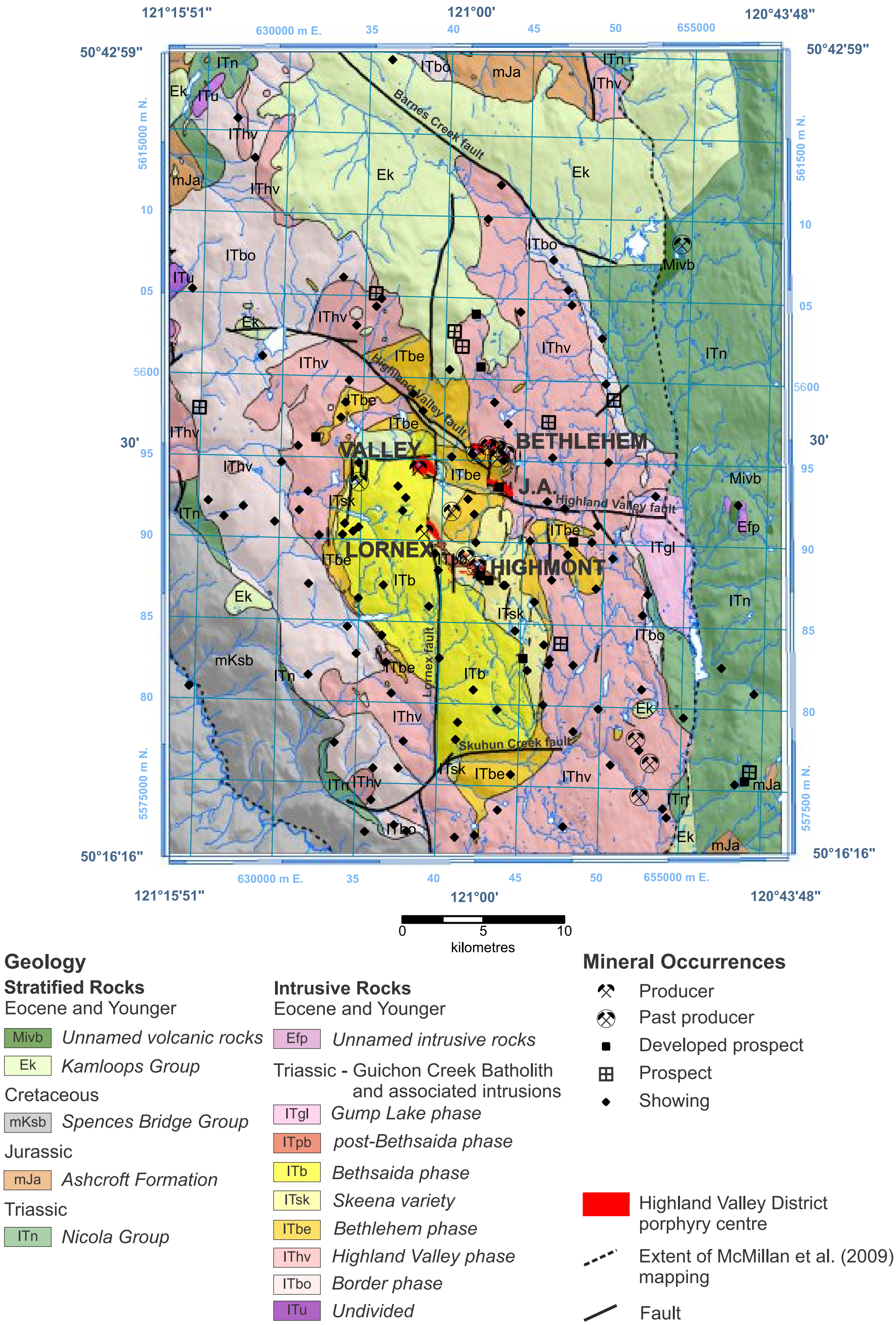

Fig. 3. Bedrock geology of Highland Valley Copper mine area (McMillan, 1978; McMillan et al., 2009; Cui et al., 2015).

glaciation, ice advanced out of alpine accumulation areas like 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, 2013).

Interpreting an area's ice-flow history is fundamental to determining the transport path of subglacial tills. Hence we mapped landform-scale features such as drumlins, flutings, and crag-and-tails on aerial photographs and measured outcrop-scale features such as striations, grooves, and rat tails in the field (Fig. 4; Plouffe and Ferbey, 2015b). To interpret the

