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doi:10.4095/287929

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Recommended citation:
Plouffe, A., Anderson, R.G., and Dunn, C.E., 2011. Till composition and biogeochemistry near a porphyry Cu-Mo deposit: Gibraltar Mine, British Columbia; Geological Survey of Canada, Open File 6755, 1 CD-ROM. doi:10.4095/287929

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Abstract

During the 2008 field season, eleven till, six lodgepole pine and seven Engelmann spruce outer bark samples were collected near a porphyry Cu-Mo deposit (Gibraltar Mine) in central British Columbia. The purpose of this survey is to test the effectiveness of these sampling medium at detecting mineralization in regions where bedrock mineralization is covered with glacial sediments. Various fractions of the till matrix and bark samples were submitted for geochemical analyses. Our results demonstrate that minor elements (Au, Ag, Ba, Cu, Mo, Te, Zn) and one major oxide (Al_2O_3) are enriched to various degree in till down-ice from the Gibraltar ore bodies compared to background concentrations reported from the Bonaparte Lake map area south of the mine. Similarly, Cu and Mo are more enriched in lodgepole pine and Engelmann spruce outer bark near Gibraltar compared to the Bonaparte survey. These results attest to the utility of till and tree outer bark geochemical surveys as means to vector towards porphyry mineralization such as that contained in the Gibraltar ore bodies.

Introduction

Mineral exploration of the mineralized basement rocks in the Interior Plateau of British Columbia is challenging because of the scarcity of outcrop, poor access, dense forests, and the glacial sediments and young basalt cover. Maps and interpretations of aeromagnetic and gravity geophysical data provide some guidance, but, in the survey area, the ore-bearing host rocks may not generate a distinctive geophysical response or may be masked by that of cover rocks. In this setting, till and biogeochemical surveys could be utilized as important exploration tools.

To test the utility of the outer bark tree geochemistry, and the geochemical and mineralogical composition of till down-ice and up-ice from an economic porphyry deposit, an orientation survey was completed at the Gibraltar Mine located in central British Columbia, approximately 65 km north of Williams Lake (Fig. 1). Gibraltar Mine is an open pit porphyry Cu-Mo deposit which has been operating since 1972, interrupted from 1998 to 2004 because of low metal prices (Liles, 2005).

The chemical analysis of tree tissues can provide insight to the composition of rocks concealed by overburden. The roots of trees can penetrate the substrate and extract metals from overburden, groundwater and locally bedrock. These metals are translocated through the roots into the aerial tissues where they are sequestered in differing proportions according to tolerances to metals and(or) the metabolic requirements of an individual species of tree (Dunn, 2001, 2007 and references therein).

During the 2008 field season, eleven till, and for a small orientation assessment outer bark was collected from just six lodgepole pine and seven Engelmann spruce samples in the vicinity of the mine. Till and plant tissue samples were submitted for geochemical analyses. In addition, till samples were processed for a study of their heavy minerals content. This report contains all analytical results and interpretation of the data set.

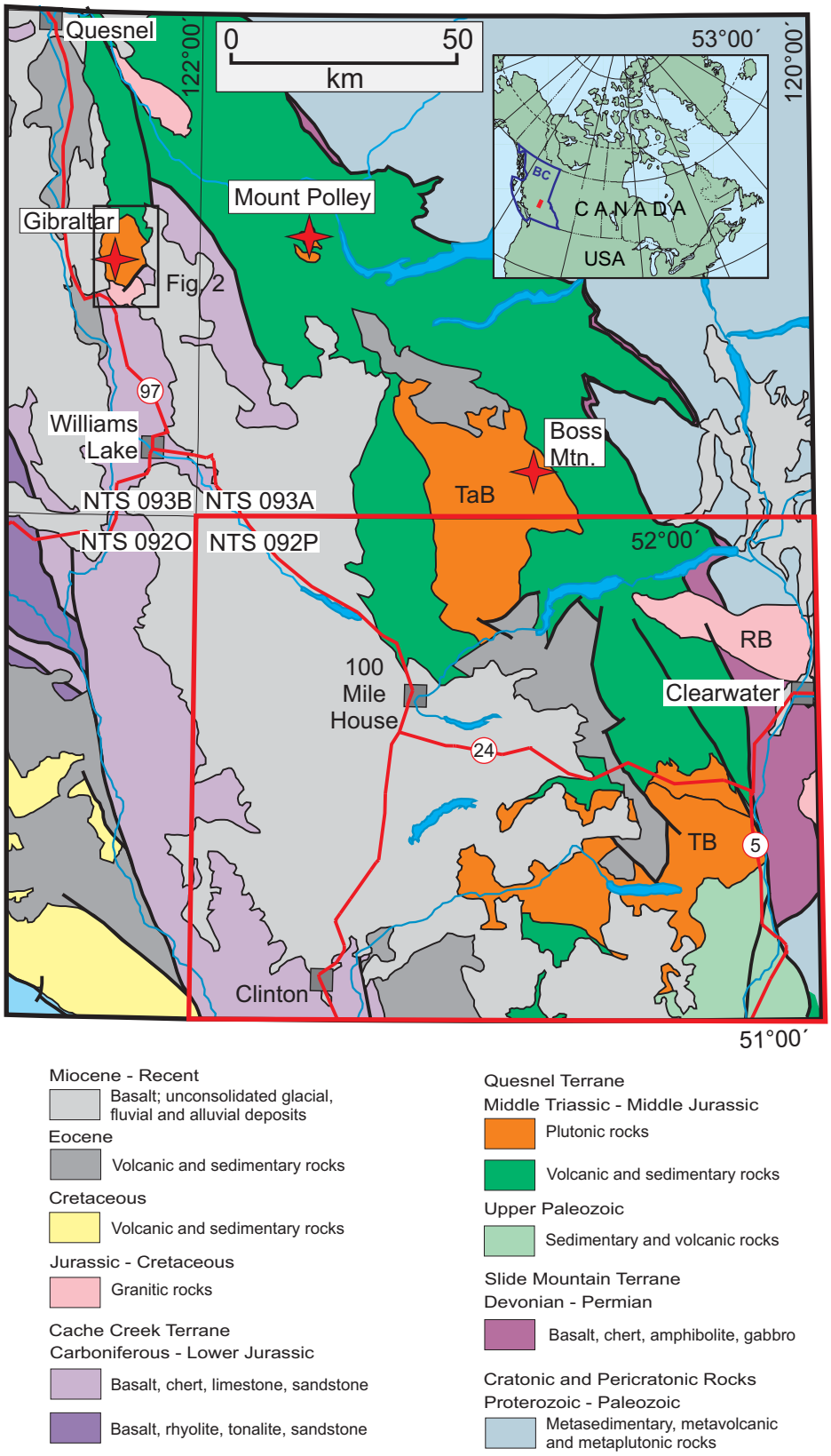

Figure 1. Generalized regional bedrock geology of a sector of central British Columbia . Red stars denote active mines. The outline of Figure 2 is shown. Inset map shows location in British Columbia (BC) and Canada. Extent of Bonaparte Lake map area (NTS 092P) shown with a red outline. TB – Thuya Batholith; TaB – Takomkane Batholith; RB – Raft Batholith.

