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Critical review

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Abstract: The Targeted Geoscience Initiative 4 is a five-year federal program to provide public geoscience knowledge to improve deep mineral exploration effectiveness. In southern British Columbia, the focus is on porphyry base- and precious-metal districts.

Preliminary, interjurisdictional activities focused on the sampling of tree bark, as a probe into the subsurface, and glacial till derived from eroded bedrock and mineral deposits. The first stage comprised pilot studies at the Woodjam district, and Gibraltar and Highland Valley mines in autumn of 2011. The determination of complex ice-flow directions from map- to outcrop-scale ice-movement indicators help trace geochemical and indicator-mineral anomalies back to the original buried deposits.

The studies helped test the sampling media (tree bark and till) as indicators of buried mineralization and thereby help increase the effectiveness of deep mineral exploration.

Résumé : L'Initiative géoscientifique ciblée 4 est un programme fédéral quinquennal dont l'objectif consiste à fournir des connaissances géoscientifiques publiques permettant d'améliorer l'efficacité de l'exploration minérale à grande profondeur. Dans le sud de la Colombie-Britannique, l'accent est mis sur les districts à minéralisations porphyriques de métaux communs et précieux.

Des activités préliminaires des divers ordres de gouvernement ont porté sur l'échantillonnage de l'écorce d'arbre, une façon de sonder le sous-sol, et du till provenant de l'érosion du socle rocheux et de gîtes minéraux. Dans un premier temps, des études pilotes ont été menées à l'automne 2011, dans le district de Woodjam ainsi qu'aux mines Gibraltar et Highland Valley. La détermination des directions complexes des écoulements glaciaires d'après les indicateurs du mouvement des glaces, à des échelles allant de la carte à l'affleurement, aide à retracer la source des anomalies géochimiques et des minéraux indicateurs jusqu'aux gîtes sources enfouis.

Les études ont permis d'analyser les matériaux échantillonnés (écorce d'arbre et till) à titre d'indicateurs de minéralisations enfouies et, de là, de favoriser une efficacité accrue de l'exploration minérale en profondeur.

INTRODUCTION

The mineral exploration industry continues to seek innovative methods and technologies to improve the effectiveness of exploration for covered or deep deposits.

The Federal Targeted Geoscience Initiative has been renewed (TGI4) with the objective of improving deep mineral exploration effectiveness in established and emerging mining camps. Its approach is to define the geoscience knowledge and information gaps that exist in seven main ore systems, including intrusion-related (porphyry) systems. The TGI4 mandate "public geoscience in support of deep exploration" is in response to the need expressed by the mineral exploration industry for publically accessible research to improve technologies for effective targeting of buried mineral deposits.

In British Columbia, the Interior Plateau physiographic region (Fig. 1) is an ideal study area to develop new technologies for deep exploration because it is underlain by well known porphyry deposits (e.g. New Afton, Highland Valley,