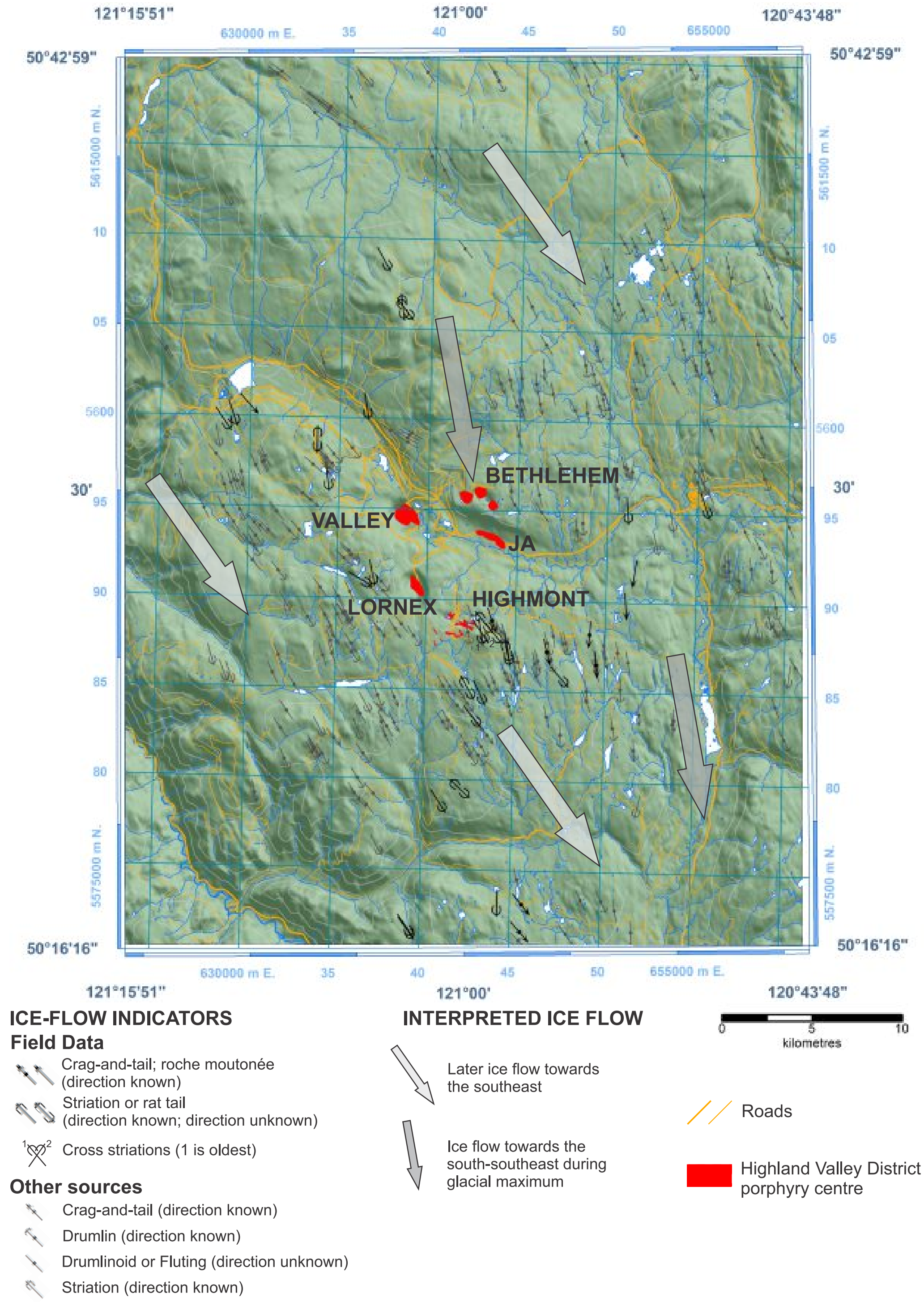

Fig. 4. Ice-flow indicators of Highland Valley Copper mine area. Interpreted ice-flow directions are generalized from data points shown, taking into account topography and expected thickness of Cordilleran ice sheet during full-glacial and late-glacial conditions. Field data from Plouffe and Ferbey (2015a), other sources from Ferbey et al. (2013).

regional Late Wisconsinan ice-flow history, we integrated these data with studies by Tipper (1971a, b), Fulton (1975), Ryder (1976), Clague (1989), Ryder et al. (1991), Bobrowsky et al. (1993, 2002), Plouffe et al. (2011), Ferbey et al. (2013), and Plouffe et al. (2013a, b).

Regionally, we recognize early south-southeast ice flow and later flow to the southeast (Fig. 4). We attribute the general southward flow to the development of an ice divide near 52°N (180 km to the north) during the Late Wisconsinan glacial maximum (Plouffe et al., 2016). The young southeast (and locally southwest) directions are likely related to times when the Cordilleran ice sheet was thinner (e.g., pre and post-glacial maximum) and ice-flow patterns were more influenced by topography. Two striations sets preserved on the same outcrop, about 800 m east of the Highmont deposit (Fig. 5), further support this chronology. At this site, striations and grooves of an ice-flow towards 170° are preserved only on the lee (protected side) of an outcrop with striations showing flow towards 145°, indicating the more southeastward flow occurred later.

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 Copper mine area. This is in contrast to palimpsest dispersal trains at Gibraltar and Mount Polley, 240 km north of Highland Valley Copper mine (north of 52° N; Fig. 1), which are the product of two and, in the case of Gibraltar, possibly three ice flows (Hashmi et al., 2015; Plouffe and Ferbey, 2015a; Plouffe et al., 2016).

Fig 5. Multiple ice-flow indicators in the Highland Valley Copper mine area. Striations from an early flow towards 170° are preserved on the lee side of the outcrop, presumably where they were protected from later flow towards 145°. Photograph taken 800 m east of Highmont deposit. Pencil is 14 cm long.

Fig. 6. Well-compacted, matrix-supported, fissile, diamicton, with clasts (about 15%) floating in a predominantly sandy silt to silty sand matrix that also contains about 6% clay. Interpreted as subglacial till. This site (15TFE018A01) is 6 km west-northwest of the Valley deposit. Pick is 62 cm long.

Fig. 7. Poorly compacted, massive, bouldery diamicton, with clasts (about 35%) floating in a predominantly silty sand to sandy silt matrix with about 2% clay. Near-vertical boulder suggests deposition by meltout. Interpreted as ablation till. Site (15PMA108A01) is 7 km south of the Highmont deposit. Pick is 62 cm long.

4.2. Till facies

Because materials in tills are both derived and deposited by different subglacial, englacial, and supraglacial processes, and might reflect the composition of different source areas, till facies need to be considered to interpret till geochemistry and mineralogy. Two till facies are exposed in the Highland Valley region, where a regionally developed well-compacted, massive, generally fissile, and relatively clay-rich cobble-boulder diamicton (Fig. 6) is locally overlain by a cobble-boulder diamicton that is poorly compacted, massive, and relatively deficient in clays (Fig. 7).