Geological setting

Gibraltar Mine lies near the top of Granite Mountain, with a summit at an elevation of 1390 m above sea level (asl), and within the flat to rolling upland of the Fraser Plateau at an average elevation of 1200 to 1500 m asl (Fig. 2). Much of the following geological description derives from previous studies of Gibraltar (Sutherland Brown, 1966; Drummond et al., 1973, 1976; Sutherland Brown, 1974; Bysouth et al., 1995; Ash et al., 1999a, b; Ash and Riveros, 2001).

Gibraltar Mine

The mineralization at Gibraltar is hosted in the deformed, metamorphosed and altered quartz diorite to tonalite of the Late Triassic Granite Mountain Batholith (215 ± 0.8 Ma, Ash and Riveros, 2001). It is in fault contact with surrounding units including Late Paleozoic oceanic rocks of the Cache Creek Terrane to the west and east, early to middle Mesozoic volcanic and sedimentary rocks of the Nicola Group to the north, quartz monzonite of the Ste. Marie Plutonic suite to the northeast, and the Sheridan stock (leucocratic quartz diorite) to the south (Fig. 2). The Sheridan stock was dated at 108.1 ± 0.6 Ma (Ash and Riveros, 2001). Contacts between the Granite Mountain Batholith and surrounding units are commonly obscured by the cover of Eocene-Miocene volcanic rocks and Quaternary glacial sediments.

The mine includes four pits: Gibraltar West, Gibraltar East, Granite Lake and Pollyanna (bold type in Fig. 2). The mineralization occurs in a metamorphosed (greenschist-grade) and variably altered, veined and deformed tonalite termed the “mine phase tonalite” (Bysouth et al., 1995). Primary minerals except quartz have been locally replaced by alteration assemblages including plagioclase, quartz, epidote, zoisite, chlorite, sericite with traces amount of titanite, zircon, apatite, iron oxides, carbonate and sulphides (Ash and Riveros, 2001). Sheeted veins (5 to 25 cm wide), characteristic of the mine phase tonalite, are composed of quartz and sulphides (pyrite, molybdenite and minor amounts of pyrrhotite and chalcopyrite) with sericitic selvedges (Drummond et al., 1973, 1976; Ash and Riveros, 2001). Sheeted veinlets, 1 to 3 mm wide, are found in association with the veins and are composed of smoky-gray quartz, chlorite, epidote, pyrite, chalcopyrite,

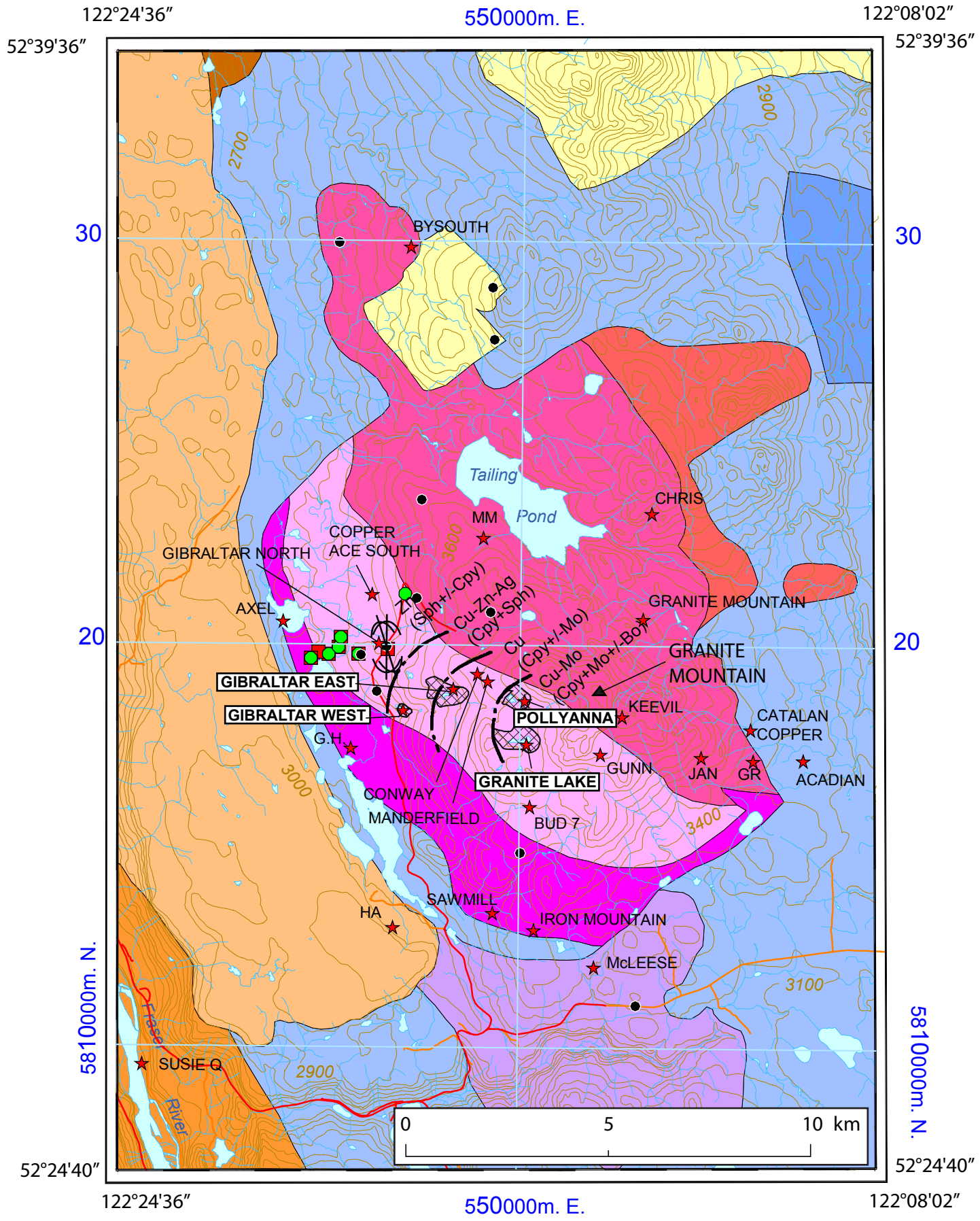

Figure 2. (A) Detailed bedrock geology map of the Gibraltar Mine area (modified from Logan et al., 2010). Mineral occurrences from MINFILE (2010). Metal and mineral zonations from Bysouth et al. (1995).

