TILL GEOCHEMISTRY AND MINERALOGY IN THE MOUNT POLLEY CU-AU PORPHYRY DEPOSIT REGION, BRITISH COLUMBIA, CANADA.

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Introduction

The Quesnel terrane within the Interior Plateau of British Columbia, Canada (Figure 1 is a highly prospective region, hosting a significant number of porphyry deposits (Anderson et al. 2012). The Interior Plateau of British Columbia has also been glaciated numerous times throughout the Pleistocene (Clague & Ward 2011). As a result, bedrock can be obscured by glacial deposits (e.g. till), hindering mineral exploration. Drift prospecting, which is the process of locating mineralized ore in glaciated terrain based on the anomalous geochemical, mineralogical and lithological patterns in till, can be used as an aid to detect porphyry mineralization in this region (DiLabio & Coker 1989). It is the ideal tool to explore for mineralization in areas where a thick cover of Quaternary sediments conceals the bedrock (McMartin & McClenaghan 2001).

Located within Quesnel terrane is the Mount Polley deposit. It is an alkaline, silica-under saturated Cu-Au porphyry deposit, situated 365 km northeast of Vancouver and owned and operated by Imperial Metals Corporation. This study was conducted as part of the Geological Survey of Canada's Targeted Geoscience Initiative 4 (TGI-4) program. The main objective of this study is to apply drift prospecting techniques to characterize the mineralized glacial dispersal at Mount Polley. We document the geochemical and mineralogical composition of till present at Mount Polley. In doing so, we identify the key minerals present in till diagnostic of the mineralization at Mount Polley, which can in turn be applied to Cu-Au porphyry exploration in other glaciation regions.

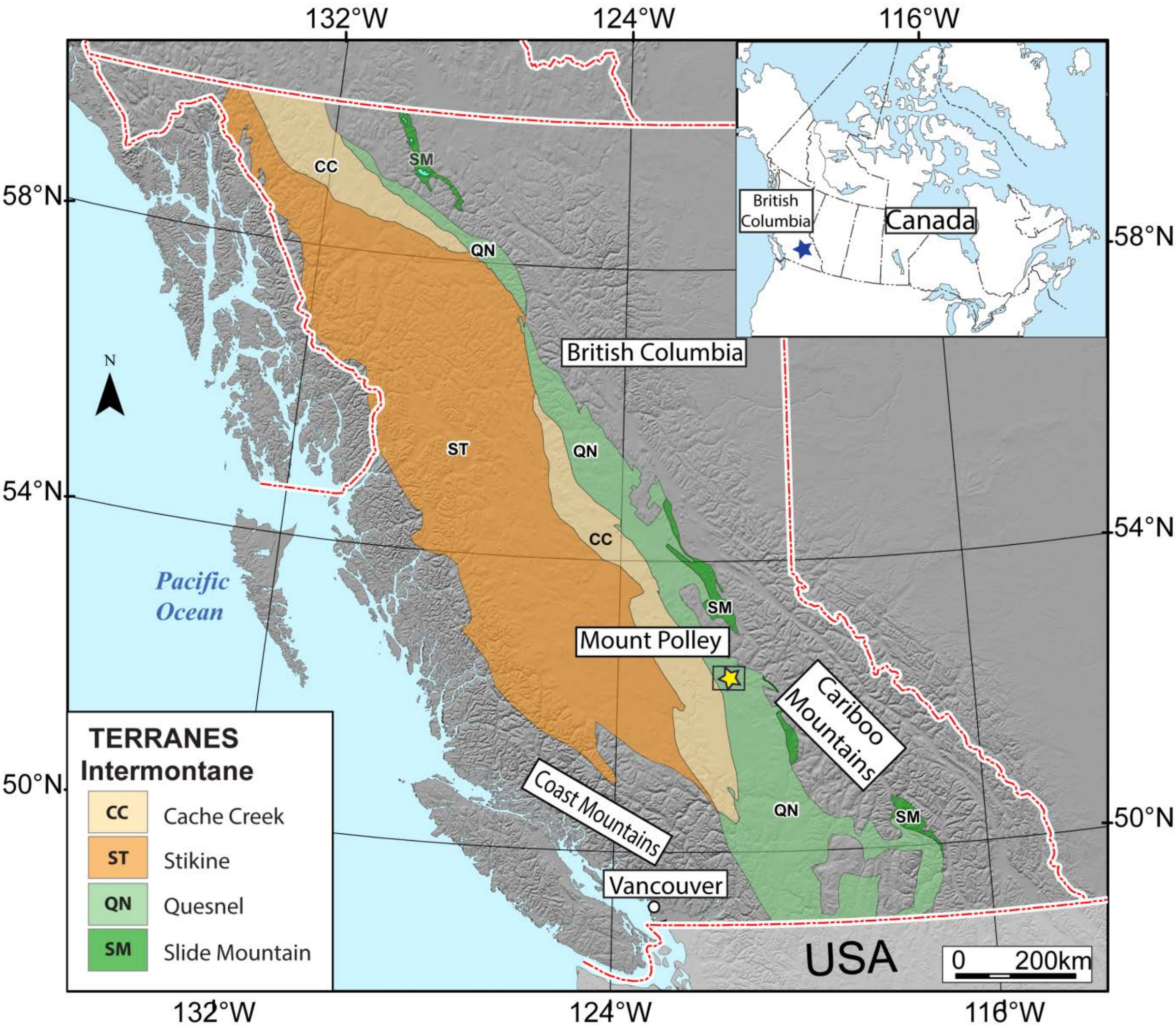

Figure 1. Location of the Mount Polley study area, modified after Colpron & Nelson (2011).

