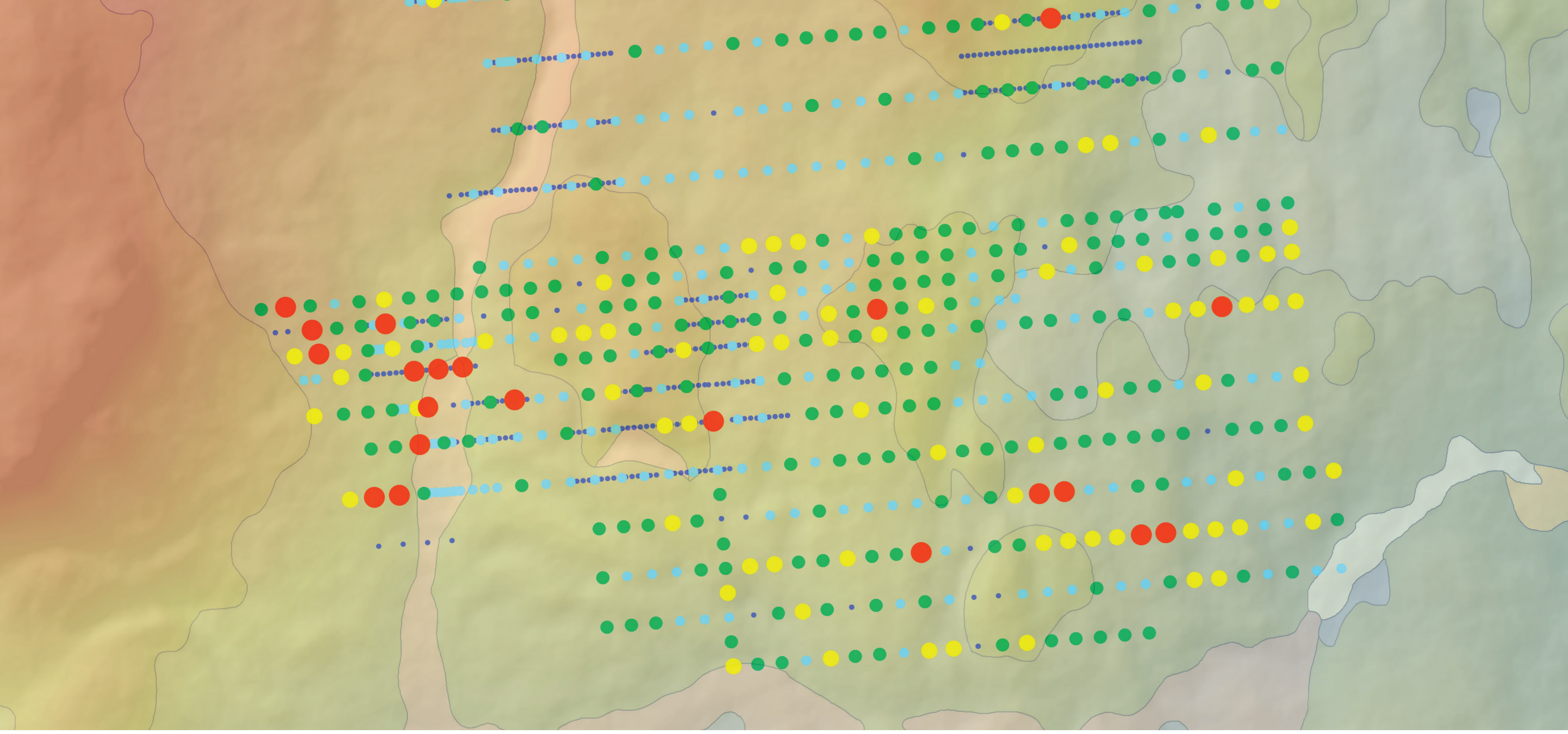

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Geoscience BC Report 2016-15

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Geoscience BC[1] Report 2016-15
Prepared by MDRU[2]

Report to accompany maps, digital data, and spatial data packages available for download at http://www.geosciencebc.com/s/2009-048.asp

[1] Geoscience BC is an independent, non-profit organization that generates earth science in collaboration with First Nations, local communities, government, academia and the resource sector. Our independent earth science enables informed resource management decisions and attracts investment and jobs. Geoscience BC gratefully acknowledges the financial support of the Province of British Columbia.