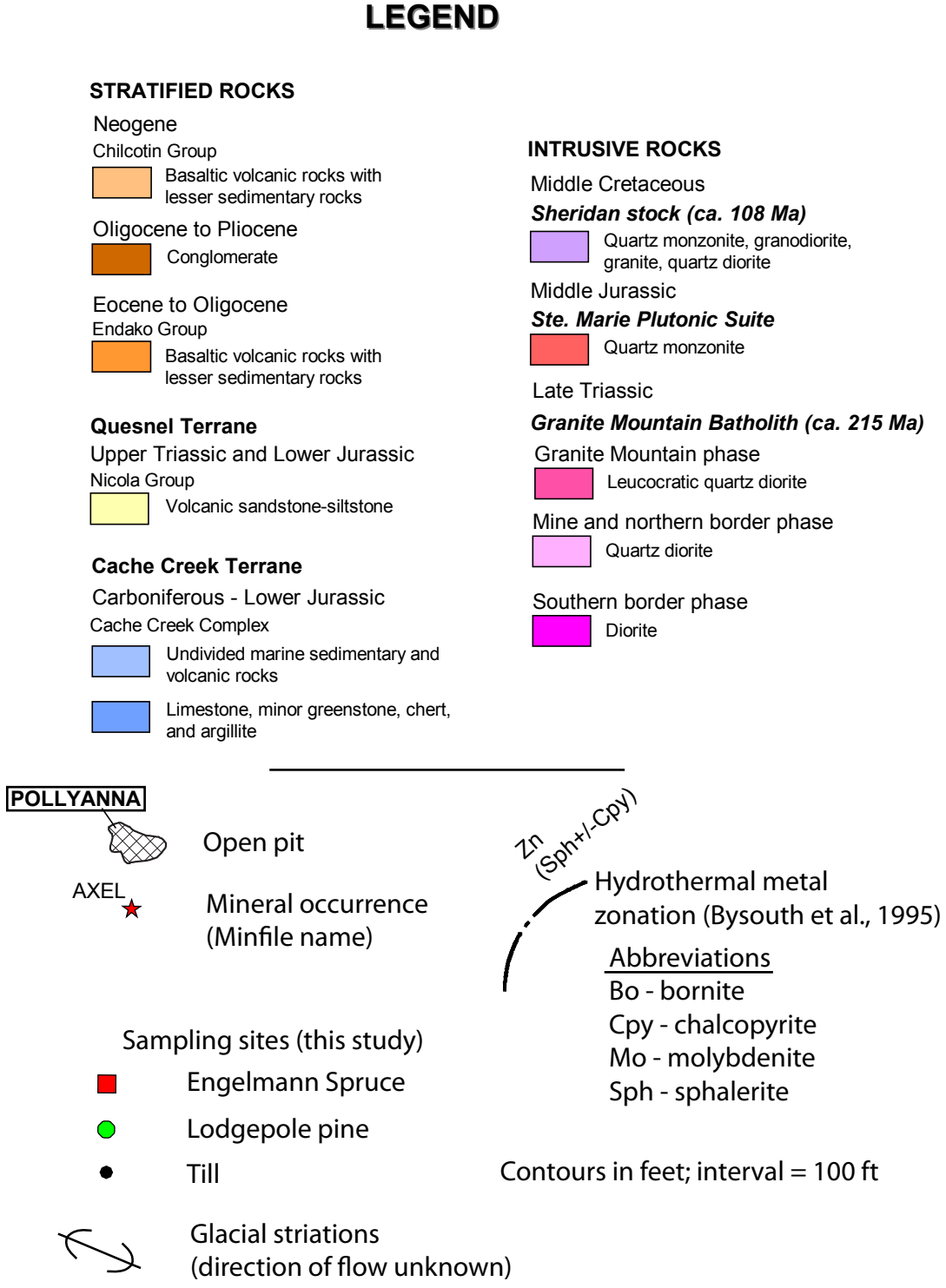

Figure 2. (B) Legend for bedrock geology map.

sericite and traces of Fe-oxides. A younger generation of veining contains quartz, chlorite, carbonate and abundant Cu-sulphide minerals but no molybdenite. Bysouth et al. (1995) have defined a sulphide zoning at Gibraltar consisting of a Cu-Mo core (chalcopyrite, molybdenite, ±bornite) changing outwards to a Cu zone (chalcopyrite ± molybdenite), a Cu-Zn-Ag zone (chalcopyrite, sphalerite) and a Zn zone (sphalerite ± chalcopyrite) within 6 km to the west of Pollyanna and Granite Lake pits (Fig. 2).

In assessing the till composition near a known mineralized zone it is crucial to establish that the mineralization was exposed to glacial erosion. If not, the mineralization will not be reflected in the till composition. According to the profiles presented in Bysouth et al. (1995) and Ash et al. (1999b), Cu grades vary with depth in the four pits and are more extensive at depth than in subcrop. Grades in excess of 0.1 % Cu (cut-off grade at the mine: 0.25 % Cu) were exposed to glacial erosion in subcrops at Pollyanna and Granite Lake and to a limited extent at Gibraltar West. At Gibraltar East and at the extension of Gibraltar West, grades >0.1% Cu did not reach subcrop. These profiles reveal that only the mineralized zones at Pollyanna and Granite Lake and to a small extent at Gibraltar West were exposed to glacial erosion.

In addition to the mine, 21 mineral occurrences have been reported in the region surrounding the Granite Mountain Batholith (MINFILE, 2010) (Fig. 2). They include one surficial placer deposit (Susie Q Minfile No 093B 067; MINFILE, 2010) and 20 showings classified as Cu +/- Mo +/- Au porphyry style mineralization.