The more regional, stratigraphically lower, well-compacted facies is up to 25 m thick, such as at on-site exposures at Highland Valley Copper mine (Bobrowsky et al., 1993). The diamicton contains about 15% clasts, which are suspended in a mixed, fine-grained matrix. Faceted and striated clasts of all sizes are abundant (average 20%). Based on grain-size determinations of 55 samples (Fig. 8, section 6.3), the matrix consists of sand (average 51%), silt (average 43 %), and clay (average 6 %). Although only rarely observed, the contact between the well-compacted till and the overlying poorly-compacted facies is abrupt.

The poorly compacted facies is 1 to >5 m thick. Framework cobbles and boulders make up about 35% of the deposit

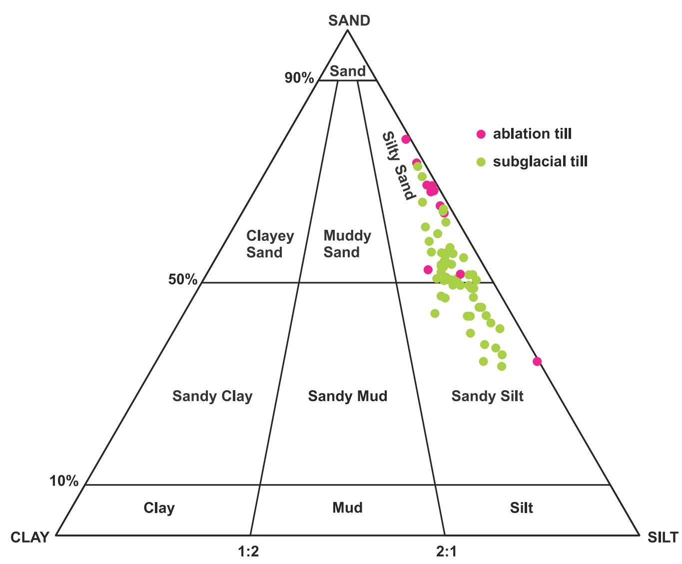

Fig. 8. Grain size analyses of matrix in subglacial (n=55) and ablation (n=11) till samples showing percentage of sand (2 to >0.063 mm), silt (0.063 to >0.002 mm) and clay (<0.002 mm). Classification follows Folk (1954). See Appendix 5.

(predominantly composed of local intrusive lithologies), but striated clasts are uncommon. A near-vertical elongate boulder was observed at one site (Fig. 7). Based on grain-size determinations of 11 samples (Fig. 8, section 6.3), the matrix consists of sand (average 63%), silt (average 34%) and, in contrast to the lower facies, sparse clay (average 2%). The facies forms less continuous bodies than the well-compacted facies. It is developed in areas mapped as till veneer (Tv), till blanket (Tb), hummocky till (Th), and streamlined till (Ts) by Plouffe and Ferbey (2015b). It can overlie bedrock or other Quaternary sediments including the well-compacted facies. The low degree of compaction and relatively low clay content distinguishes this diamicton from the well-compacted unit. The poorly compacted till lacks a distinctive surface expression and therefore its spatial distribution cannot be mapped from aerial photographs.

We interpret the well-compacted facies as a subglacial till, deposited under moving ice at the glacier/substrate interface, based on the high degree of compaction, marked fissility, massive and poorly sorted nature, and the presence of abundant faceted and striated clasts. In contrast, given, the low degree of compaction, sparse striated clasts, the near-vertical clast (suggesting that deposition did not occur under an oriented stress field imparted by flowing ice), we interpret the poorly-compacted facies as an ablation till deposited by meltout processes. The lack of hummocky surface expression, and similarity between clast lithologies in this facies and local bedrock, suggest deposition in the subglacial environment (Dreimanis, 1990). We attribute the abundance of sand and silt in the matrix of both till facies to glacial erosion of Guichon Creek batholith medium-grained, granodiorites, which predominate the local bedrock geology. The lower silt and clay content of the ablation till likely records less subglacial transport, which resulted in less comminution relative to sediment transported near the substrate-ice interface.

5. Till sampling

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), has a predictable transport history, is deposited down-ice of its bedrock source, and produces a geochemical and mineralogical signature that is areally more extensive than its bedrock source (Levson, 2001). Consequently, subglacial till was the preferred sampling medium in our survey (Fig. 9). Nonetheless, to compare compositions for use in mineral exploration, we sampled both subglacial and ablation till facies at a limited number of field sites.

We sampled tills from 99 sites (Fig. 10), following general procedures outlined in Spirito et al. (2011) and McClenaghan et al. (2013) and the protocols for sampling glacial sediment for indicator mineral analyses outlined in Plouffe et al. (2013c). Sampling was opportunistic, commonly from vertical exposures along forestry roads accessible by truck. Samples were generally collected from a depth of 130-150 cm below surface. Two samples were collected at each site; a large one (9 to 15 kg) for indicator mineral processing and a smaller one (1 to 2 kg) for geochemical determinations. Appendix 1 contains basic sample site information including the interval of sample collection (centimetres below surface), sample type,

Fig. 9. Typical subglacial till sample site (15PMA053) with large (9 to 15 kg) and small (1 to 2 kg) samples. View is towards north. Shovel is 1.6 m long.

1:50 000-scale NTS map sheet, coordinates (UTM, latitude and longitude). A complete set of digital field notes for the 2011 and 2012 samples, including sample descriptions, is presented in Plouffe and Ferbey (2015b). Sampling methods were consistent for the 2011, 2012, and 2015 field seasons.