Setting

Bedrock and deposit geology

The Mount Polley study area lies within Quesnel terrane, an accreted belt represented primarily by Triassic mafic volcanic, volcaniclastic and sedimentary rocks of the Nicola Group (Figure 2) (Logan & Mihalynuk 2005). Also associated with Quesnel terrane are the syenitic to monzodioritic rocks of the late Triassic to early Jurassic Mount Polley Intrusive Complex (Logan et al. 2007). The oldest rocks are Permian to Triassic marine sedimentary and volcanic rocks of the Cache Creek terrane, a subduction accretionary complex, in the southwest part of the study area (Logan et al. 2007; Rees 2013). The youngest rocks in the area are Tertiary basaltic and calc-alkaline volcanic rocks of the Chilcotin and Kamloops groups, respectively (Logan et al. 2007).

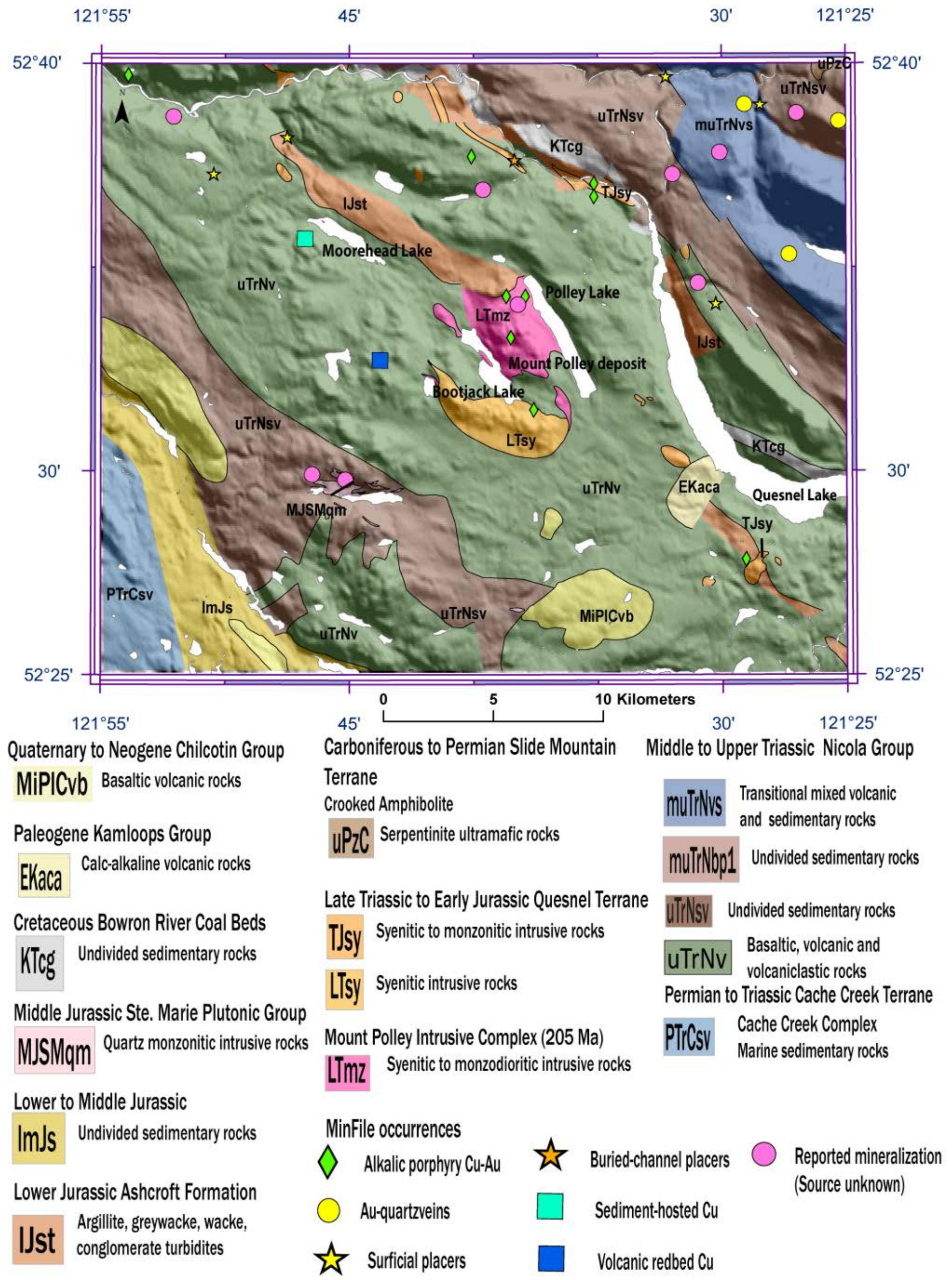

Figure 2. Bedrock geology of the Mount Polley study region including reported MinFile occurrences, modified after Logan et al. (2007).