[2] The Mineral Deposit Research Unit (MDRU) is an internationally-recognized collaborative venture between the mining industry and Earth, Ocean and Atmospheric Sciences Department at The University of British Columbia (UBC), established with assistance from the Natural Sciences and Engineering Research Council of Canada (NSERC), and devoted to solving mineral exploration-related problems.
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Surficial Geochemical Exploration Data for British Columbia Porphyry Copper Deposits

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INTRODUCTION

The application of geochemical methods to surficial materials for the exploration and discovery of British Columbia (BC) porphyry deposits has resulted in many successes, but is fraught with challenges that contribute toward decreasing success in areas of cover. Porphyry copper systems themselves are invariably diverse, large and zoned; their geochemical signatures can vary considerably over large areas, depending on sample and survey location within the system. Post-mineralization dispersion of surficial materials by glacial, alluvial and mass-wasting processes further diffuses the signal. Additionally, the pedogenic processes involved in soil formation, such as oxidation, bio- and cryoturbation, leaching and hydromorphic dispersion, further contribute to modifying the geochemical signal and patterns.

Savvy explorers are well aware of these challenges, and tools have been developed to assist in their recognition. Geochemical-exploration models, for example, were first developed and presented by Bradshaw (1975) for deposits in the Canadian Cordillera and Canadian Shield. General, conceptual geochemical-exploration models (GEMs) were created for ore deposits in BC based on fundamental scientific principles and a limited number of case histories. These preliminary models summarized the potential controls on geochemical dispersion, and the expected results of the modified geochemical distributions. Subsequent efforts emphasized GEMs in volcanogenic massive-sulphide and shale-hosted Pb-Zn-Ag deposits in the Canadian Cordillera (Lett and Jackman, 2000; Lett, 2001; Lett and Bradshaw, 2003). Although it was recognized by Lett and Bradshaw (2003) that greater development and refinement of GEMs related to Cordilleran porphyry deposits was required, little progress was made and advances in the scientific literature were few.

This Geoscience BC1–sponsored MDRU research project aims to create a framework to expand on the conceptual models presented by Bradshaw (1975), by providing an abundance of spatially enabled data that can contribute toward the development of real and constrained, empirically-defined geochemical exploration models for BC porphyry systems in various environments. The largest step toward improving GEMs comprises the compilation and updating of information relevant to evaluating such models, which can be sourced from the accumulated historical exploration data from both industry and government sources.

The purpose of this project and these results is to provide the mineral-exploration community with easy access to surficial geochemistry data and related information to facilitate exploration and discovery of BC porphyry deposits. For a selected group of 15 porphyry deposits, geochemical information available in print form has been compiled, digitized and updated to meet modern geospatial standards, and paired with spatial datasets related to the physiographic setting, glacial history, surficial materials and other geological factors that may influence geochemical distributions. These data packages are presented as 15 self-extracting data archives in ArcGIS® .mpk map package format that allow the user a high degree of flexibility to visualize the data with their own constraints. Users can thus visually and mathematically interrogate data to reveal relationships within the datasets, and potentially develop new models of geochemical dispersion in post-glacial environments. Examples of how such data can be utilized to understand the relative importance of surficial processes, terrain and climate in producing modern geochemical signals in these types of environments are provided in Blaine and Hart (2012), and discussed briefly in the Development of Geochemical Exploration Models section of this report.