The usefulness of a till survey targeted at detecting buried mineralization may be limited by the lack of appropriate sampling material (subglacial till), anthropogenic disturbance and, of greater concern to our study, relatively thick sections of unconsolidated sediment intervening between the bedrock-ice contact that would have shielded bedrock from glacial erosion. In the present example, although the Lornex, Highmont, and Bethlehem porphyry centres were exposed to glacial erosion during the Late Wisconsinan, parts of Valley, and all of JA, were not (Fig. 11; Byrne et al., 2013; Plouffe and Ferbey, 2015b). For example, Bobrowsky et al. (1993) reported that the eastern parts of the Valley deposit are covered by at least 160 m of glacial and non-glacial sediments. Similarly, MacMillan (1976) reported that the JA deposit is covered by up to 300 m of unconsolidated sediments. In both cases, this cover stratigraphy includes pre-Late Wisconsinan sequences that would have protected mineralized bedrock from glacial erosion during the Late Wisconsinan (Fig. 11), and these bedrock subcrops did not contribute directly to the geochemical or mineralogical composition of Late Wisconsinan tills.

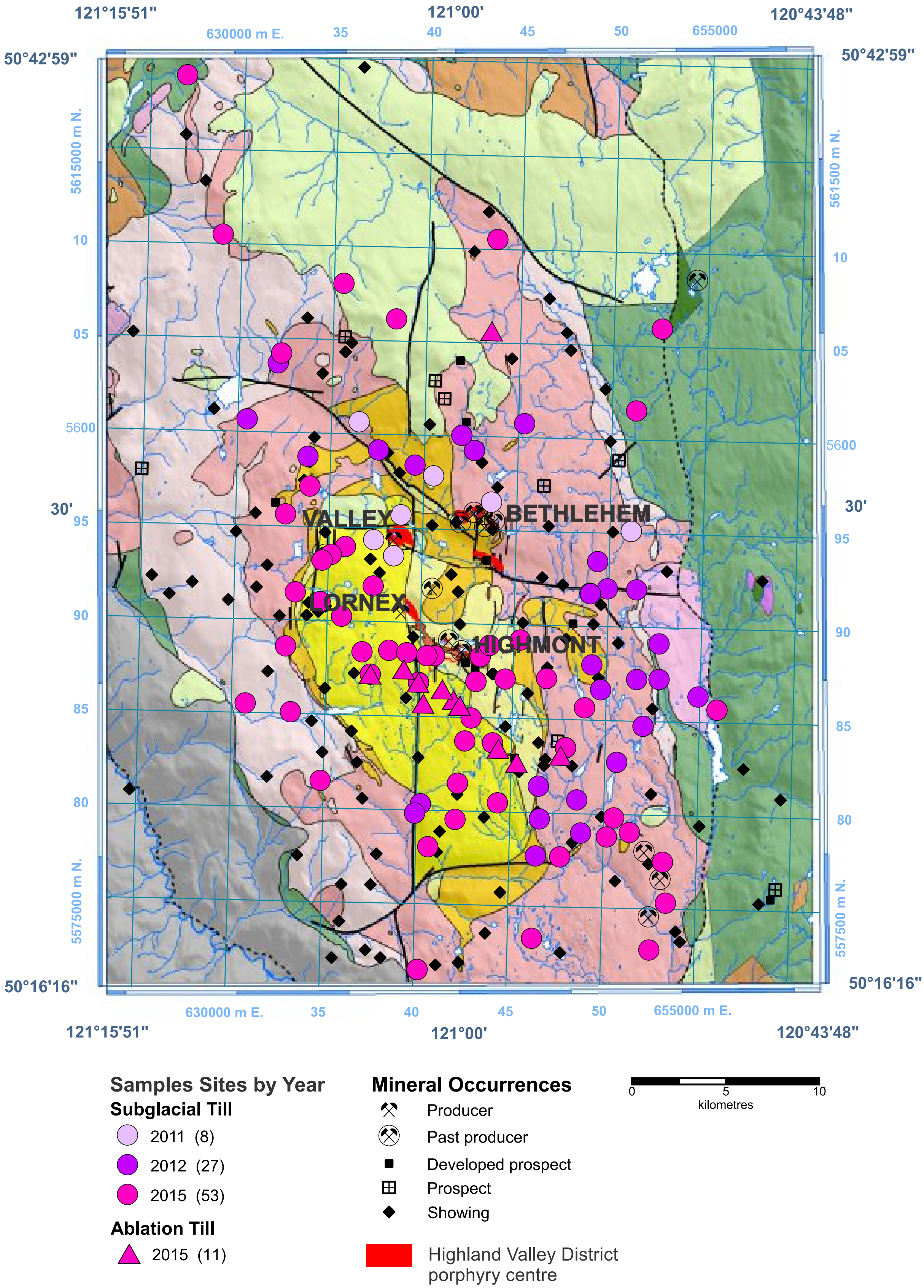

Fig 10. Till sample sites. See Fig. 3 for bedrock geology legend.