Surficial geology and ice-flow history

The first regional surficial geology map of the Quesnel area (National Topographic System 093B), including the Gibraltar Mine area, was published in 1971 (Tipper, 1971c). The map shows the dominant surficial geology elements including distribution of glaciolacustrine sediments along with glacial landforms (e.g. eskers, moraines, drumlins). Based on the interpretation of glacial landforms, Tipper (1971a, b) described the glacial history of a large sector of central British Columbia. According to his reconstruction of the Late Wisconsinan Fraser Glaciation, glaciers first formed in the Coast and Cariboo mountains and advanced over the Interior Plateau. Following a recent surficial geology and regional till sampling project southeast of Gibraltar Mine within the Bonaparte Lake

map area (NTS 092P), Plouffe et al. (2009a, b, in press) demonstrated that the original ice flow from the Cariboo Mountains advanced westerly at least as far as the Lac la Hache region (Fig. 3). The extent to the north and west of glaciers from the Cariboo Mountains at the onset of the last glaciation is still undetermined and therefore, it is unknown if the Gibraltar Mine region was first covered by glaciers derived from the Cariboo Mountains at the onset of the last glaciation. Following the coalescence of glaciers from the Cariboo and Coast mountains, an ice divide oriented approximately east-west formed in the vicinity of the 52nd parallel, from which glaciers were flowing north and south. During that event, ice was flowing north-northwest over Gibraltar Mine.

Methods

Details of the field and laboratory methods for till sampling are presented in Plouffe et al. (2009a, 2010). In summary, eleven till samples were collected during the 2008 field season during a one day period by two field crews. Samples were collected on road side sections at a minimum depth of 1 metre below the depth of most intense soil weathering and oxidation. Sample site locations were recorded with a global positioning system (GPS). Sample locations and sampling depth are provided in Appendix 1. Field notes were recorded digitally at every sample site. Special effort was made to collect samples immediately down-ice (NNW) and up-ice from the mine to evaluate elemental enrichment in till derived from the mineralization compared to background concentrations. Glacial striations were measured on bedrock at a single site (Fig. 4).

The clay- (<0.002 mm) and silt and clay-sized (<0.063 mm) fractions and heavy mineral concentrates (HMC) (<0.250 mm; specific gravity >3.2) from the till matrix were submitted for geochemical analyses as summarized in Figure 5. Appendices 2 to 5 contain all geochemical results. Quality assurance and quality controls measures were applied to monitor analytical precision and accuracy. All results are reported in Plouffe et al. (2009a, 2010). Analyses by inductively coupled plasma – mass spectrometry (ICP-MS) and emission spectroscopy (ICP-ES) were completed at Acme Analytical Laboratories Ltd. (AAL) in Vancouver, BC using methods 1F and 4A, respectively. Instrumental neutron activation analyses (INAA) were done at Becquerel Laboratories, Mississauga, Ontario.

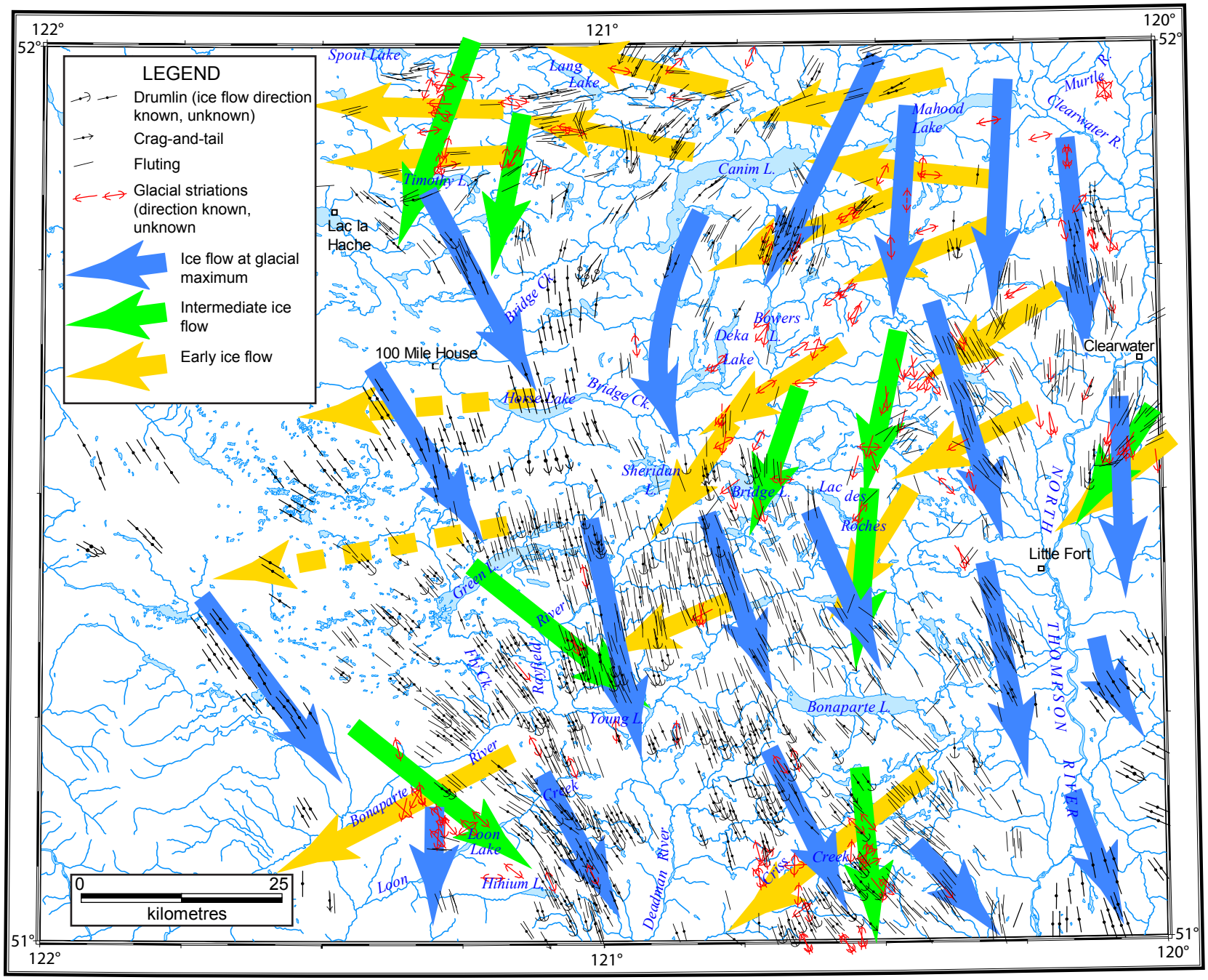

Figure 3. Ice-flow map of the Bonaparte Lake region modified from Plouffe et al. (2010).

As part of the heavy mineral separation procedure, completed at Overburden Drilling Management Ltd. (ODM Ltd., Nepean, ON), the till samples were washed on a shaking table and the pebbles >2 mm were recovered on a sieve. They were classified into four broad categories based on visual estimation: 1) volcanic and sedimentary rocks, 2) granitoids, 3) limestone and carbonates, and 4) others. The estimated percentages of clasts lithologies in till are provided in Appendix 1.