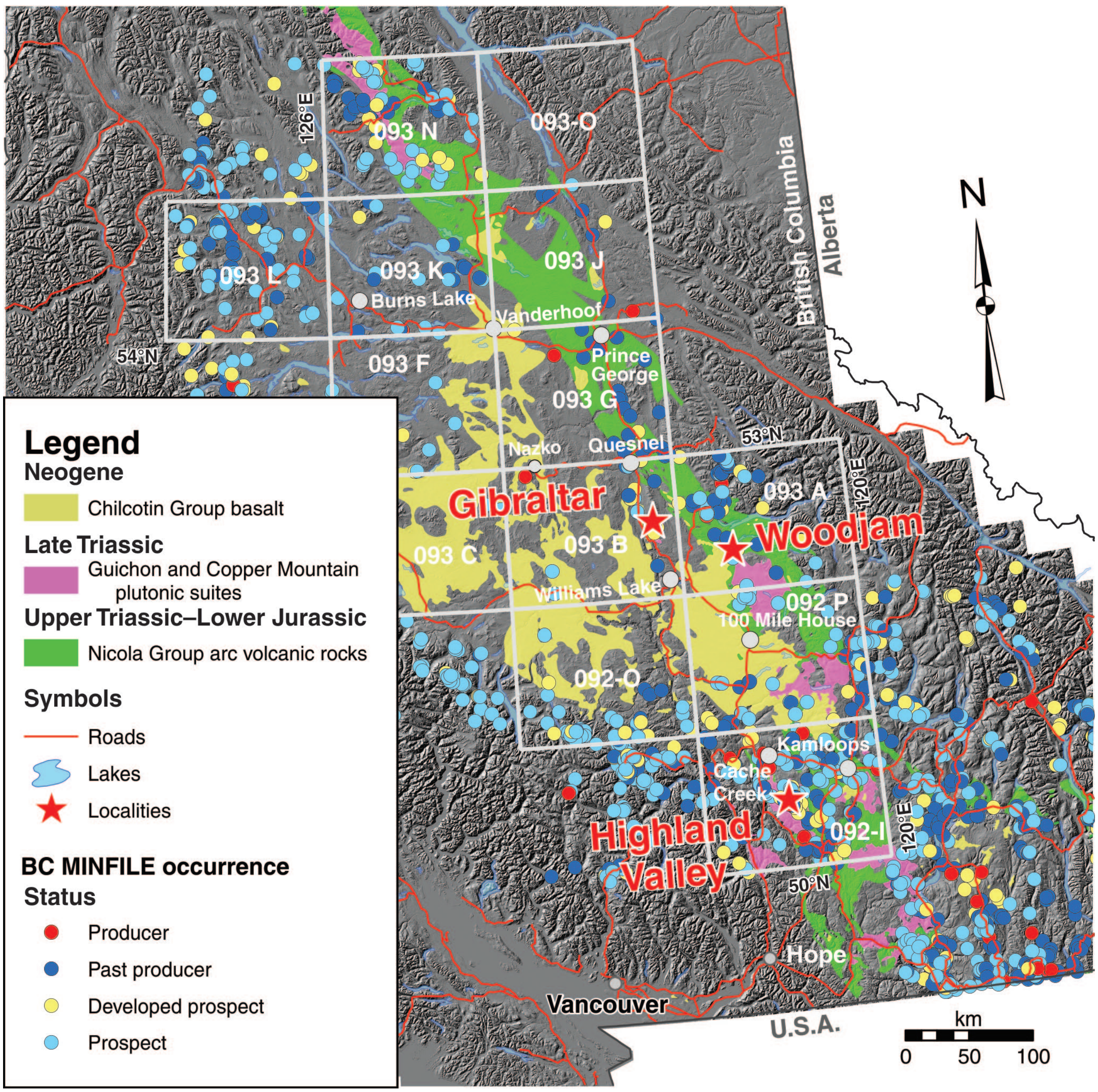

Figure 1. Shaded digital elevation model which shows the extent of Tertiary basalt cover, the Nicola Arc assemblage bedrock and distribution of known mineral occurrences of all types in the Interior Plateau. The general location of the study areas of Gibraltar mine, Woodjam district, and Highland Valley district are shown.

Gibraltar, and Mount Polley) and has a high potential for further porphyry deposits (e.g. Woodjam) that are obscured by glacial deposits and unmineralized Tertiary basalt flows.

Below, the authors summarize the TGI4 activities in British Columbia under the intrusion-related ore system project including the 2011 pilot studies undertaken at Woodjam district and Gibraltar and Highland Valley mines over a two-week period in autumn of 2011. The studies included the collection of 66 biogeochemical samples and 47 till samples for geochemical and mineralogical analysis. Results from the pilot field studies will serve to design future, more comprehensive surveys to be conducted in 2012 and 2013.

OBJECTIVES

Industry needs access to case studies that define methodological protocols and demonstrate how analysis of tree bark or surficial sediments can help find buried mineral deposits and increase the effectiveness of deep mineral exploration. Previous studies in the Cordillera by the Geological Survey of Canada (GSC) and British Columbia Geological Survey (BCGS) have demonstrated that the geochemical compositions of trees and glacial sediments are influenced by underlying or nearby mineral deposits (e.g. Plouffe, 1995, 2001; Levson, 2001; Dunn, 2007; Dunn and Thompson, 2007, 2009; Ferbey et al., 2009; Ferbey, 2010; Dunn and Anderson, 2011; Plouffe et al., 2011a, c, and references therein); however, the elements and components in trees and surficial sediments indicative of the buried fertile porphyry systems need to be identified and modelled to test if their distribution can be used to vector toward concealed mineralization. The present authors plan to identify the key components in trees and sediments and the areal extent over which they typically occur in the vicinity of porphyry mineralization. This approach could be useful in the search for buried mineral deposits and increase the effectiveness of deep mineral exploration.

The very productive Gibraltar and Highland Valley mines are Cordilleran type areas for large porphyry Cu-Mo deposits. The districts are also characterized by in situ glacial deposits which overlie the mineralized outcrops and surviving patches of woodlands on those surficial deposits. The Woodjam district was selected as a study area because its mineralized zones are entirely covered by glacial deposits and partly by Tertiary basalt cover.

At the Gibraltar and Highland Valley mines, results from the studies will help define the geochemical and biogeochemical ‘footprint’ for classic buried Cordilleran calc-alkaline porphyry Cu-Mo systems and establish best practices when incorporating these in an exploration program. Potential correlations among till mineralogical and geochemical and biogeochemical responses and the distribution of the geochemical anomalies over a region that extends beyond the zones of mineralization are key to the success of this approach. In the mine areas, the research will identify pathfinder elements indicative of fertile mineralization in the underlying rocks, but which are not introduced into the plants by anthropogenic activities related to mining operations. Results from the pilot studies conducted at the Woodjam district and the Gibraltar and Highland Valley mines will be compared with published regional studies (e.g. Bonaparte Lake; Plouffe et al. (2010, 2011a); Dunn and Anderson (2011); and, regionally; e.g. Lett (2008)) that ultimately might serve to identify new anomalies and potential mineral exploration targets.

The till samples will be submitted for geochemical analyses and processed for heavy-mineral separation and identification. Results from these analyses will identify the geochemical and mineralogical signatures of classic Nicola Arc calc-alkaline porphyry Cu-Mo and Cu-Au systems in glacial sediments.

Till sampling is completed concurrently with the mapping of surficial sediments and ice-flow indicators at map- (e.g. drumlins) and outcrop- (e.g. glacial striations) scales. Reconstruction of the ice-flow history based on these indicators is key to tracing the geochemical and mineralogical anomalies back to their source(s) in glaciated terrains particularly where the ice-flow history is complex (e.g. Ferbey and Levson, 2009; Ferbey, 2010; Plouffe et al., 2011a).

Ultimately, the results will be published as case studies and will include recommendations on applications of this integrated approach to the exploration for hidden porphyry-related mineral deposits in Canada.

BACKGROUND

Till sampling surveys

For more than 20 years, the BCGS and the GSC have implemented surficial geology and till sampling surveys within the Canadian Cordillera with the main objective of evaluating the mineral potential of regions covered by glacial sediments (*see* Bobrowsky et al. (1995) and Ferbey (2010) for examples). The surveys were completed by processing the till samples for geochemical analyses and tracing the bedrock source of anomalies in the up-ice flow direction. The success of these surveys relies on reconstructed ice-flow histories based on mapping of glacial sediments and ice-flow indicators at all scales measured in the field and on aerial photographs.

Over that period, a number of biogeochemical surveys were conducted at regional and property scales with the main objectives of detecting a geochemical signal in plants related to buried mineralization (Dunn, 1995; Dunn and Hastings, 1998; Dunn and Thompson, 2007, 2009; Dunn and Anderson, 2011).