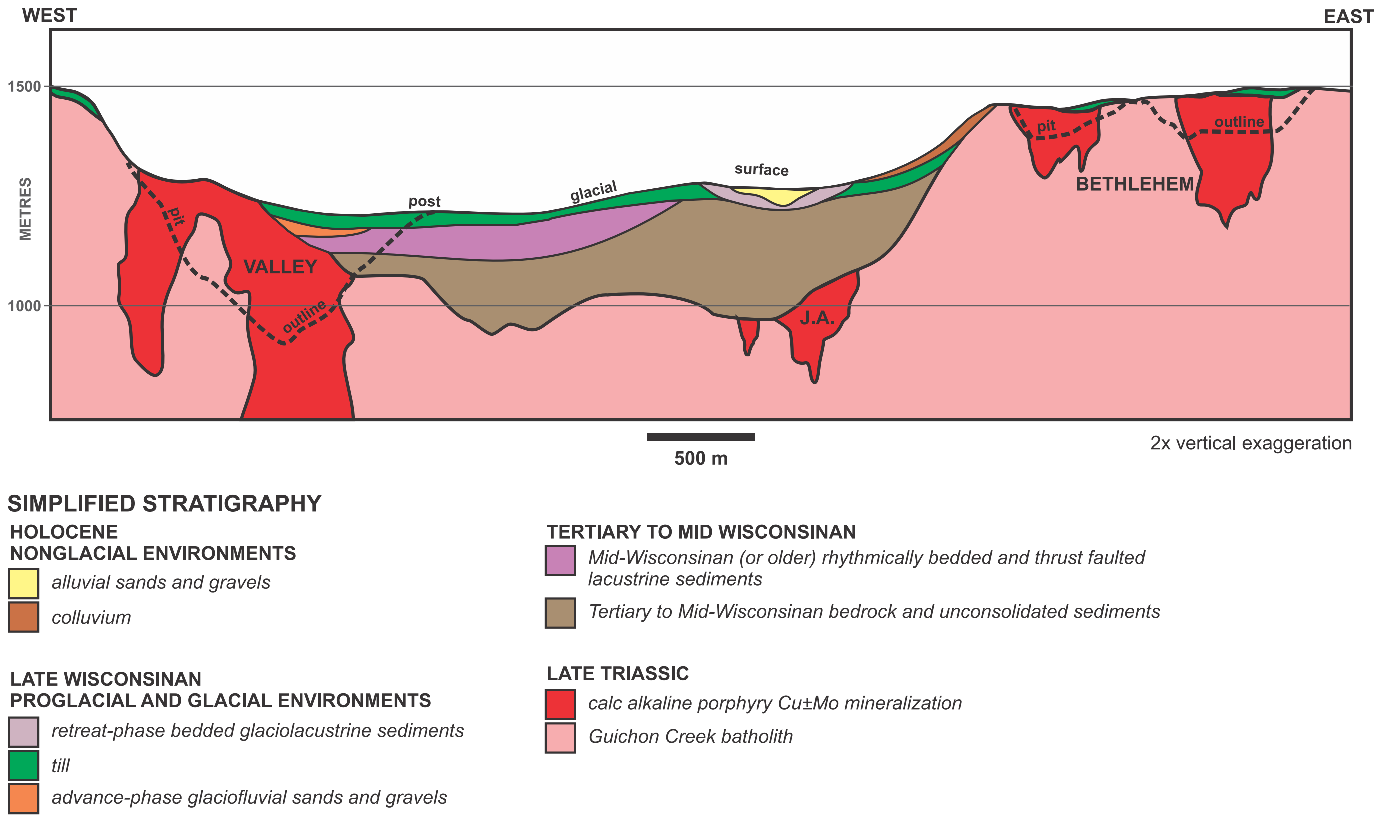

Fig.11. Composite cross-section through Valley, J.A., and Bethlehem porphyry centres showing generalized bedrock topography and simplified cover stratigraphy (see Fig. 3 for porphyry centre locations). Subglacial till samples were collected at surface from the Late Wisconsinan till unit. Units underlying these tills protected bedrock subcrop from glacial erosion during the Late Wisconsinan. These protected bedrock subcrops therefore did not contribute to the geochemical or mineralogical composition of sampled subglacial tills. Simplified stratigraphy modified after Bobrowsky et al. (1993), Byrne et al. (2013), and Plouffe and Ferbey (2015b).

6. Laboratory methods

Identical laboratory methods were used for 2011, 2012, and 2015 samples except for scheelite. In 2015, the routine for determining scheelite grain counts was changed. Samples collected in 2011 and 2012 were re-run using this new routine to produce a consistent data set.

6.1 Geochemical analyses

Geochemical analyses were completed on the clay (<0.002 mm) and the silt plus clay-sized (<0.063 mm) fractions from the 1 to 2 kg till samples (Fig. 12). The grain size separations were completed at the Sedimentology Laboratory of the GSC (Ottawa, ON). Upon arriving at the laboratory, an 800 g archive split was taken from each sample. The silt plus clay-sized fraction was then separated from the remaining sample by dry sieving, and the clay fraction by centrifuge and decantation following procedures outlined in Girard et al. (2004). Both size fractions were submitted for the following analytical procedures at Bureau Veritas Commodities Canada Ltd. (Vancouver, BC): 1) 0.2 g aliquots were digested with lithium metaborate/tetraborate, fused at 980°C, dissolved in 5% HNO_3 (lithium-fusion), and then analyzed by inductively coupled plasma emission spectrometry and mass spectrometry (ICP-ES and ICP-MS); 2) 0.5 g of clay and 30 g of silt plus clay aliquots were diluted in a hydrochloric and nitric acid solution (ratio 1:1, modified aqua regia) and analyzed by ICP-MS; 3) 0.1 g aliquot were ignited at >1650°C in a Leco analyzer for total carbon and sulphur determination; and 4) loss on ignition (LOI) was determined on 1 g aliquots by weight difference after ignition at 1000°C. Large aliquots (30g) of the silt plus clay fraction were submitted for gold analyses by ICP-MS to reduce the 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 2A (2015), 2B (modified aqua regia; 2011, 2012, 2015) and 2C (lithium-fusion; 2011, 2012, 2015) for the clay-sized fraction and in Appendix 3A (2015), 3B (modified aqua regia; 2011, 2012, 2015), and 3C (lithium-fusion; 2011, 2012, 2015) for the silt and clay-sized fraction. Appendix 2A and 3A include a worksheet (see QA_QC_listing) that lists field duplicates, blind duplicates, analytical standard samples, and silica blanks.