Figure 4. Faint glacial striations visible on a wet quartz diorite bedrock surface near Gibraltar. Striated site shown on Figure 2.

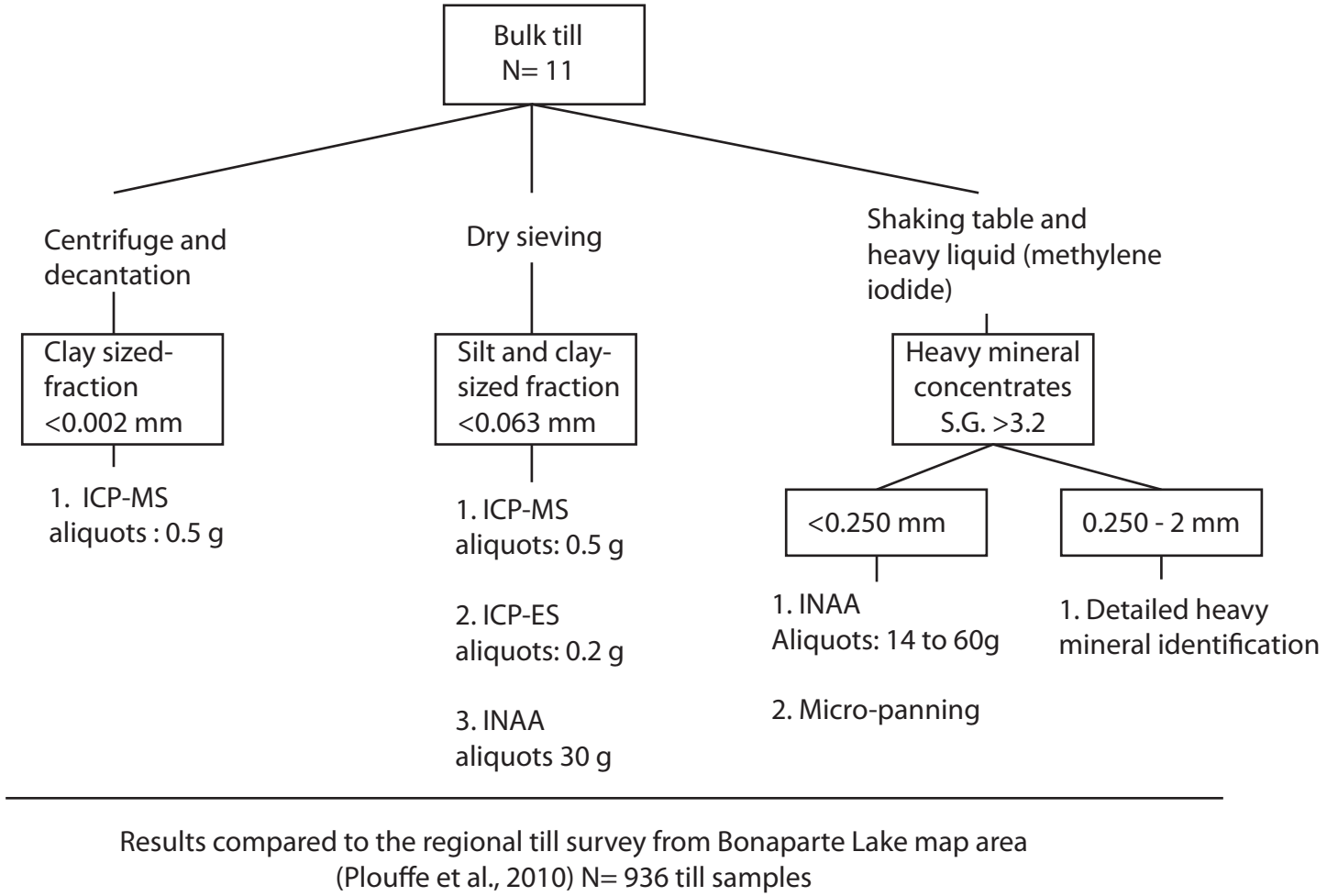

Figure 5. Analytical flow chart for till samples. See text for details. ICP-MS – Inductively coupled plasma mass spectrometry; INAA – Instrumental neutron activation analysis; ICP-ES – Inductively coupled plasma – emission spectroscopy

Identification of the mineralogy of the HMC was completed at ODM Ltd. Mineral identification was done on two separate size fractions. Minerals in the <0.250 mm fraction, the same concentrates submitted to INAA, were identified with a binocular microscope following micro-panning. Such approach allows only a crude evaluation of dominant minerals in the <0.250 mm HMCs. Minerals in the 0.250-2 mm fraction were examined under a binocular microscope and identified by a mineralogist based on physical properties including color, lustre, cleavage, crystal habit and magnetism. The identification of a number of mineral grains was verified with a scanning electron microscope.

Details of the field and laboratory methods for the biogeochemistry samples are provided in Dunn and Anderson (in press). In summary, lodgepole pine and Engelmann spruce outer bark samples were collected during one day of the 2008 field season by a two person crew near the Gibraltar North and Copper Ace South showings (Fig. 2). Bark and till samples were collected at different times by different crews and are not from identical sites. Samples were collected with a clean paint scraper and placed in paper bags. Sample sites were recorded with a GPS and field notes filled out on a digital field form. Sample locations are provided in Appendix 1 and field data in Appendix 6. Samples were oven-dried at 75°C for 24 hours to remove all moisture then reduced to powder by milling and sent to Acme Laboratories in Vancouver for analysis by their method 1VE2-MS. This involves digesting 0.5 g of the dry tissue in nitric acid, then aqua regia. Analytical determinations were by ICP-MS. Results of geochemical analyses are provided in Appendix 6. Quality assurance and control measures are presented in Dunn and Anderson (in press). The overall quality of the data is considered acceptable with remarkably good precision for many elements, given the low levels present (Dunn and Anderson, in press).

Results

Results gathered in the course of this survey are briefly described including glacial striations, geochemical and biogeochemical results plotted as proportional and coloured dot plots, and till pebble counts depicted as pie diagrams in Appendix 7. Each page in Appendix 7 contains single element geochemical abundances in all media. Till geochemical results are presented by size fraction and analytical method. Outer bark

geochemistry is plotted for each plant species. For till geochemical results, elemental enrichment in till derived from mineralization at Gibraltar are evaluated by comparing samples up-ice (to the SSE) and down-ice (to the NNW) from the mine but also with results obtained as part of a regional survey in the Bonaparte Lake map area located to the south of Gibraltar Mine (Fig.1) (Plouffe et al., 2010, in press) which included a total of 936 samples. Similarly, elemental enrichment in the outer bark samples are compared with the results of the regional plant geochemical survey completed in the Bonaparte Lake map area to the south (N=500 samples) (Dunn and Anderson, in press), which likely represent "background" values. The regional geology near Gibraltar Mine and over the Bonaparte Lake map area is similar (contact between Quesnel and Cache Creek terranes intruded by mid-Triassic to mid-Jurassic plutonic rocks and covered by Eocene-Miocene volcanic and sedimentary rocks; Fig. 1) and consequently, we assume that elemental background concentrations in the surficial environment in both regions are comparable. The bedrock geology including Minfile occurrences in Fig. 2A are depicted on all geochemical plots (Appendix 7) following the same color scheme and point symbol.