The Mount Polley Intrusive Complex which hosts the Mount Polley deposit is a 5.5 km by 4 km body, consisting of a central potassic core, surrounded by sodic-potassic alteration zone with an outer propylitic alteration rim (Figure 3) (Fraser *et al.* 1993, 1995; Fraser 1994; Tosdal *et al.* 2008).The Cu-Au mineralization within the central potassic core is vein/fracture controlled. It is disseminated in igneous bodies and within the intrusion and hydrothermal breccias (Fraser 1994; Rees 2013). The Bell, Springer and Cariboo pits are hosted within this zone. The sodic-potassic zone (hosting Wight pit) is characterized by breccia-hosted, coarse grained, Cu-Fe sulphides (primarily chalcopyrite, pyrite and bornite) and alteration minerals andradite garnet and epidote (Rees 2013; Rees *et al.* 2014). The propylitic alteration rim is mapped in the south and southeastern portion of the Mount Polley Intrusive Complex. The Southeast and Pond pits are hosted within this zone. Mineralization in the propylitic rim is concentrated within sulphides and the alteration mineral of interest include epidote (Rees 2013). The main ore sulphides at Mount Polley are chalcopyrite, pyrite and minor quantities of bornite (Rees 2013). Native Au is present as micron-scale inclusions within chalcopyrite and pyrite (Rees 2013).

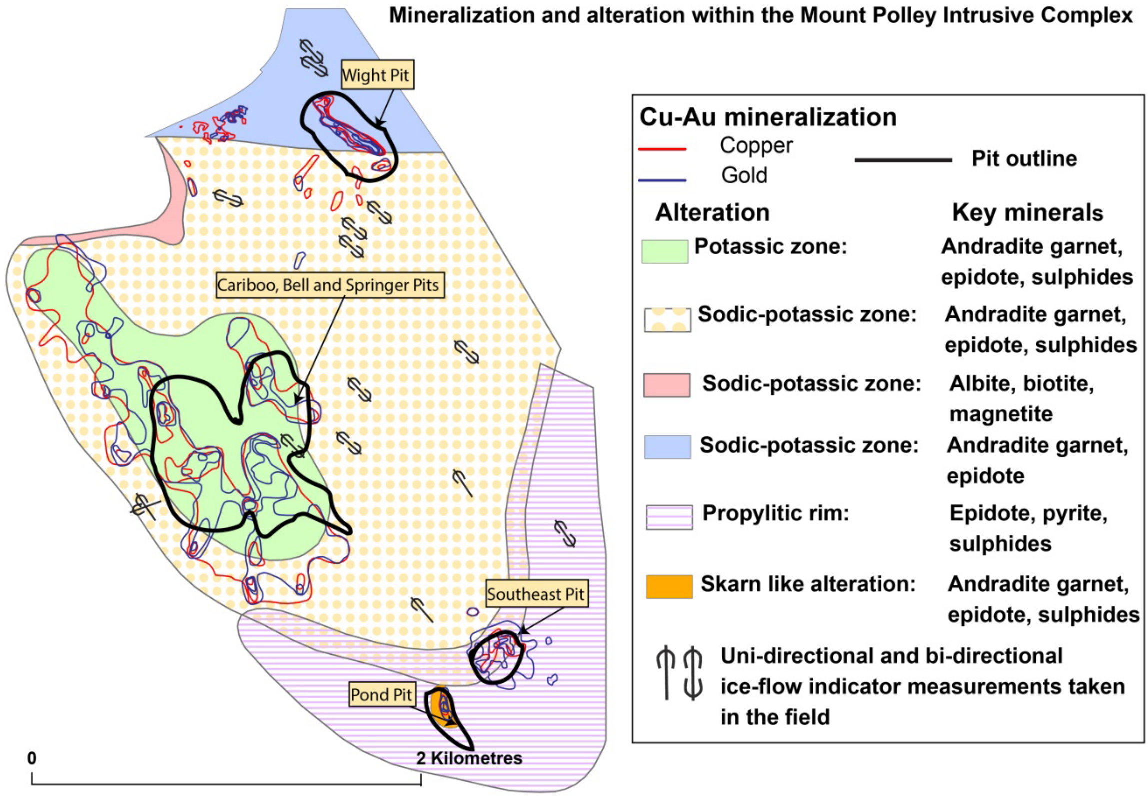

Figure 3. Key minerals present within the Mount Polley Intrusive Complex, modified after Hashmi et al. (in press).

Glacial geology

British Columbia has undergone numerous glaciations during the Quaternary period and the last glacial event, referred to as the Fraser Glaciation, began at about 29 ^{14}C ka BP (radiocarbon years before present) (Ryder *et al.* 1991). During Fraser Glaciation, the Cordilleran Ice Sheet extended from Yukon and Alaska across the region into northern Washington (Clague & Ward 2011). At the onset of the Fraser Glaciation, the Coast and Cariboo Mountains served as ice accumulation centres. Valley glaciers from the Cariboo Mountains developed into piedmont glaciers and advanced over the Interior Plateau in a general westward to southwestward direction (Tipper 1971; Plouffe *et al.* 2011*a*, *b*, c*)*. At the maximum extent of glaciation between 14.5 to 14 ^{14}C ka BP (Ryder *et al.* 1991), glaciers flowing from the Coast and Cariboo Mountains coalesced over south-central British Columbia. As a result, ice flow in the Mount Polley study area was deflected to the northwest (Tipper 1971; Fulton 1991).