6.2 Indicator mineral processing and identification

The large (9 to 15 kg) till samples were sent for indicator mineral separation and identification at Overburden Drilling Management Ltd. (Ottawa, ON). An archive split was not taken and so the entire sample was processed. Heavy mineral concentrates were produced following the protocol adopted at the GSC (Plouffe et al., 2013c; Fig. 13). Samples were first wet sieved to <2 mm and pre-concentrated on a shaking

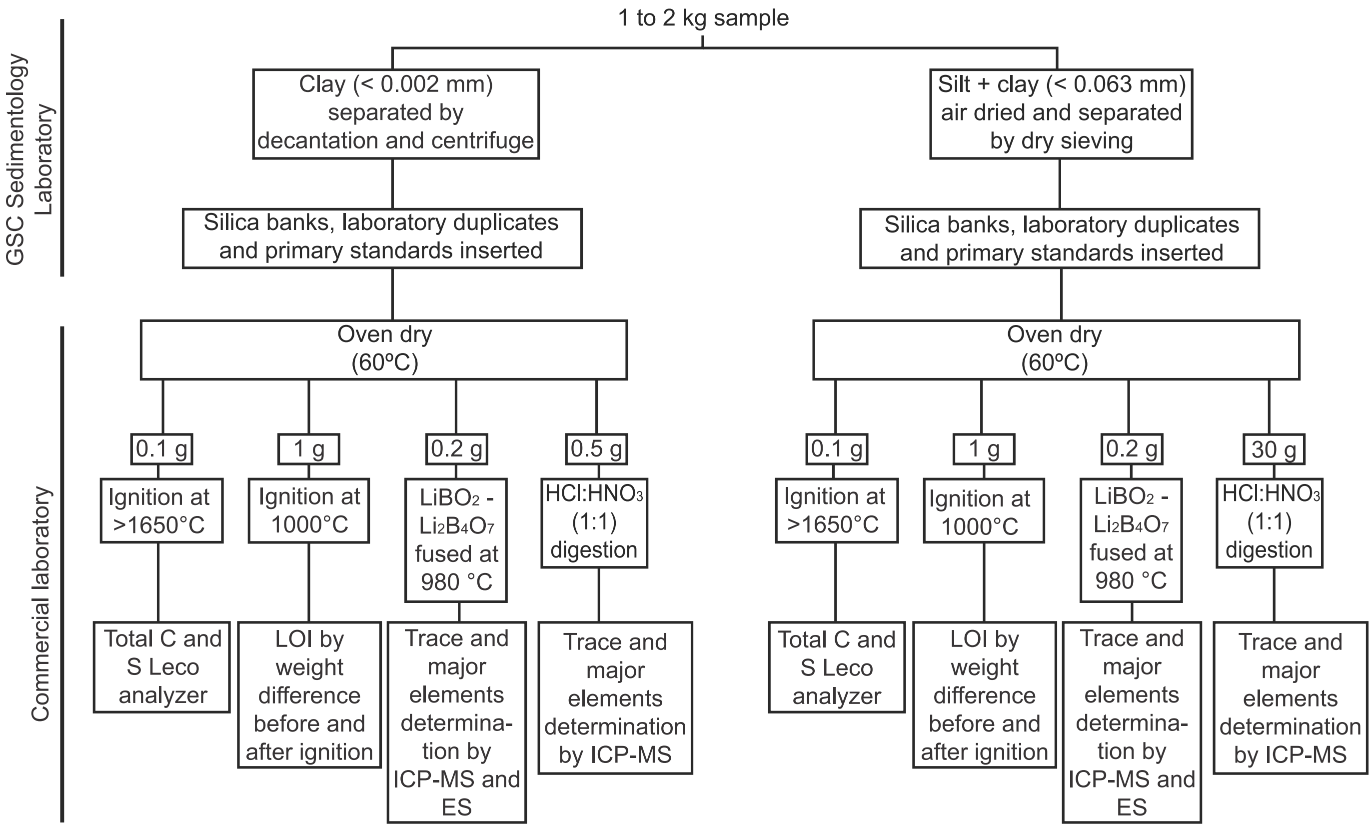

Fig. 12. Sample processing and geochemical analyses flow chart (Plouffe and Ferbey, 2015a)

table. Clasts in the >2 mm fraction were classified and their amount estimated into four broad classes (volcanic rocks/sedimentary rocks, granitoids, carbonate rocks, 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. Averill (1988) estimated that, on average, 80% of gold grains larger than 0.001 mm are recovered in this procedure; this size represents the smallest gold particles visible under the binocular microscope. 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- (>2.8-3.2) 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 0.25-0.5 mm, 0.5-1 mm, and 1-2 mm fractions. The >3.2 SG, 0.25-0.5 mm separate was subjected to a paramagnetic separation using a Carpco® magnetic separator set at 0.6, 0.8, and 1 amp to help mineral identification (McClenaghan, 2011; Plouffe et al., 2013c). 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 0.8-1.0 amp fraction. The unmodified laboratory reports produced by Overburden Drilling Management Ltd. are included in Appendix 4A.

The scheelite grain counts from samples collected in 2011 and 2012 differed from those taken at neighbouring sites in 2015, when Overburden Drilling Management Ltd. began to run all mineral concentrates under an ultraviolet (UV) lamp to identify scheelite. Before this, a UV lamp was used only if scheelite, or likely candidates, were observed. To produce a consistent mineral grain database, we re-ran the 2011 and 2012 samples using the new routine, and scheelite grains were identified in six samples (Appendix 4B). Scheelite grain counts for 2011, 2012, and 2015 samples using this new routine are compiled in Appendix 4C.