Glacial striations

Glacial striations were measured at a single site (Fig. 4). An outcrop of polished diorite located along the access road to the mine reveals striations oriented 345º to due north with no indication of direction of movement. As part of the regional context presented by Tipper (1971a, b), these striations are interpreted to be related to the ice movement to the NNW during the existence of the ice divide south of the mine region. This single site close to the mine indicates that at some point during the last glaciation, debris from the mineralized bedrock was eroded and transported in a NNW direction.

Till pebble lithologies

Percentages of till pebble lithologies are tabulated in Appendix 1 and depicted on a map in Appendix 7. The till pebble lithologies are dominated by granitoid intrusive rocks (80-100 %) which are interpreted to be dominantly derived from the local intrusive rocks: Granite Mountain Batholith and Sheridan stock. The different phases of the intrusive rocks could not be identified in the pebbles given their small size. In the northern-most till samples, near bedrock of the Cache Creek Complex and Nicola Group, the percentage

of sedimentary and volcanic rocks increases to 40-80 %. These results indicate that the pebble size fraction of till near the mine is dominated by intrusive rock types of local provenance.

Clay-sized fraction geochemistry: aqua regia leach

A number of elemental concentrations in the clay-sized fraction of till appear to be good indicators of the mineralization because they show enrichment with respect to samples collected up-ice (SSE) from the mine: Au, Ag, Cu, Mo, Te, and Zn (Appendix 7 and Table 1). Data for Au and Te should be evaluated with caution because the analytical precision for both elements is low: +/- 56% for Au and +/-25% for Te (see Plouffe et al., 2010 for details). All of these elements, except Te, are known to be enriched to various degree in bedrock at and near Gibraltar (see geological setting section above) from which they are interpreted to be derived. Tellurium is likely present in various sulphide phases associated with mineralization. Gold and Ag are enriched mostly at the west end of the mine area. Copper is enriched on the west side, like Au and Ag, but also north of the mine pits, down-ice from the Cu zones identified by Bysouth et al. (1995) (Appendix 7). Likewise, the Mo enrichment on the east side and the Zn enrichment to the west match the metal zoning. For these elements, the maximum concentrations measured at Gibraltar are significantly higher compared to the regional survey to the south within the Bonaparte Lake map area (Table 1). In summary, Gibraltar Mine is well targeted with elevated concentrations of Au, Ag, Cu, Mo, Te, and Zn in the clay-sized fraction of till compared to regional background levels.

Table 1. Maximum elemental concentrations in the clay-sized fraction of till near Gibraltar Mine and percentile equivalent to the regional till survey in the Bonaparte Lake map area (Plouffe et al., 2010).

Element	Unit	Gibraltar max. concentration	Bonaparte percentile equivalent
Au	ppb	134	99th
Ag	ppb	3284	89th
Cu	ppm	2332	99th
Mo	ppm	5.26	93th
Te	ppm	0.48	99th
Zn	ppm	2668	99th

Silt and clay-sized fraction geochemistry: total leach

Al_2O_3, Ba, and K_20 concentrations in the silt and clay-sized fraction of till show moderate enrichment immediately down-ice (NNW) from the mine compared with samples from the up-ice region (Appendix 7 and Table 2). However, only the maximum Al_2O_3 concentration near the mine is significant if compared to the regional data from the Bonaparte survey (Table 2). The Al_2O_3 enrichment in the silt and clay-sized fraction of till could be derived from phyllosilicate minerals associated to sericitic selvages noted as a type of alteration associated with the mineralization.

Table 2. Maximum elemental concentrations in the silt and clay-sized fraction of till (ICP-ES) near Gibraltar Mine and percentile equivalent to the regional till survey in the Bonaparte Lake map area (Plouffe et al., 2010).

Element	Unit	Gibraltar max. concentration	Bonaparte percentile equivalent
Al_2O_3	%	16.17	92^{th}
Ba	ppm	998	62^{th}
K_20	%	1.93	45^{th}

The silt and clay-sized fraction contains a few high loss-on-ignition (LOI) values down-ice (NNW) from Gibraltar compared to the up-ice region. Bysouth et al. (1995) also noted high LOI values in some bedrock samples. Such high LOI values could be related to an artefact of the analytical method. During combustion of samples at 1000°C (Acme Laboratory procedure), other elements can be volatilized (e.g., S, N, H, O, Hg) contributing to elevated LOI values.

Silt and clay-sized fraction geochemistry: aqua regia

The silt and clay-sized fraction was analysed by ICP-MS using the same methodology as for the clay-sized fraction (Fig. 5). Elemental enrichment in this fraction down-ice from the mine (NNW) compared to the up-ice region is noted for Ag, Al, Au, Ba, Cd, Cu, K, Mo, Zn, and Te (Table 3 and Appendix 7). Although there is a local enrichment of Al, Ba, and K in the silt and clay-sized fraction of till near Gibraltar, the enrichment is less significant (i.e. $<80^{th}$ percentile) if compared to the regional Bonaparte survey (Table 3). All these elements except Cd and Te are known to be enriched in various zones of the mineralization at Gibraltar Mine or are found in the periphery to the mineralization. These two elements are likely present in various sulphide minerals present in the deposit. Silver and Au in the silt and clay-sized fraction, as with the clay, are more enriched on the west side of the pits. Copper in the silt and clay-sized is more enriched on the west and to a lesser degree north of the pits down-ice from the Cu zones defined by Bysouth et al. (1995) (Appendix 7). Molybdenum is enriched mostly on the east side, down-ice from the Mo zone, but also to a lesser degree to the west. Zinc in the silt and clay-sized fraction, as with clay, is enriched in the Zn zone (Appendix 7).

Table 3. Maximum elemental concentrations in the silt and clay-sized fraction of till (ICP-MS) near Gibraltar Mine and percentile equivalent to the regional till survey in the Bonaparte Lake map area (Plouffe et al., 2010).