Methodology

Ice-flow measurements and sample collection

Ice-flow movement reconstruction is crucial to interpreting till composition and locating the source of buried mineralization (DiLabio & Coker 1989; McMartin & Paulen 2009). Orientation of small-scale ice-flow indicators were measured at bedrock outcrops using a Brunton compass. The data set presented here includes bi-directional striations and grooves and uni-directional rat-tails and roches moutonnée.

Eighty six basal till samples (1-4 m in depth) were collected from exposures along road cuts up-ice, overlying and down-ice from the Mount Polley deposit with the objective of defining the glacial dispersal from Mount Polley. At each site, a 2 kg and 10 kg sample were collected for geochemical analysis and indicator mineral recovery, respectively, following procedures recommended by McClenaghan *et al.* (2013) and Plouffe *et al.* (2013) (Figure 4).

Sample processing and analytical methods

The clay (< 2 µm) and silt plus clay-sized (< 63 µm) fractions of the 2 kg till samples were separated (Figure 4) following procedures outlined in Girard *et al.* (2004) and Spirito *et al.* (2011). Geochemical analyses were completed on the clay- and silt plus clay-sized fractions, at ACME Analytical Laboratories, Vancouver, British Columbia. The 10 kg till samples were processed to recover indicator minerals at Overburden Drilling Management Limited, Ottawa (Figure 4), following protocols used by the Geological Survey of Canada (McClenaghan *et al.* 2013; Plouffe *et al.* 2013). Indicator mineral results are reported as either grain counts (normalized to a 10 kg weight of the < 2 mm bulk fraction processed on the shaking table) or as percent observed.

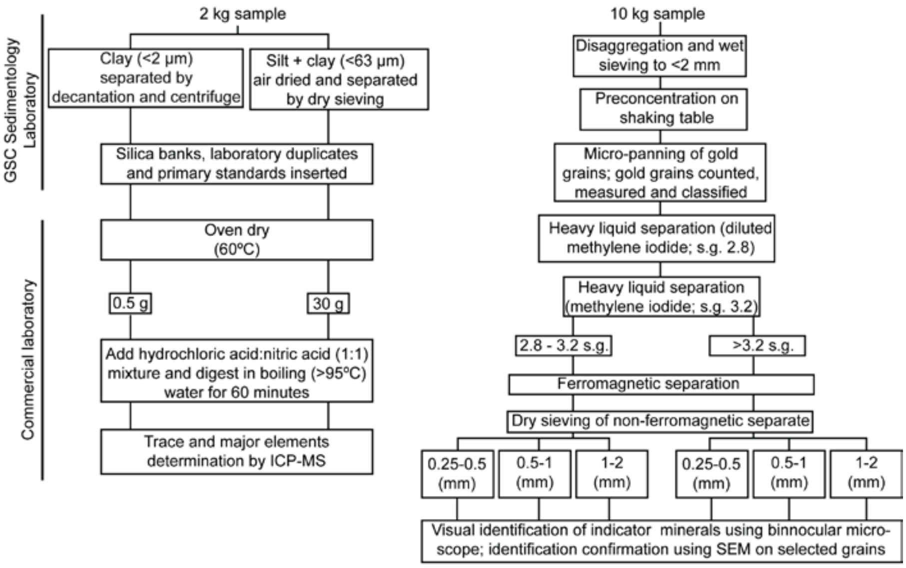

Figure 4. Sample processing, geochemical analysis and indicator mineral separation procedures conducted on the till samples (Hashmi et al. in press).

Results

Ice flow

Two well-defined ice-flow movements have been established in the Mount Polley region (Hashmi *et al.* 2014). The chronology established from the ice-flow events suggests that there was an earlier west-southwestward movement (averaging 265°) derived from the Cariboo Mountains, which was followed later by a northwestward flow (averaging 315°) which occurred at glacial maximum when glaciers from the Coast and Cariboo mountains coalesced over the Interior Plateau.

Till geochemistry

Cumulative probability plots were generated to determine elemental threshold, i.e. value above which element content is determined as anomalous (Hashmi et al. in press). Threshold values were determined based on the “inflection points” or breaks in slope resulting in the division of population densities (Reimann *et al.* 2005). The proportional dot plots were created in ArcGIS (10.1) to reflect the spatial distribution in element and mineral data. Results for both the till geochemistry and mineralogy reflect a decrease in element content with an increase in distance to the northwest, similar to the glacial dispersal model described by Miller (1984).

Copper content (threshold determined as 380 ppm) in the < 2 µm size fraction of till, ranges from 108 to 1548 ppm (Figure 5). Anomalous Cu contents are observed in samples overlying the Mount Polley Intrusive Complex, extending to 2.6 km down-ice (northwest) from mineralization. The highest Cu content of 1548 ppm is observed approximately 840 m down-ice.