This TGI4 project intends to build on this existing knowledge. Consequently, not only will till samples be processed for geochemical analyses, but also for indicator minerals, which will include heavy-mineral separation and identification of key minerals associated with mineralization (e.g. sulphide minerals, gold grains, alteration minerals, etc.). Geochemical analyses will include minor and major element analyses on the silt+clay- (<0.063 mm) and clay- (<0.002 mm) sized fractions following protocols suggested in Spirito et al. (2011). At each sample site, 2 kg and 10 kg samples will be collected for geochemical and mineralogical analyses, respectively.

As part of this project, surficial geology maps will be produced for each study site at a scale of 1:50 000 to provide a regional account of surficial geology sediments and landforms necessary for the reconstruction of the ice-flow history and interpretation of any till compositional anomalies. The ice-flow history will be reconstructed based on macro- and meso-landforms visible on aerial photographs and digital elevation models; micro-landforms (e.g. glacial striations, roches moutonnées) visible at the outcrop scale; and the mapping of surficial geology (glacial landforms and sediments). Field investigation will include 'ground-truthing' the aerial photograph interpretations used for surficial geology mapping, till sampling at short intervals (about 250–500 m) near mineralization and at larger spacing (about 1 km) along forestry roads to provide regional coverage at 10–20 km from the mine (e.g. Fig. 2), and measurement of glacial striations on bedrock outcrops.

Figure 2. Typical till sample sites. The small sample (about 2 kg of material) is processed for geochemical analysis and the large one (about 10 kg of material) for indicator minerals. Field notes are captured digitally with a personal digital assistant device. The notebook is 20 cm long. 2012-008

Biogeochemical surveys

The underlying rationale for applying biogeochemical methods to mineral exploration is that trees and shrubs absorb metals present in the ground and transfer these metals via their root systems to the growing plant. Metals are absorbed from soil, groundwater, and locally, bedrock where roots penetrate faults, joints, and cleavage planes. The significant advantage of applying plant chemistry to exploration is that the root system of a tree or shrub may penetrate through many cubic metres of the substrate, and therefore integrate the geochemical signature of a large volume of all soil horizons, the contained groundwater, and bedrock that is covered by only a few metres of overburden. Tree roots penetrate into, and locally through the cover to absorb elements and transfer them to various parts of the tree structures.

Depth of root penetration is not critical for a biogeochemical response, because local conditions may be favourable for elements to migrate upward from considerable depth in solution, by diffusion, in electrochemical cells, associated with bacterial fluxes, and possibly by seismic pumping (i.e. release of metals due to earth tremors) to be accessed by root systems. Consequently, there is commonly no direct correlation between plant and soil chemistry. Further details are found in Dunn (2007).

The sampling plan includes collections of bark from Engelmann spruce and lodgepole pine as available from the vicinity of the mines and to a distance of 10 km from the mines. A typical sample site includes one till sample and at least one, and preferably the two targeted tree species depending on the type of vegetation present. Consequently, the tree- and till-sample spacing will generally be similar. Duplicate samples are collected as part of the sampling protocol. The bark samples will be prepared, interspersed with biogeochemical standard samples, and all analyzed for 53 elements.

SCOPING STUDY

Gibraltar mine

Gibraltar mine, centred within the Granite Mountain batholith (Fig. 1, 3), is one of British Columbia's largest and longest producing copper-molybdenum porphyry deposits (Oliver et al., 2009). The six ore zones which make up the deposit are hosted by the well mapped and well explored composite, peraluminous Late Triassic Granite Mountain batholith (e.g. Drummond (1973); Bysouth et al. (1995); Ash et al. (1999a, b); Ash (2001); Oliver et al. (2009); and references within) and this summary is taken from those references.