Element	Unit	Gibraltar max. conc.	Bonaparte percentile equivalent	Element	unit	Gibraltar max. conc.	Bonaparte Percentile equivalent
Ag	ppb	319	96th	Cu	ppm	525	99th
Al	%	1.74	54th	K	%	0.11	33th
Au	ppb	21	96th	Mo	ppm	3.02	94th
Ba	ppm	194	78th	Te	ppm	0.18	98th
Cd	ppm	1.23	97th	Zn	ppm	512	99th

Silt and clay-sized fraction geochemistry: instrumental neutron activation analyses

The silt and clay-sized fraction of till was analysed by instrumental neutron activation analyses (INAA) (Fig. 5; Appendix 4). Elemental concentrations by this analytical method represent a total element content of the analyte, compared to the "near-total" obtained from an aqua-regia leach. Gold, Mo and Zn levels determined by INAA are more elevated down-ice compared to the up-ice region of the mine (Appendix 7). Compared to the regional Bonaparte survey, the enrichments are all significant (Table 4). The Au enrichment determined by INAA on the silt and clay-sized is dominant on the west side. The highest Mo level is on the east side down-ice from the Mo zone identified by Bysouth et al. (1995) (Appendix 7). The Zn enrichment in till corresponds to the Zn zone in bedrock (Fig.2 and Appendix 7).

Table 4. Maximum elemental concentrations in the silt and clay-sized fraction of till (INAA) near Gibraltar Mine percentile equivalent to the regional till survey in the Bonaparte Lake map area (Plouffe et al., 2010).

Element	unit	Gibraltar max. concentration	Bonaparte percentile equivalent
Au	ppb	28	95th
Mo	ppm	4	93th
Zn	ppm	730	99th

Heavy mineral concentrates: instrumental neutron activation analyses

The HMCs obtained from the bulk till samples (<0.250 mm; >3.2 specific gravity) were submitted for INAA. Several elements are showing enrichment down-ice from the mine compared to the up-ice region (Au, Ba, Mo, and Zn; Appendix 7). The highest Au level in the HMC is found on the west side of the pits. Molybdenum is enriched at three sites north of the pits. Like the other size fractions, Zn enrichment in the HMCs correspond with the Zn zone defined at Gibraltar (Bysouth et al., 1995; Appendix 7). Compared to the regional survey of the Bonaparte Lake region, the Au, Mo and Zn enrichments are significant (Table 5). The Au and Zn abundances measured in HMCs near Gibraltar exceed the maximum values observed in the Bonaparte Lake region.

Table 5. Maximum elemental concentrations in the HMCs of till near Gibraltar Mine and percentile equivalent to the regional till survey in the Bonaparte Lake map area (Plouffe et al., 2010).

Element	unit	Gibraltar max. concentration	Bonaparte percentile equivalent
Au	ppb	1800	100th
Ba	ppm	140	77th
Mo	ppm	7	95th
Zn	ppm	1200	100th

Several other elements exhibit elevated concentrations in HMCs down-ice from Gibraltar compared to the up-ice region (e.g., Hf, Lu, and, at some distance from the mineralization, Na, Ni, Sb, and Sc; Appendix 7). The source and significance of these elevated concentrations in the heavy mineral concentrates of till are still unclear.

Heavy mineral concentrates: mineralogy

Results of heavy mineral identification are tabulated and depicted on maps in Appendix 8. Heavy mineral counts are normalized to 15 kg table feed on all maps.

Till HMCs in the Gibraltar Mine region are dominated by an assemblage of almandine, hematite (goethite) and epidote. Other minerals present in trace amounts and potentially useful to identify mineralization include sulphides (pyrite, chalcopyrite and sphalerite) and oxide (rutile). A single grain of sphalerite (normalized to 2 grains per 15 kg table feed) was identified in the <0.250 mm fraction of sample 08-PMA-A192A-01 on the west side of the mine. Pyrite was identified in the <0.250 mm and 0.250-0.500 mm fractions. Samples with the largest numbers of pyrite grains are located down-ice from Gibraltar but the background content of pyrite grains in till is not low as shown with one sample up-ice from Gibraltar (08-PMA-A194A-01) which contains 179 pyrite grains normalized to 15 kg. In this case, the pyrite might be derived from the Minfile occurrences south of 08-PMA-A194A-01.

Chalcopyrite was identified only in the 0.250-0.500 mm fraction and is more abundant in till down-ice from the mine compared to the up-ice region. The absence of chalcopyrite in the finer fraction (<0.250 mm) is most likely related to the methodology used for this size fraction (micro-panning) which does not allow an efficient isolation of chalcopyrite grains. Indeed, chalcopyrite has a lower specific gravity (4.1-4.3) than pyrite (5.1) and therefore is more difficult to concentrate by micro-panning.

Red rutile has been identified as a potential indicator mineral for porphyry copper deposit (Williams and Cesbron, 1977). Its presence in Gibraltar till HMCs up to 26 grains per 15 kg might corroborate that conclusion; however, the “background” red rutile content of till HMCs in the region may be relatively high. For instance, a sample located in the up-ice region of Gibraltar contains 5 grains of red rutile per 15 kg (08-PMA-A195A).

Olivine is identified in the 0.250-0.500 mm size fraction of HMCs up to 488 grains per 15 kg down-ice from Gibraltar. The presence of olivine likely reflects the presence of material in the till matrix derived from the Eocene-Miocene basalt farther south (Fig. 1). Indeed, olivine is dominant in till HMCs above Miocene basalt within the Bonaparte Lake map area, reaching an estimated count of 250 000 grains per 15 kg (unpublished data).

Lodgepole pine and Engelmann spruce outer bark biogeochemistry

Most elements depict similar distribution patterns in outer bark from the two tree species attesting to the robustness of the biogeochemical method and reinforcing the significance of the signatures (Appendix 7) . Elements that tend to show different patterns (e.g., Ba, Sr) are those that are more concentrated in a particular sample medium (Appendix 6). In summary, the pine bark is more enriched than the spruce bark in Ag, Al, Cd, La, Pb and Sb. Conversely, spruce is more enriched in Ba, Ca, Mn, Rb, Sr and Zn.

The analytical precision obtained for Au was characteristically poor for the low levels present. However, even the sub-ppb levels outlined areas of relative enrichment that proved to be coincident with areas of known mineralization, and which could be related to zones of Au enrichments that had recently been identified in till.