6.3 Sample grain size analysis

Grain-size analysis of the till sample matrix was completed at the Sedimentology Laboratory of the GSC. About 200 to 300 g from each 1 to 2 kg sample was wet sieved to obtain the >0.063 mm fraction. Size fractions between 0.063 and 2 mm were determined by wet sieving followed by digital image processing using a CAMSIZER particle size analysis system. Size fractions <0.063 mm were determined using a Lecotrac LT100 Particle Size Analyser on a separate split. Results for

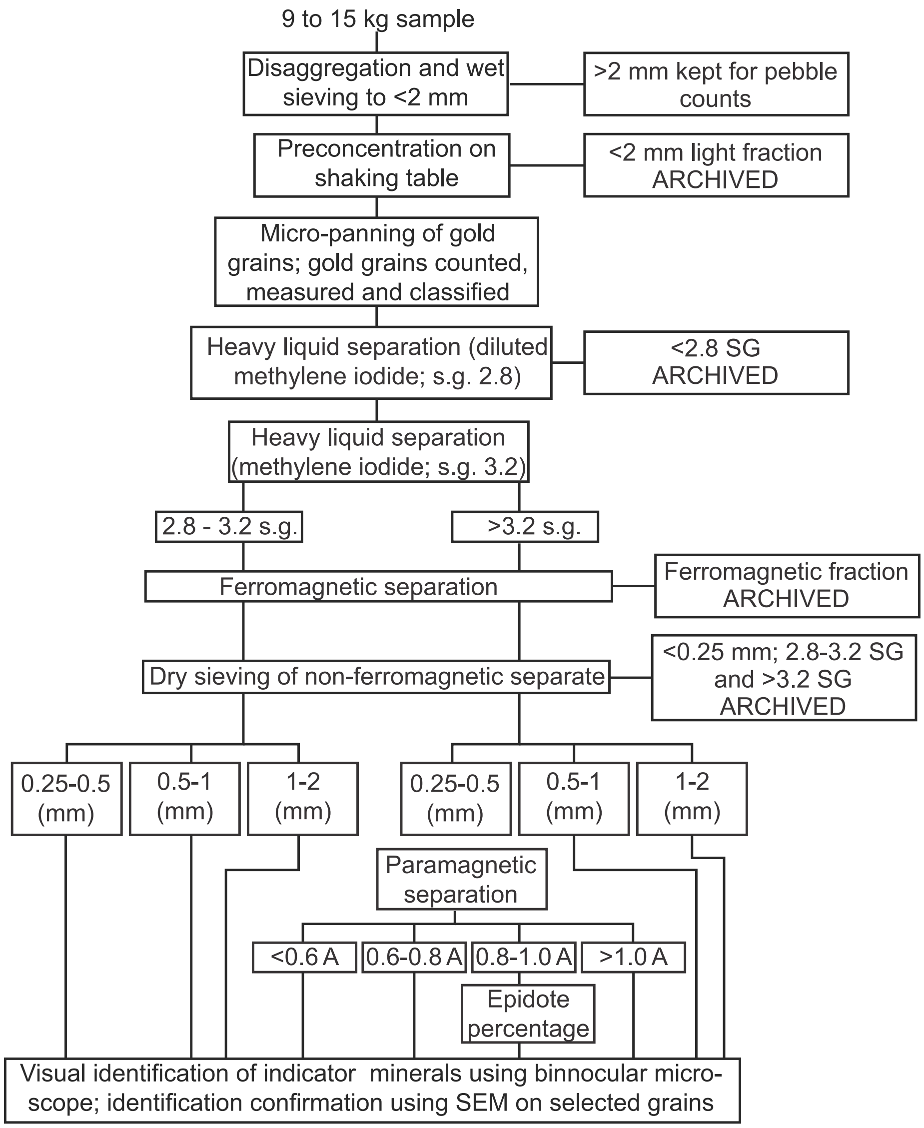

Fig. 13. Indicator mineral processing and identification flow chart (modified from Plouffe and Ferbey, 2015a).

2015 samples are presented in Appendix 5A. Results for 2011, 2012, and 2015 grain size analyses are compiled in Appendix 5B.

7. Quality assurance/quality control measures

Quality assurance/quality control (QA/QC) results for 2011 and 2012 (Plouffe and Ferbey, 2016) and 2015 (this paper) data sets indicate that geochemical and mineralogical results obtained as part of this project are suitable for geological interpretation and are not a product of analytical artefact. Results and interpretations of QA/QC data for 2015 samples are detailed below.

7.1. Geochemical analyses

Field and blind duplicates, analytical standards, and silica blanks were inserted in the sample suite sent for geochemical analysis to estimate data accuracy and precision. Field duplicates were collected at about one site out of 20. To evaluate local-scale sediment heterogeneity, the duplicate samples were collected from the same sample pit and geologic unit as the routine sample. The routine and duplicate samples were not homogenized at the sampling site. Blind duplicates (i.e., laboratory duplicates) were prepared by splitting the separated field duplicates following procedures outlined in Spirito et al. (2011) and McClenaghan et al. (2013) and were used to evaluate analytical variability. The certified analytical standard TILL-4 (from NRCan's Canadian Certified Reference Materials Project; see Lynch, 1996 for analytical results) was inserted in the sample suite to evaluate analytical accuracy. Lastly, silica blanks were included to monitor potential contamination from one sample to the next. About one analytical standard and one silica blank were inserted for every 20 routine samples.

The precision of analytical data can be analyzed in many ways (Abzalov, 2008; Piercey, 2014). The GSC Laboratory Information Management System defines analytical precision as the relative standard deviation (RSD), calculated by the method outlined in Garrett (1969), but without log normally transforming the analytical values.

The blind duplicates and estimated analytical precision are provided in Appendix 2D for the clay-sized fraction and Appendix 3D for the silt plus clay-sized fraction. Results of the analytical standards and silica blanks submitted with the clay-sized fraction are included in Appendix 2E; those submitted with the silt plus clay-sized fraction are in Appendix 3E.

7.1.1. Blind duplicates

Analytical precision for most elements in blind duplicates is ≤15% RSD and is considered acceptable for geologic interpretation (Abzalov, 2008; Appendices 2D and 3D). Precision values of >15% RSD are typical for elements with determinations close to detection limit (e.g., Ge, Pt, Re, Se, Te) or for elements that are heterogeneously distributed as discrete grains (e.g., Au). As with 2011 and 2012 samples (Plouffe and Ferbey, 2016), the analytical precision for Au is generally better in the clay-sized (RSD=31.9%) compared to the silt plus clay-sized fraction (RSD=64.0%) suggesting it is more homogenously distributed in the finer fraction.