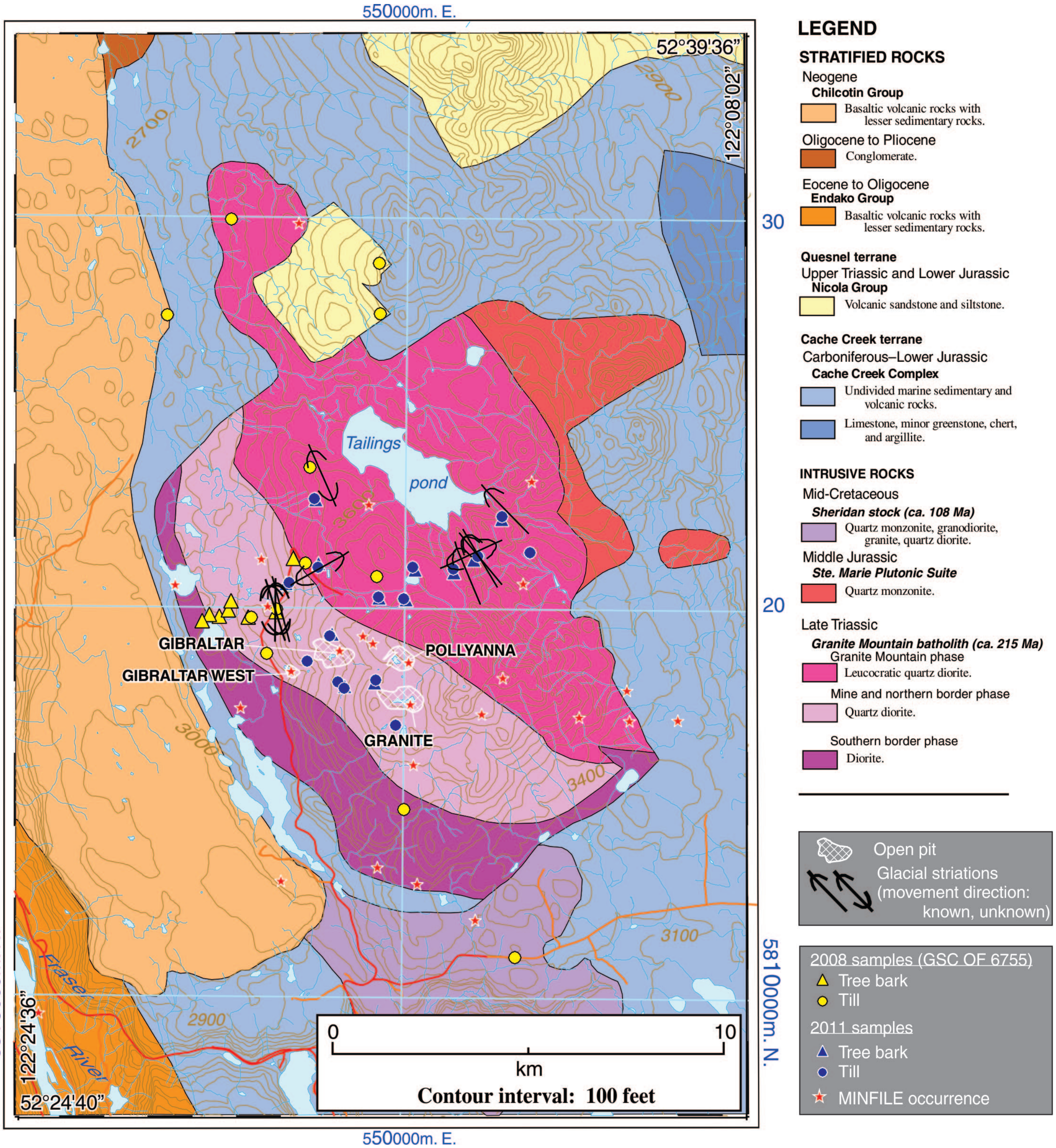

Figure 3. General geology of Gibraltar mine (*after* Ash et al., 1999a). Glacial striations and till and biogeochemical sample locations from this study.

Bedrock geology, mineralization, and alteration

The Late Triassic Granite Mountain batholith demonstrably intruded the Permian Cache Creek Group. Hornblende-bearing diorite and quartz diorite (southern border phase) and biotite-hornblende tonalite (mine or northern border phase) hosted deposition of sulphide mineralizion (chalcopyrite, molybdenite, pyrite, and minor sphalerite). Trondhjemite (Granite Mountain phase) and minor, late leuco-trondhjemite (quartz- and quartz-feldspar porphyry) are generally barren (Oliver et al., 2009). The country rocks, batholith, and early phases of the ore deposits and alteration were polydeformed, with the development of gently southwesterly dipping and plunging planar and linear fabrics, and metamorphosed to upper-greenschist grade in the Early Jurassic; structures are crosscut by late molybdenite-bearing veins. Epidote and chlorite alteration of the mafic minerals in all phases is characteristic, even distal to the mine.

The Gibraltar deposit displays well developed and closely associated hydrothermal alteration patterns and zonation of base metals. Quartz, sericite, chlorite, epidote, and carbonate are the common alteration minerals; distal, weak propylitic alteration linked with lowest grade copper changes to quartz-sericite-pyrite alteration correlated with moderate copper-molybdenum grades. Highest grade copper is commonly associated with either intense quartz-sericite-pyrite or quartz-sericite-chlorite zones or with zones of 'darkened chlorite'. Potassium-enriched zones of chlorite-biotite-iron carbonate are commonly spatially linked to intense fabric development. A characteristic and marked sulphide zonation includes chalcopyrite-molybdenum in the core through chalcopyrite to chalcopyrite-sphalerite and finally to sphalerite at the margins of the batholith and was observed in a pilot study around the deposit (Plouffe et al., 2011b).

Surficial geology elements

A regional geomorphology map of the Quesnel map area (NTS 93B) depicts ice-flow indicators (flutings, drumlins, and crag-and-tail features), meltwater channels, eskers, moraines, pitted terrains, and areas of glacial lake sediments (Tipper, 1971c). Based on the mapping of glacial landforms from aerial photographs, Tipper (1971a, b) published an interpretation of the glacial history of a vast sector of central British Columbia. Based on his interpretation, ice generally flowed to the north-northwest in the region of the Gibraltar mine from an ice divide located near 52°N latitude during the last glaciation. Clague (1988) presented an account of the Quaternary stratigraphy and reconstructed glacial history of the Quesnel region north of Gibraltar mine.

New work in an area southeast of the Gibraltar mine illustrates the utility of field mapping in unravelling complex ice-flow history. Identification of glacial landforms observed on aerial photographs and outcrop (e.g. glacial striations) by Plouffe et al. (2011a) revised the ice-flow history of the Bonaparte Lake map area first provided by Tipper (1971a, b). The latest work showed that at the onset of the last glaciation (Late Wisconsinan Fraser Glaciation), ice was flowing generally to the west out of the Cariboo Mountains onto the Interior Plateau, at least as far west as the Lac la Hache region where the westernmost striations were measured (Plouffe et al., 2011a). This general westward flow was followed by a regional southward flow in the Bonaparte Lake region after the development of the 52°N latitude ice divide. Plouffe et al. (2011a, c) clearly demonstrated that evidence of westward and southward glacial transport resulting from both phases of ice flow are present in the Bonaparte Lake region.

A modern surficial geology map and reconstructed ice-flow history is lacking for the Gibraltar mine region and this knowledge gap will be filled by this TGI4 project. Ice-movement direction indicators were measured at seven sites (Fig. 2, 4). At two sites, northeast-southwest oriented striations might be related to a first ice movement from the northern sector of the Cariboo Mountains at the onset of the last glaciation, similar to the early advance observed in the Bonaparte Lake region (Plouffe et al., 2011a); however, most striations trend north-northwest and are likely related to ice movement derived from the ice divide to the south.

During the scoping study conducted in the fall of 2011, till veneer (<2 m thick) and blanket (>2 m thick) were observed in the Gibraltar mine region with limited glaciofluvial sediments associated with meltwater channels. A total of 19 till samples were collected in the region of the Gibraltar mine including samples from the open-pit walls where undisturbed till is exposed (Fig. 2, 3, 4, 5).