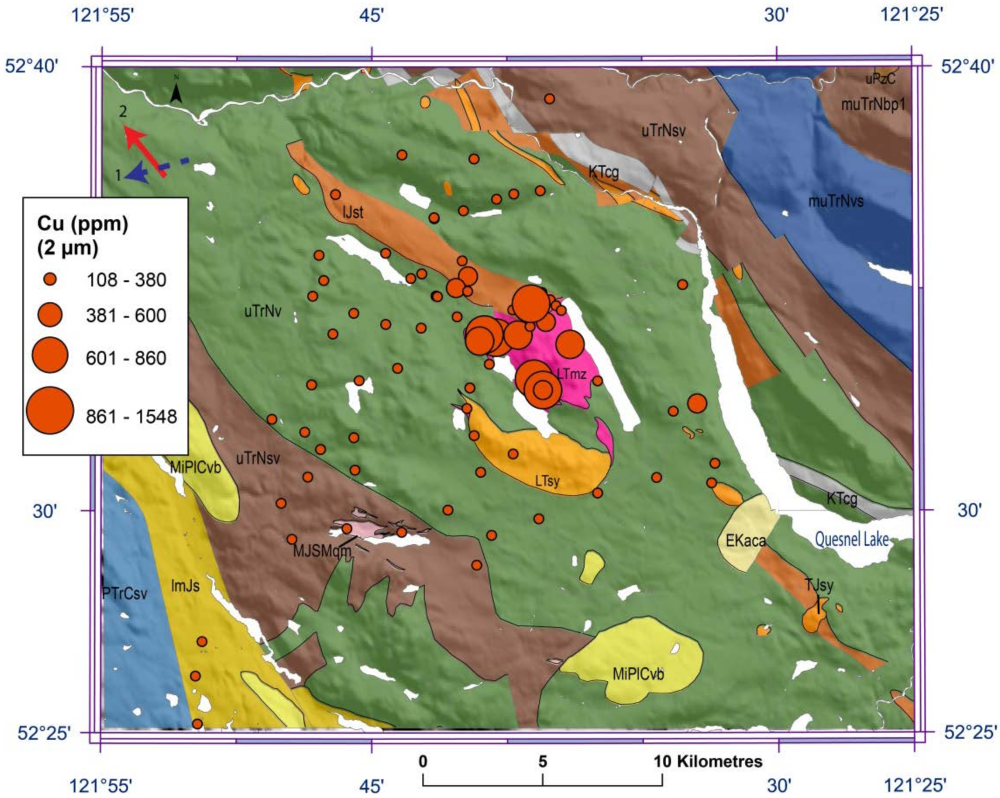

Figure 5. Proportional dot plot for Cu.

Gold contents (threshold determined as 15 ppb) in the < 63 µm fraction of till range from 0.4 to 90.2 ppb (Figure 6). The highest Au content (90.3 ppb) is observed overlying the deposit. Gold content in samples immediately down-ice (northwest) from the deposit range from 5.3 to 41 ppb and decreasing to 20.4 ppb, approximately 8.5 km northwest of the pluton.

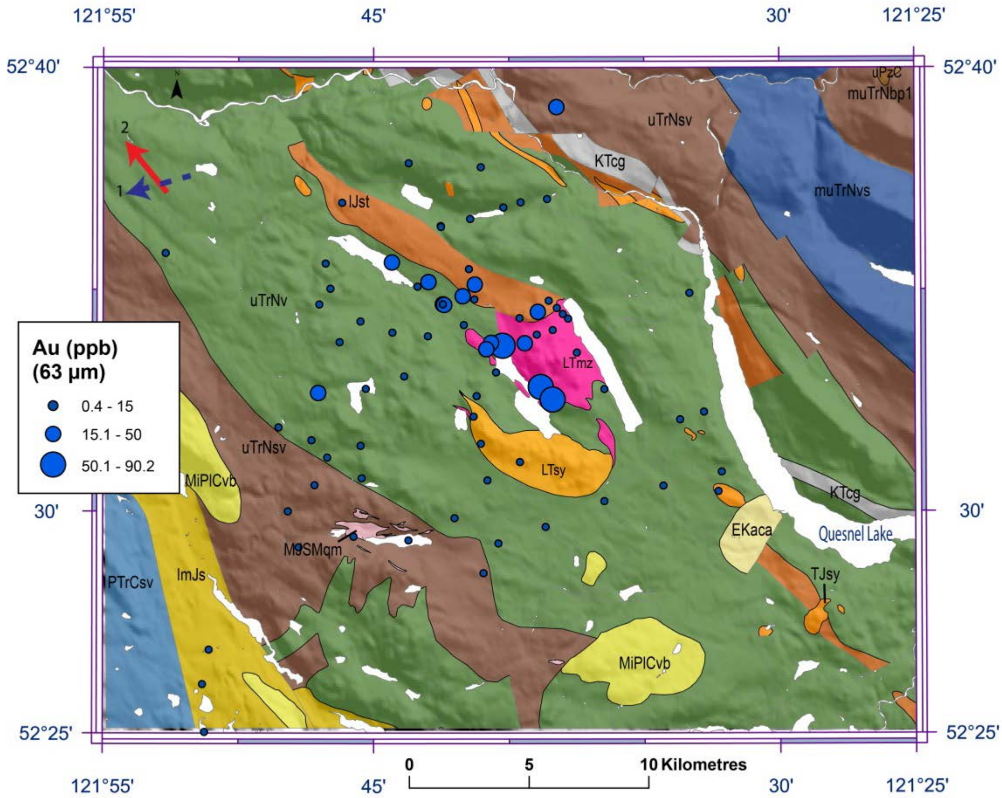

Figure 6. Proportional dot plot for Au.