To detect elemental enrichment in outer bark samples near Gibraltar Mine, the average concentrations near the mine (average values) are compared to the median concentrations in the regional survey of the Bonaparte Lake map area ((Dunn and Anderson, in press) (Table 6). From Table 6, different levels of metal uptake by the two plant species are evident. The two commodity metals at the mine (Mo and Cu) are significantly enriched to various levels in both plant species. Molybdenum is 56 times more enriched in pine and 25 times in spruce near Gibraltar compared to the regional survey. Copper is enriched 32 times in pine and 13 times in spruce near the mine compared to the Bonaparte survey. Other notable enrichments of elements compared to common background levels are Ag, Al, Li, Sn, Th, U and Y. At sites #71 to 74 (Appendix 6), concentrations are substantially greater for Ag, REE (Ce, La), Cu, Li, Mo, Nb, Ni, P, S, Sb, Sn, Th, Ti, U, Y and Zn.

Although it must be appreciated that there are very few samples, it is worthy of note that Cu and Mo concentrations in the outer bark of lodgepole pine and Engelmann spruce are enriched compared to the concentrations measured in the same plant tissue in the regional survey of the Bonaparte Lake area.

Table 6. Elemental concentration in outer bark samples of pine and spruce near Gibraltar mine compared to the median concentrations in the Bonaparte Lake study (Dunn and Anderson, in press).

Pine				
		Average	**Median**	**Conc. Factor**
		Gibraltar	*Bonaparte*	*Gibraltar vs. Bonaparte*
		n=6	n=198	
Ag	ppb	34	13	3
Al	%	0.07	0.04	2
Ce	ppm	0.56	0.17	3
Co	ppm	0.59	0.13	5
Cu	ppm	130	4.1	32
Fe	%	0.10	0.017	6
La	ppm	0.24	0.08	3
Li	ppm	0.27	0.04	7
Mo	ppm	3.9	0.07	56
Nb	ppm	0.03	0.01	3
Ni	ppm	0.92	0.5	2
P	%	0.03	0.02	1.3
S	%	0.08	0.03	3
Sb	ppm	0.05	0.03	2
Sn	ppm	0.05	0.01	5
Th	ppm	0.05	0.01	5
Ti	ppm	25	8	3
U	ppm	0.04	0.005	8
Y	ppm	0.42	0.061	7
Zn	ppm	48	34.5	1.4

Spruce				
		Average	**Median**	**Conc. Factor**
		Gibraltar	*Bonaparte*	*Gibraltar vs. Bonaparte*
		n=7	n=180	
Ag	ppb	19	8	2
Al	%	0.02	0.005	5
Cd	ppm	0.21	0.1	2
Co	ppm	0.42	0.14	3
Cu	ppm	66	5	13
Fe	%	0.05	0.012	4
Li	ppm	0.16	0.05	3
Mo	ppm	1.53	0.06	25
Y	ppm	0.15	0.038	4

Discussion

Based on till geochemistry, there is evidence of northward to north-northwestward glacial transport in the Gibraltar Mine region. As indicated in the Geological Setting section, the extent of westward glacial advance out of the Cariboo Mountains onto the Interior Plateau at the onset of the last glaciation is still not fully mapped. It is still unknown if westerly-flowing glaciers reached the Gibraltar Mine region. If they did, the westward to northwestward glacial dispersal remains to be mapped with more sampling in that

direction. However, our preliminary data on till geochemistry indicate that the geochemical dispersal train from Gibraltar ore bodies is short, likely no more than two to three kilometres at the most, depending on the element. Defining the exact length of the dispersal trains would require a more dense till sampling survey. However, the estimated short dispersal trains derived from a mineralized zone located on top of a hill (Granite Mountain) is likely related to the fact that only a small part of the mineralization, compared to the extent of mineralization outlined at depth, was exposed to erosion during the last glaciation.

This conclusion has important implications for the interpretation of regional till surveys in which sample spacing is in the order of 2-5 km (see Ferbey, 2010 for the list of regional till surveys in British Columbia). For instance, it is unlikely in a regional survey that two consecutive samples would be collected within a dispersal train. Therefore, it implies that a single anomalous sample in a regional survey could be indicative of buried mineralization. Follow-up on anomalous samples would have to rely on other data sets including bedrock geology, geochemical data (plants, streams, lakes) and geophysics.

Sutherland Brown (1966) presented the Hg concentrations in soil samples collected along a 3.6 km long transect above Gibraltar East, Gibraltar West and Pollyanna pits. The transect shows a subtle enrichment in mercury (around 50 ppb) above the mineralized zone compared to background concentrations close to 25 ppb. No noticeable Hg enrichment was noted in till, but the bark samples yielded up to double the Hg concentrations (maximum of 279 ppb Hg) near Gibraltar compared to background levels (approximately 150 ppb Hg).

Conclusions

Our results reveal that minor elements (Au, Ag, Ba, Cu, Mo, Te, Zn) and one major oxide (Al_2O_3) are enriched to various degree in till down-ice from the Gibraltar ore bodies compared to background concentrations reported from the Bonaparte Lake map area. Similarly, Cu and Mo are more enriched in lodgepole pine and Engelmann spruce outer bark near Gibraltar compared to that large survey area to the south. Furthermore, elemental enrichment in till follows in large part the metal zoning identified in bedrock mineralization by Bysouth et al. (1995). The number of samples and the extent of the till

sampling is not large enough to adequately define the form and the exact length of the glacial dispersal train at Gibraltar. This orientation till sampling survey would need to be extended and the sample density increased to define these parameters.

These preliminary results tentatively suggest that the geochemistry of till and outer tree bark along with the mineralogy of the HMCs from till are efficient exploration tools in the Interior Plateau of British Columbia. Furthermore, based on the geochemical composition of till and outer tree bark at Gibraltar, exploration targets could be identified in existing regional data sets by identifying geochemical anomalies of similar nature as the ones observed at Gibraltar. Several regional biogeochemical surveys (e.g. Dunn, 1997; Dunn and Hastings, 1998, 1999; Dunn and Thompson, 2007) and till surveys (Ferbey, 2010 ; for an account of all till surveys in British Columbia) have been completed in British Columbia and results are available for reference and to identify significant anomalies for follow-up mineral exploration.

Acknowledgements

This project was conducted as part of the Mountain Pine Beetle Program of the GSC (Natural Resources Canada) under the capable leadership of C. Hutton as well as the Cordilleran Project of the Targeted Geoscience Initiative 3 (S. Hanmer, Program Manager). Field logistics were facilitated following the support of B. Madu (Kamloops Regional Geologist, BC Geological Survey Branch). This paper was reviewed by Peter Outridge as part of the GSC internal review process. Capable field assistance was provided by Blair Underhill, A. Carter-Mcauslan, A. Courtenay, L. Day, and E. Giesbrecht. John Fleming (Gibraltar Mines Ltd.) kindly provided a tour of the mine geology and generous access to the mine site.

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