Biogeochemical sampling

Biogeochemical stations were established at many of the till sites and 21 bark samples were collected at fourteen sites, including three sites at the rim of the open-pit areas (Fig. 2). An additional two localities were directly above granite outcrop. Spruce and pine are common and were the tree species sampled; poplar, aspen, and fir are also present. The woodlands sampled were generally dry, open to moderately dense forests developed on flat to gentle slopes.

Woodjam district

Bedrock geology and mineralization

The 56 170 ha Woodjam gold-copper-molybdenum district is located at and around the village of Horsefly, about 45 km east of Williams Lake (Fig. 1) and 35 km southeast of the Mount Polley copper-gold mine. It occupies low-elevation, relatively flat terrain typical of the Interior Plateau (Schroeter, 2009; Fjordland Exploration Inc., undated). The district encompasses at least five mineralized zones including

Figure 4. In the region of the Gibraltar mine, views to northwest to **a)** striations trending 320°. The Brunton compass is 20 cm long; and **b)** a roche moutonnée trending 315°. The person is 1.7 m tall. 2012-010 and 2012-009, respectively.

(north to south): Deerhorn, Megabuck, Spellbound, South East, and Takom (Fig. 6). The well explored zones were geophysically defined by the coincidence of large areas of high chargeability and low resistivity IP signatures, with regional-scale northeast-trending magnetic highs demarcating the alteration zone produced by the contact of the Takla Group volcanic rocks with the Takomkane batholith (Fjordland Exploration Inc., undated).

The Deerhorn, Megabuck, Takom, and Spellbound zones (Fig. 6) comprise copper-gold-molybdenum alkalic porphyry-type deposits (Schroeter, 2009) that occur as mineralized quartz stockwork and breccia zones in the Takla Group volcanic and volcaniclastic country rock up to 1.5 km west of the north-trending contact with the Takomkane batholith (Logan et al., 2007; Schiarizza et al., 2009a, b) within contact aureoles of monzonite satellite intrusions. The South East zone (Fig. 6) is a large-scale calc-alkalic copper-molybdenum-gold porphyry-type deposit comprising pyrite, chalcopyrite, molybdenite, and trace bornite along fractures, in quartz veinlets, and as disseminations wholly within mafic to felsic intrusive phases of the Takomkane batholith (e.g. Fjordland Exploration Inc., undated; Schiarizza et al., 2009a, b; Logan et al., 2011).

Isotopic dates for the South East zone reported and summarized by Logan et al. (2007, 2011) indicate contemporaneous crystallization of zircon in the host granodiorite-monzogranite and molybdenite mineralization at about 197 Ma (U-Pb date for the host, Re-Os date for molybdenite), followed abruptly, ca. 193–192 Ma (Ar-Ar dates), by cooling of feldspar and biotite through 360–280°C and, subsequently by intrusion at ca. 164 Ma (Ar-Ar date for biotite) by a postmineralization dyke.

Surficial geology elements

No surficial geology map has been published for the Woodjam district. The preliminary interpretation of the ice-flow patterns at Woodjam presented here derives from multiple sources. Glacial striations measured as part of the exploration program conducted by Gold Fields Canada Exploration and Fjordland Exploration Inc. indicated two dominant and generalized trends: east-west and northwest-southeast (J.W. Hertel, pers. comm., 2011). Two striated outcrops were measured as part of this study (Fig. 6). The regional ice-flow patterns to the northwest as identified by Prest et al. (1968), Tipper (1971b), Clague (1989), and Ryder et al. (1991) for the southeastern sector of the

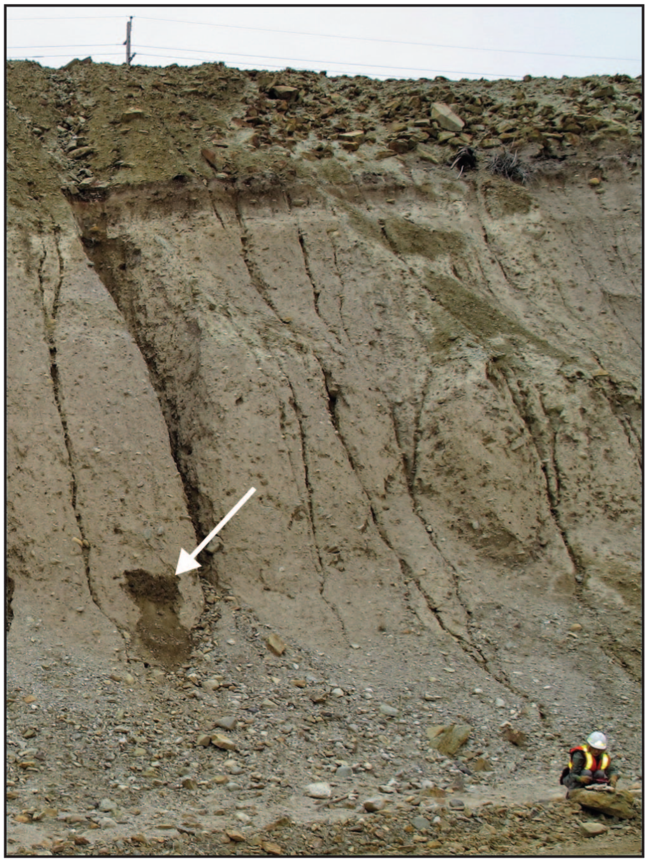

Figure 5. Till sampling site (arrow) in the open-pit wall at Gibraltar mine in undisturbed till underneath waste rock. The sampling scar is about 1 m in diameter. 2012-033

Interior Plateau where the Woodjam district is located are well known. These data sets integrated with recent findings in the Bonaparte Lake region to the south (Plouffe et al., 2011a, c) expand the coverage. The cumulative data suggest the preliminary interpretation that the two glacial striation sets at the Woodjam property derive from an early westward ice flow from the Cariboo Mountains at the onset of the last glaciation followed by a northwest ice movement from the ice divide at 52°N latitude.