Till mineralogy

Porphyry indicator minerals (PIMs) presented in this paper are: 1) high density (> 3.2 s.g.) minerals, 2) strongly to somewhat resistant to physical and chemical weathering, and 3) associated with, and characteristic of porphyry deposits (Averill 2011; McClenaghan 2011). We have identified several potential Cu-Au PIMs associated with the mineralization (chalcopyrite and gold grains) or the alteration zones (andradite garnet and epidote).

Normalized chalcopyrite grains (recovered in the 0.25-0.5 mm size fraction; > 3.2 s.g.) (Figure 7) is recovered in 21 till samples, ranging from 1 to 98 grains normalized to 10 kg of bulk sediment (<2 mm). Background chalcopyrite content is estimated to be 0 to 1 grains per sample. Of the 10 anomalous samples, four overlie the deposit. The highest grain count (98 grains) was observed approximately 840 m to the northwest. Chalcopyrite dispersal extends 10 km to the northwest of Mount Polley.

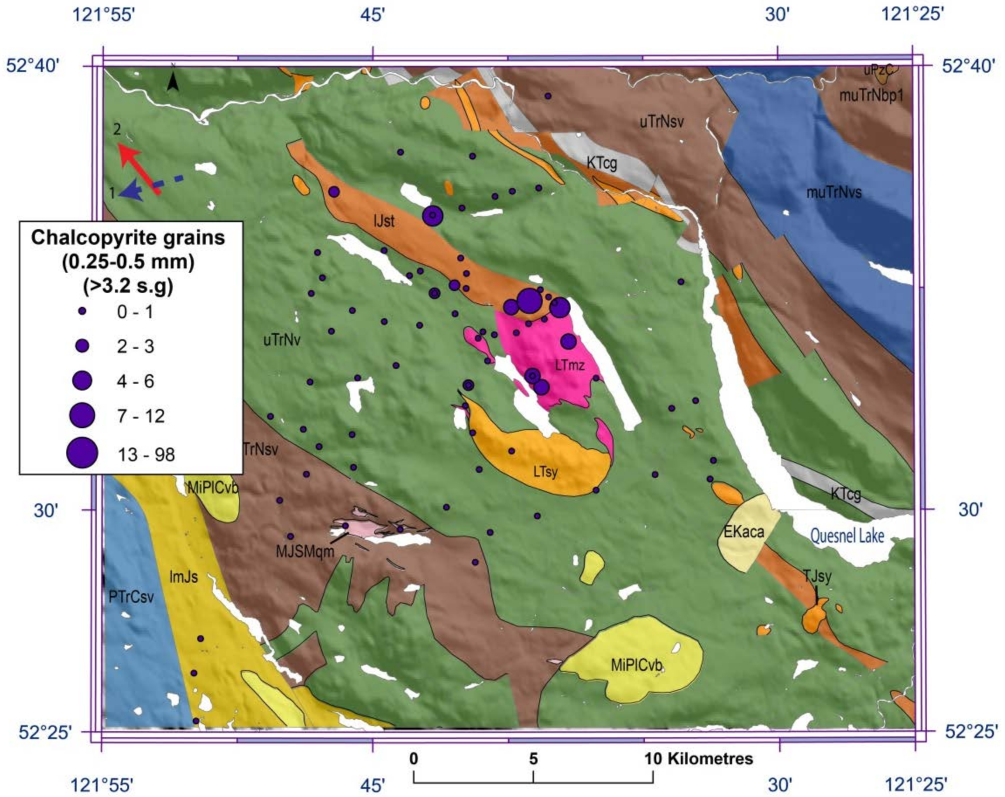

Figure 7. Proportional dot plot for chalcopyrite. Grain counts are normalized to 10 kg of bulk sediment (<2 mm).

Normalized gold grain counts (recovered in the 0.015-0.425 mm size fraction; shaking table concentrates) (Figure 8) ranged between 0 to 105 grains. The gold grain counts threshold in the Mount Polley region is estimated as >15. With two exceptions, all till samples containing >15 gold grains were taken down-ice or overlying the Mount Polley deposit. Anomalous gold grain counts in till extends as far as 5.2 km down-ice (northwest) of the Mount Polley deposit.