One pair of blind duplicate samples returned questionable results for Ag in the clay-sized fraction: 94 ppb Ag in 15PMA038B01-L and 25 ppb Ag in 15PMA070A02-L (Appendix 2D). This single analysis resulted in low precision (RSD=32%) for Ag in the clay-sized fraction.

7.1.2. Certified standards

Most analytical results on the TILL-4 standard used in this study are within, or very close to, two standard deviations of the provisional value stated for a given element (Lynch, 1996; Appendices 2E and 3E). This indicates that analytical determinations produced for this study are accurate for most elements. One exception is sample 15TFE063C01, which returned below detection values for Hg (<5 ppb) in the clay- and silt plus clay-fraction (provisional value = 39 ppb). It is unknown why the value for this one element, in this one sample, is poorly reproduced. Determinations for Pb, Mn, and Bi, in both the clay- and silt plus clay-fractions, are higher than stated provisional values, but are within two standard deviations of themselves suggesting that, although analytical accuracy for these elements may be low, precision is high.

7.1.3. Blanks

Analyses of silica blanks (qtz-J29623) returned elemental concentrations below or very close to detection limit for most elements except for SiO_2, Sr, and Zr, which are expected in the silica sample blank. These results indicate that sample cross-contamination is not a concern. Two analytical results on silica blanks are above expected results: 15 ppb Ag in 15TFE001C01 (Appendix 2E) and 3.2 ppb Au in 15PMA001C01 (Appendix 3E). The exact source of the low concentrations of Au and Ag in the silica blanks is unknown.

7.2. Indicator mineral processing and identification

The accuracy and precision of mineral separations and mineral identification was assessed using protocols outlined by Plouffe et al. (2013c). We collected field duplicates from about one site out of 20, following the same procedure as the geochemical duplicate samples (section 7.1). To monitor contamination from previously processed samples, blank samples were included as the first sample in a sequence of 20. These samples were from a weathered Silurian-Devonian granite (grus), of the South Nepisiguit River plutonic suite in New Brunswick (Plouffe et al., 2013c). Additionally, one blank sample was spiked with chalcopyrite grains to monitor the accuracy of the heavy mineral separation and identification procedures (Plouffe et al., 2013c).

7.2.1. Field duplicates

In general, results of field duplicate samples (Appendix 4D) indicate that till mineralogy is relatively consistent over small areas. A duplicate pair (15PMA038A1 and 15PMA038A3) was collected 500 m down-ice of the Rateria Cu-prospect (MINFILE 092ISE199). The samples contain 7 (038A1) and 2 (038A3) gold grains and, 9 (038A1) and 3 (038A3) chalcopyrite grains likely derived from the known mineralization. This duplicate pair suggests local-level till heterogeneity down-ice of a sub-economic mineralized zone.

7.2.2. Blank samples

Results from four blank samples (Appendix 4D) show no indication of cross-contamination between samples or from previous sample batches.

7.2.3. Spiked sample

One blank sample (15PMA027A02) was spiked with 10 very angular chalcopyrite grains from a bedrock sample of the Highland Valley mineralization (Fig. 14). These spiked grains were described and photographed so they could be differentiated from any others recovered (Fig. 14). Nine of the 10 spiked grains were recovered; five in the 0.5-1.0 mm fraction and four

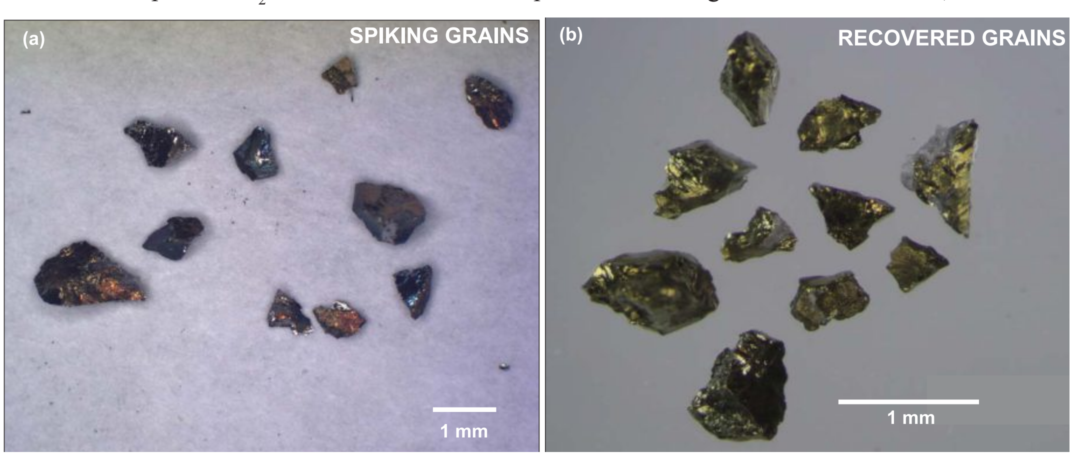

Fig. 14. a) Chalcopyrite spiking grains introduced in sample 12PMA027A02 (see Appendix 4D) and **b)** chalcopyrite grains recovered in the same sample (courtesy of Overburden Drilling Management Ltd.).

in the 0.25-0.5 mm fraction (Appendix 4D). This represents a recovery of 90% and indicates that the laboratory processing circuit and mineral picking protocols produce accurate grain count results. One 0.5-1.0 mm chalcopyrite grain broke into two pieces while manipulating for photography. Consequently, 10 recovered grains appear in Figure 14b.

8. Conclusion

Quality assurance/quality control results indicate that, uncontrolled by analytical artefact, the geochemical and mineralogical results for the dataset presented herein are suitable for geological interpretations. Geologic analysis of this dataset, detailing the dispersal of porphyry indicators in till from known sources at Highland Valley mine, will be presented elsewhere.

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