A total of 18 till samples were collected at Woodjam property (Fig. 6). The Woodjam property is generally underlain by a till blanket (>2 m thick) with rare bedrock exposures. Based on drilling, the glacial sediment succession is of highly variable thickness, but locally exceeds 250 m in the South East zone and up to 278 m elsewhere (J.W. Hertel, pers. comm., 2012).

Biogeochemical sampling

In the Woodjam area, twenty-seven bark samples were collected at fifteen biogeochemical sites including many at the till sites and four sites above volcanic outcrop (Fig. 6). Six sites were located at or near the Deerhorn, three at or near Megabuck, and one at the Spellbound zone. Spruce dominates over pine, and poplar, aspen, and fir are also present in the forests. The woodlands sampled were generally dry, open to moderately dense forests developed on flat to moderate slopes.

Highland Valley district

The Highland Valley district (Fig. 1, 7) represents the largest group of operating Cu mines in Canada. The porphyry Cu-Mo deposits of the Highland Valley district are contained within the Guichon Creek batholith (e.g. McMillan, 2005; McMillan et al., 2009). The following summary from McMillan (1976, 1985) and Woodsworth et al. (1991) is updated from more recent work reported by Ash et al. (2007) and Davis et al. (in press).

Bedrock geology

The Guichon Creek batholith (Fig. 7), which hosts the Highland Valley district deposits, is a large composite Late Triassic intrusion within Mississippian to Upper Triassic Cache Creek Complex and volcanic and sedimentary rocks of the Upper Triassic Nicola Group (Monger and McMillan (1984) and references therein; McMillan (1985); McMillan et al. (2009); Davis et al. (in press)). The batholith is variably covered by glacial deposits, with its northern part overlain by Eocene volcanic rocks of the Kamloops Group.

Based on textural and compositional criteria, McMillan (1985) originally subdivided the batholith into four phases, which in relative decreasing age, included the Border, Highland Valley, Bethlehem, and Bethsaida phases. As well, he recognized the Guichon and Chataway 'varieties' within the Highland Valley phase, and the Skeena 'variety' within the Bethsaida phase. Contacts between the phases, though locally sharp, are commonly gradational and define an annular zoning with the older phases toward the outer margins of the batholith and the younger phases within the central area. The different plutonic units define two geochemical suites (McMillan, 1985). New geochemical modelling by Davis et al. (in press) revise this to include (Fig. 7) the Highland Valley suite, which includes the earlier Border and younger Guichon and Chataway phases; and the Bethlehem suite, which includes the Bethlehem and Bethsaida phases and the Skeena subphase plus various felsic porphyry dyke types, the largest of which is the Gnawed Mountain subphase. The Bethlehem suite is generally more felsic than the Highland Valley suite.

The northerly elongation of the batholith suggests control by basement structures manifest in syn- and postintrusion faults including the north-trending Lornex and Guichon Creek faults and northwest-trending Barnes Creek, Highland Valley, and Skuhun Creek faults (Fig. 7). Mid- to upper crustal emplacement is suggested by interphase intrusive relations and dykes, probable semiconcordant to discordant batholith-country rock contacts, intrusion into