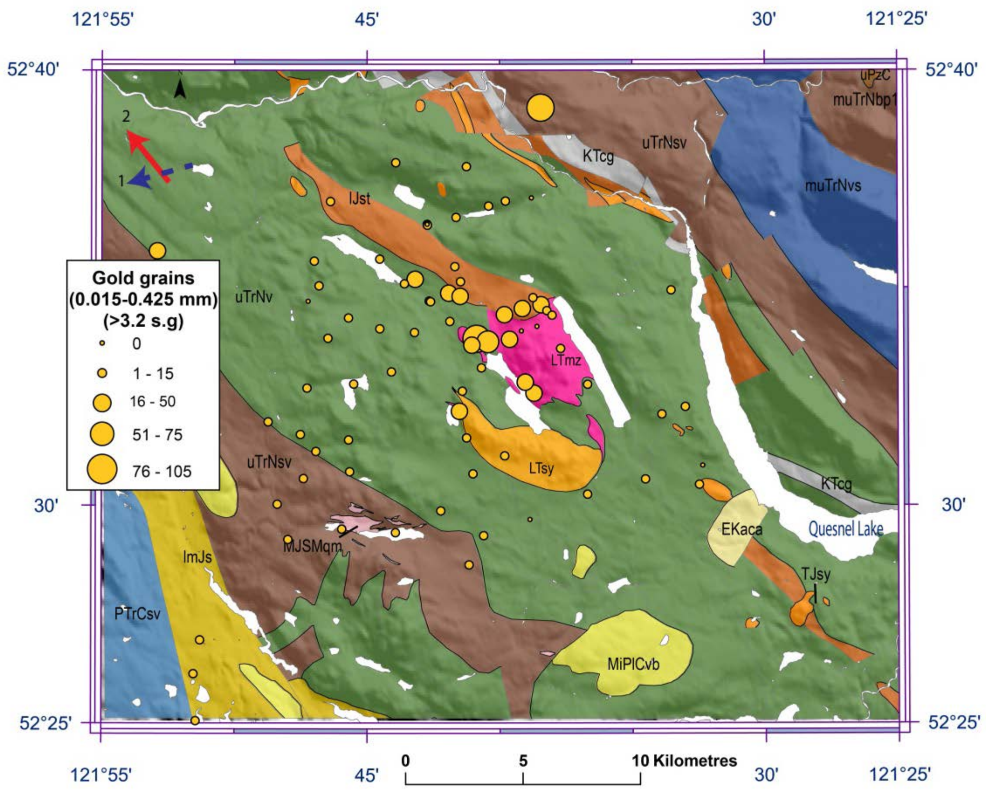

Figure 8. Proportional dot plot for gold grains. Grain counts are normalized to 10 kg of bulk sediment (<2 mm).

Andradite garnet (recovered in the 0.25-0.50 mm size fraction; > 3.2 s.g.) is recovered from 63 of the 87 till samples (Figure 9). Normalized (10 kg) andradite grain counts range from 1 to approximately 78,000 grains with samples containing anomalous amount of andradite (i.e. > 290 grains) located overlying and along the west margin of the Mount Polley Intrusive Complex. Andradite dispersal in till extends 2.6 km to the northwest.

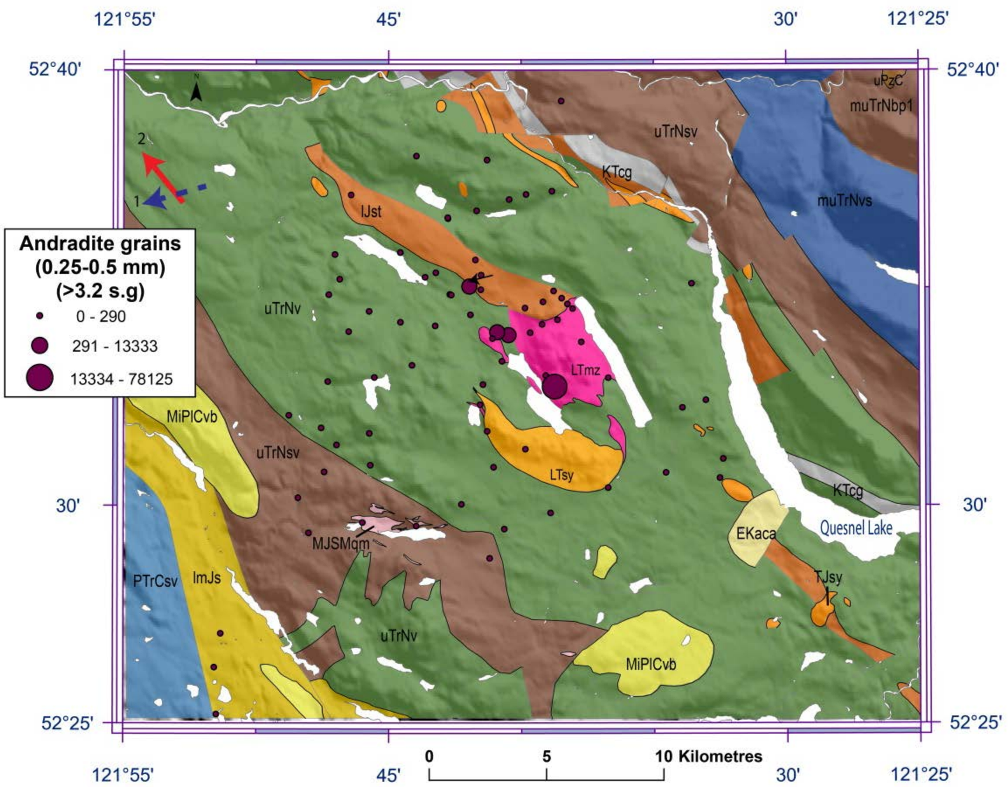

Figure 9. Proportional dot plot for andradite garnet. Andradite counts are normalized to 10 kg of bulk sediment (<2mm).