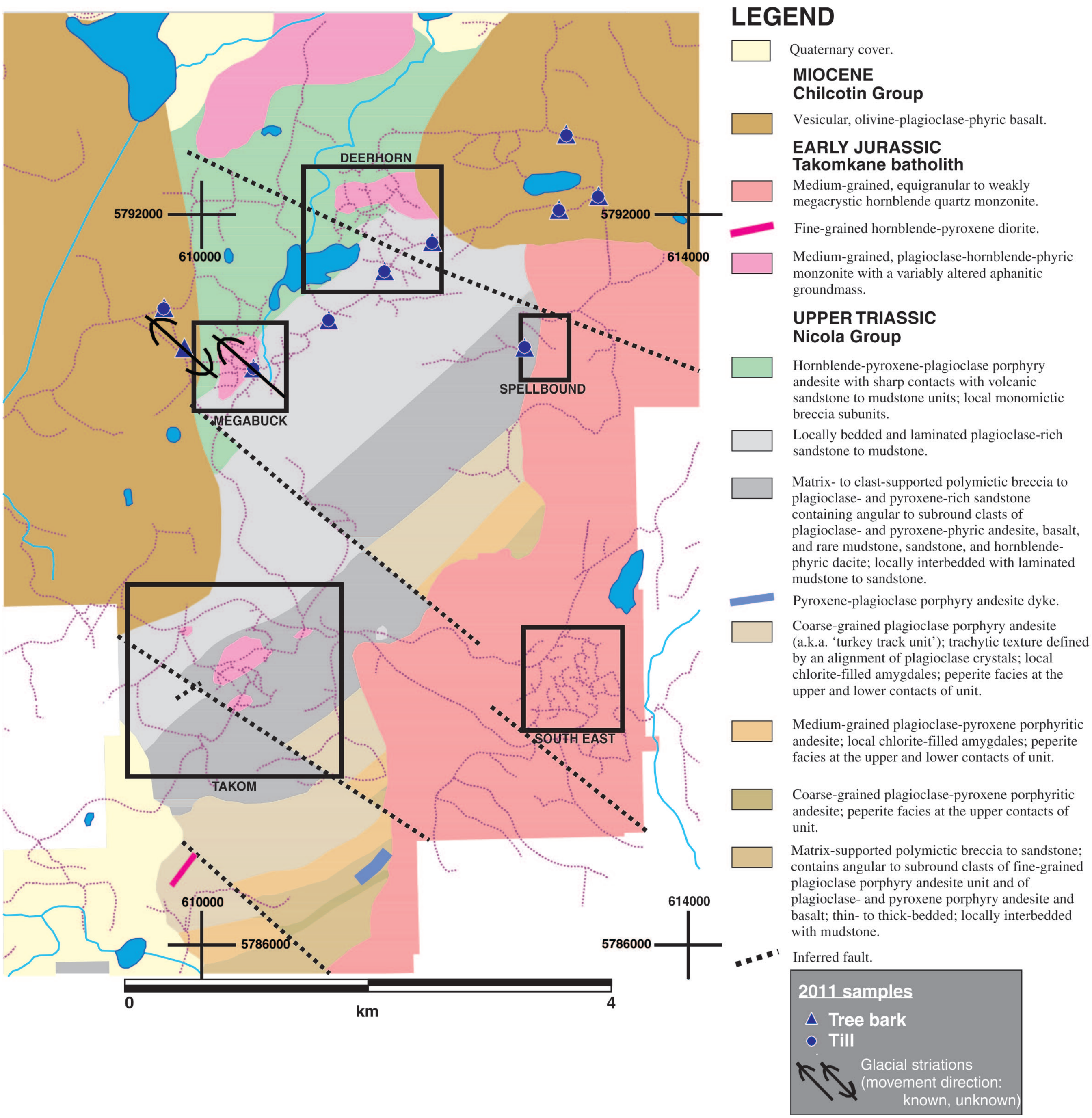

Figure 6. General geology of the Woodjam district (*after* Blackwell et al., 2010). Glacial striations, till, and biogeochemical sample locations from this study. The location of four regional samples plot off the extent of map.

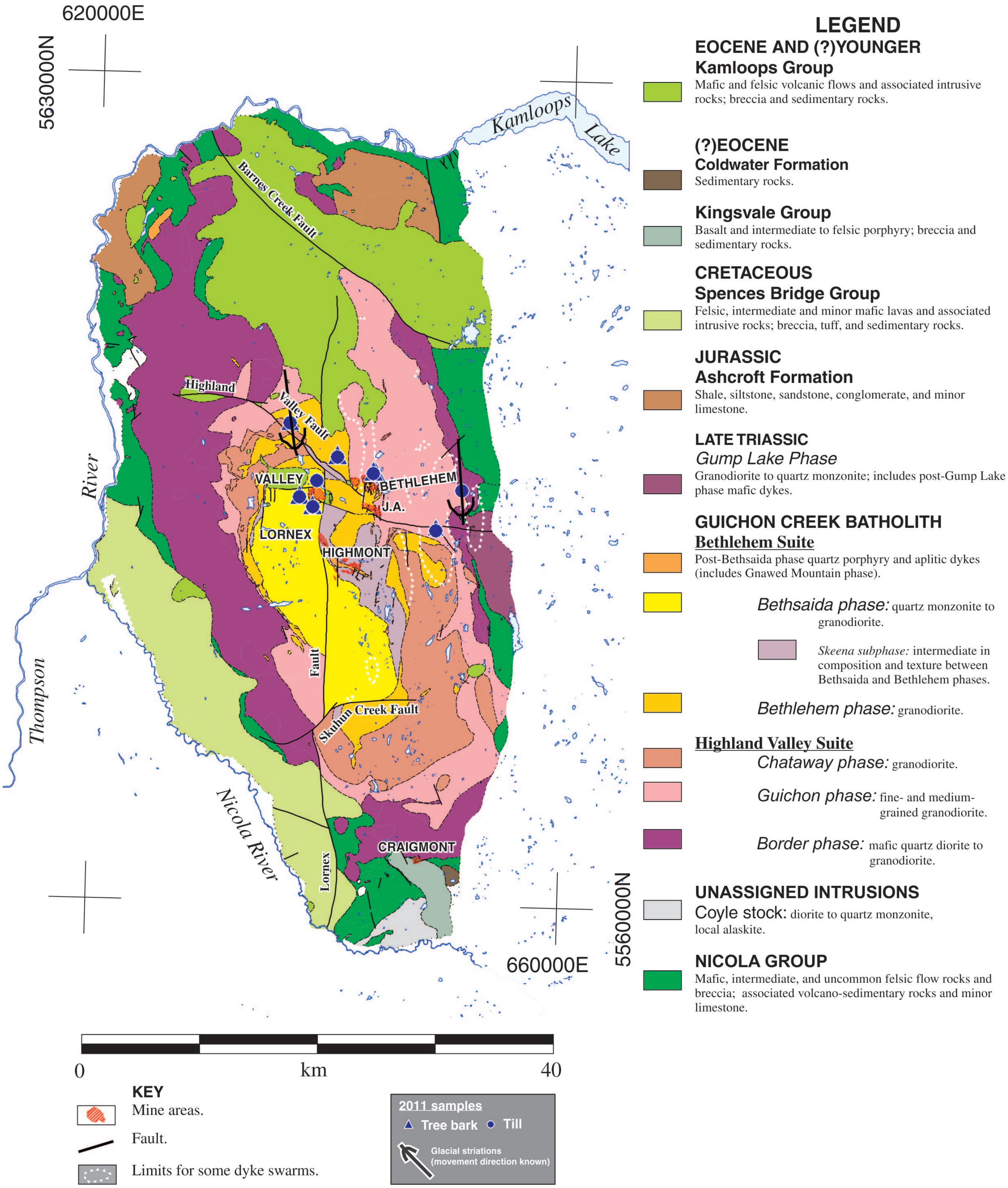

Figure 7. General geology of the Guichon batholith, Highland Valley district (*after* McMillan et al., 2009). Glacial striations and till and biogeochemical sample locations from this study.

slightly older Nicola Group volcanic country rocks, and a 0.2–0.8 km wide albite-epidote to hornblende hornfels facies metamorphic aureole (Northcote, 1969; McMillan, 1976). Interpretation of geological and geophysical observations, including gravity, magnetic, velocity and LITHOPROBE seismic-reflection data, indicate the Guichon Creek batholith to be a funnel-shaped feature extending to depths of about 10 km (Roy and Clowes, 2000). The mineral deposits are located in the centre of the structure above the stem of the batholith and near the intersection of the major brittle structures described above.

Mineralization

Mineralization at Highland Valley mine has a Cu-Mo association with little gold and is hosted in calc-alkalic to calcic plutonic rocks (Fig. 7). This contrasts with younger ca. 204–200 Ma Cu-Au porphyry mineralization associated with the alkaline Copper Mountain plutonic suite, such as at Iron Mask batholith and Mount Polley (Lang et al., 1995; McMillan et al., 1996).

The major vein- and fracture-controlled ore deposits (Valley, Lornex, Highmont, Bethlehem, and JA) occur within the central part of the batholith where they are hosted by the Bethlehem and Bethsaida phases, but smaller deposits (Krain and South Seas) occur within the older Guichon phase. According to McMillan (1985), there were two porphyry deposit–forming events within the Guichon Creek batholith, an earlier pre-Bethsaida event that produced the Bethlehem ore bodies, plus smaller Krain and South Seas deposits, and a second more significant post-Bethsaida event, during which the Valley, Lornex, Highmont, and JA deposits formed. These observations have been largely corroborated and refined by precise isotopic age dates (e.g. Ash et al., 2007; Davis et al., in press).

Surficial geology elements

The Quaternary geology and geomorphology of a vast region east of Highland Valley mine was studied by R.J. Fulton (GSC) during the 1960s and 1970s (Fulton, 1965, 1967, 1969, 1975; Fulton and Walcott, 1975; Fulton and Smith, 1978). Ryder (1976, 1981) reported on the Quaternary geology of the Ashcroft and Lytton regions, northwest and west of Highland Valley mine. Detailed stratigraphic study of the Quaternary succession in the Merritt region revealed the presence of deposits from four glaciations and two interglaciations (Fulton et al., 1992). Bobrowsky et al. (1993) reported on the unconsolidated sediment stratigraphy in the Valley pit at Highland Valley mine which includes glaciolacustrine sediments of Middle Wisconsinan age or older and one till unit most likely related to the Late Wisconsinan glaciation. Kerr et al. (1993) reported a copper dispersal train defined by concentrations greater than 200 ppm in the till C-horizon, up to 1 km down-ice from the Galaxy porphyry copper-gold deposit in the Iron Mask batholith southwest of Kamloops (*see also* Lett, 2011). Also, they observed elevated copper concentrations in the stems, leaves, and flowers of rabbitbush (*Chrysothamnus nauseosus*) sampled as part of a biogeochemical survey within the region of the dispersal train. Bobrowsky et al. (2002) completed a Quaternary geology reconnaissance study in the Merritt and Logan Lake region.

Based on the regional ice-flow patterns depicted in Prest et al. (1968), Tipper (1971b), Clague (1989), and Ryder et al. (1991), along with glacial striations reported by Bobrowsky et al. (2002) and measured as part of the present investigation (Fig. 7), glaciers derived from the ice divide located at the 52°N latitude were generally moving to the south in the region of the Highland Valley mine during the last glaciation.

One of the key characteristics of the Valley pit at the Highland Valley mine is the presence of a Quaternary unconsolidated sediment succession over 300 m thick overlying mineralized bedrock. This sediment succession was preserved in a buried valley (Bobrowsky et al., 1993). The lower part of the succession includes nonglacial sediments and glacial lake sediments which predate the last glaciation (Bobrowsky et al., 1993). The preservation of these unconsolidated sediments underneath the till of the last glaciation indicates that a large part of the mineralized bedrock was not available for erosion during the last glacial event. Therefore, neither the mineralogy nor bulk composition of that part of the mineralized zone covered by preglacial sediments will be found in the till down-ice from the mine.

The plateau region outside Witches Brook valley is generally underlain by till veneer and blanket. Glacial lake sediments are present in Witches Brook valley and are most likely related to the damming of the valley during deglaciation.

Sampling locations

During the autumn 2011 fieldwork, till samples were collected from nine sites in the walls of the Valley and Bethlehem pits and surrounding region (Fig. 7). Six of the till localities and one site (without till sampling) yielded biogeochemical material for a total of 18 bark samples. All but three stations were above outcrop, including four stations near the rim of the Valley and Jersey (Bethlehem) open-pit areas. Spruce and pine are common; poplar, aspen, and fir are also components the forests. The woodlands sampled were generally dry, moderately open forests developed on gentle to moderate slopes.

SUMMARY

Preliminary activities under the new Targeted Geoscience Initiative 4 will focus federal and provincial survey work in identifying ice-movement histories, geochemical characterization of tree bark, and in the collection and mineralogical and geochemical characterization of glacial till derived from eroded bedrock and mineral deposits. The determinations of complex ice-flow directions from map- to outcrop-scale ice-movement indicators help to trace bulk till and fertile till mineral assemblage geochemical anomalies back to the original buried deposits.

Pilot studies at the Woodjam district and Gibraltar and Highland Valley mines type areas include 47 till samples and 41 biogeochemical sample sites (yielding 66 samples). Results from these samples will help test and improve these technologies and demonstrate how analysis of the same sediments that hinder surface mineral exploration can help pinpoint buried mineral deposits and increase the effectiveness of deep mineral exploration.

The till and bark sampling undertaken in 2011 completed as part of this study was designed to identify geochemical or mineralogical anomalies associated with the deposits covered by glacial sediments. At the Gibraltar mine, this sampling builds on the preliminary results of Plouffe et al. (2011b; Fig. 2). In all study areas the new results will help in the design of more extensive surveys planned for 2012. Those will identify the magnitude of the target ‘footprint’ and nature and distribution of the various metal geochemical anomalies.

Mineralogical studies, which amplify those undertaken in the Bonaparte Lake area by Plouffe et al. (2009, 2011a), coupled with an expanded knowledge of the glacial-movement history, are anticipated to provide a robust suite of porphyry indicator-mineral assemblages and source and compositional information on the fertility of the intrusions from which they were derived. These studies will complement early work by Bouzari et al. (2011). An ancillary, but first-order contribution will be maps which portray the nature and distribution of glacial-sediment deposits near all three study areas.

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