Epidote (recovered in the 0.25-0.5 mm size fraction; >3.2 s.g.) (Figure 10) content ranged between 0-90%. Samples with more than 15% epidote (i.e. threshold value) were taken overlying, southwest and northwest of the Mount Polley Intrusive Complex, (i.e. down-ice for the two phases of ice flow). The highest epidote value (90%) was reported for a sample taken approximately 2 km southwest of the Mount Polley deposit. Anomalous epidote content is observed in sample up to 2.6 km down-ice both in the northwest and southwest directions.

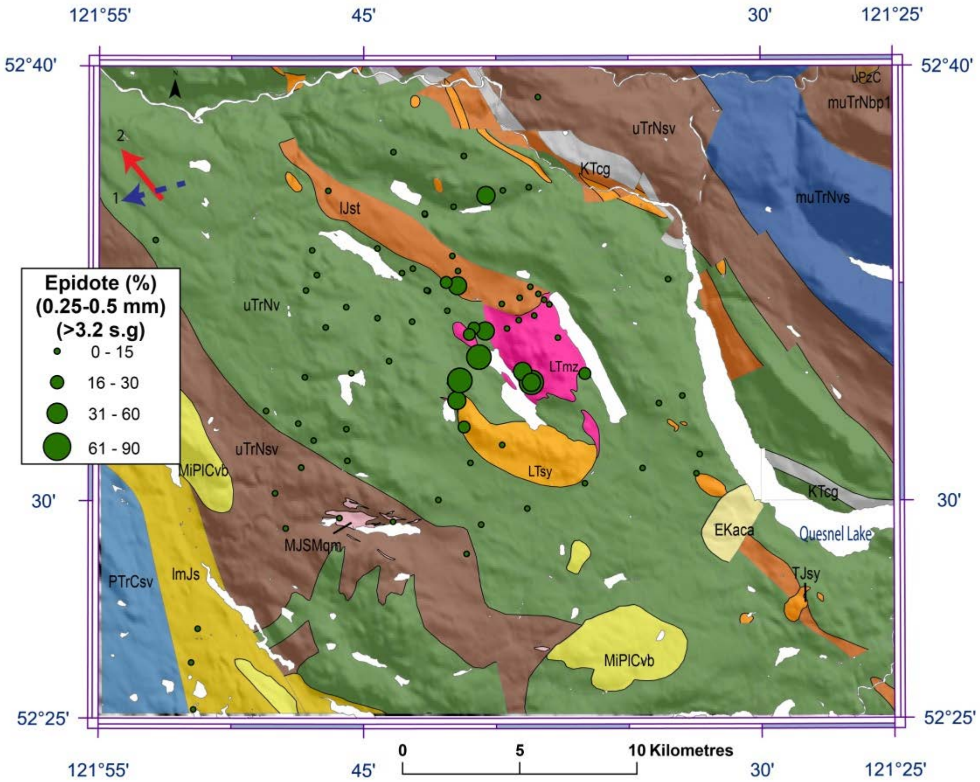

Figure 10. Proportional dot plot for epidote.

Discussion

The two distinct ice-flow movements documented at Mount Polley as well as the mineralogical dispersal suggest that the mineralization eroded and transported by the first ice-flow phase was in part modified, transported and deposited by the second ice-flow phase. The glacial dispersal pattern documented here is a palimpsest dispersal train (e.g. Parent *et al.* 1996; Plouffe *et al.*, 2011c). The maximum northwestward dispersal of the geochemical and mineralogical signal from Mount Polley extend up to 10 km, whereas the anomalous mineralogical content extends up to 2.6 km, both to the northwest and southwest. The southwestward dispersal documented by the till mineralogy show that processing for PIMs is advantageous and complements the till geochemistry. Evidence of southwestward glacial dispersal associated with the first phase of ice movement is only detected in till mineralogy (gold grains and epidote) but not till geochemistry.

Even though anomalous Au distribution extends further than gold grains, samples containing anomalous counts of gold grain were recovered from samples containing background values for Au. These results highlight the heterogeneous distribution of gold in sediments as a result of the nugget effect, emphasizing that combining till geochemistry and mineralogy increases the possibility of intercepting gold dispersal in till.

Using alteration minerals may also prove useful in detecting buried porphyry deposits where only the alteration zones and not the Cu-Au mineralization was exposed to glacial erosion. In this scenario, till transported down-ice from the deposit would only be enriched in elements and minerals derived from the alteration zones.

Conclusions

The use of till geochemistry and mineralogy is well suited to detect Cu-Au porphyry mineralization in glaciated terrain. Gaining a complete understanding of the glacial history is crucial for interpreting the element and mineral distribution in till down-ice of the Mount Polley deposit. Ore elements Cu and Au were detected up to 8.5 km to the northwest of the deposit. Northwestward dispersal of ore minerals chalcopyrite and gold grains is up to 10 km and 5.2 km, respectively, whereas alteration minerals andradite garnet and epidote are dispersed in till 2.6 km to the northwest. The results from this study establish gold grains, chalcopyrite, andradite garnet and epidote as suitable Cu-Au PIMs.

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