LOCATION SELECTION

Of the 280 or so porphyry mineral occurrences listed within MINFILE (http://minfile.gov.bc.ca/) with a classification of "developed prospect", "past producer" or "current producer" in 2009, 73 of these porphyry deposits and prospects were determined to have geochemical data that were contained within 273 assessment reports within the BC Assessment Report Indexing System (ARIS). At the time of this project's completion, the ARIS report database hosted over 35,000 individual reports, with at least 22,500 reporting geochemical results of some kind. These geochemical surveys report results of industry-conducted surficial geochemical surveys, and include from a wide variety of geochemical digestion and analytical methods applied to all manner of sampling media, such as water, till, soil, moss mats, and vegetation. The data contained within these reports, however, are of highly variable quality and much of the data are of limited use or are not extractable due to poor print quality. Furthermore, the number of accessible reports is also limited by confidentiality periods; many of them are not yet available, although a record for them is maintained in the ARIS database.

The initially identified 73 deposits were subsequently reduced to 44 porphyry deposits of interest (Figure 1), for which there has been significant historical interest and exploration. These 44 deposits were evaluated according to a range of features related to their geographic and physiographic settings. These included pedogenic and geomorphic factors potentially affecting geochemical dispersions, such as the glacial history, the thickness and type of glacially derived cover, topography and climate. From these, 15 porphyry deposits and/or groups of deposits were selected as localities deserving of greater attention due to availability of Assessment Report Indexing System (ARIS) data. These deposits are Brenda, Getty, Iron Mask region (contains Afton, Ajax and Galaxy deposits), Mount Polley, Primer, Mouse Mountain, Davidson, Louise Lake, Pitman, Hearne Hill and Morrison, Takla-Rainbow, Mount Milligan, Shaft Creek North, Alwin and Red Chris (Figure 1).

CAPTURING ARCHIVAL DATA

To assess the relative roles of the external controlling factors and geochemical signal distribution processes, geochemical data must be compared against the spatial patterns of geologic and geomorphic deposits at each deposit. Geochemical sample data have been captured from many industry and government sources, including regional geochemical surveys carried out by the Geological Survey of Canada (Lett, 2011) and the BC Geological Survey (BCGS); the results of updated sampling and archival sample analysis available from Geoscience BC; deposit- and area-specific studies carried out by the BCGS and Geoscience BC; and historical geochemical data generated through exploration by industry.

The primary source for the geochemical data compiled in this study is the ARIS archives, maintained by the BC Ministry of Energy and Mines. To be selected for this project, reports must have contained a minimum amount of information including sample type/horizon, digestion method, analytical finish and detailed spatial data.

The ARIS documents are generally stored as scanned-to-PDF documents and vary widely in scan quality. Data of good quality for the selected deposits were retrieved through optical character recognition (OCR) of the scanned PDF documents and manually reviewed for errors. Optical character recognition (OCR) using ABBYY® FineReader® software was used to capture the data from the assessment reports. All OCR-collected data were manually verified with analytical certificates or submitted data tables to ensure the highest level of data quality and consistency. Where OCR was not successful or error rates were high, data were manually entered into tables.

Due to the large amount of data, variety of data sources, and often incomplete or missing quality control, full quality assurance/quality control procedures were not completed for all surveys. Where below detection limit data are reported, values are maintained in the digital data files as the negative of the detection limit.

All geochemical data and metadata were converted to a consistent format including column headings, units, and projection method; metadata were added as required. This process resulted in the creation of approximately 50 000 spatial data points, each pertaining to individual geochemical samples for the 15 selected porphyry deposits shown in Figure 1. Compiled geochemical data were then re-projected into either geographic (latitude and longitude) or UTM co-ordinate systems for ease of use and to provide internal spatial confidence. The confidence of the text conversion process from scanned reports, as well as the spatial conversion parameters from local and/or sampling grids to standard Universal Transverse Mercator (UTM) grid coordinates are supported with a table and narrative that can be found in Appendix 1. The full references for these ARIS reports is provided in Appendix 2. The breakdown of these data by sample type is given in Table 1 providing a quick reference to the data available for each porphyry deposit.

CONTROLS ON GEOCHEMICAL DISTRIBUTION AND PORPHYRY CLASSIFICATION CRITERIA

Although this study is restricted to porphyry deposits in relatively similar settings, there are a number of variables that influence both the nature and geometry of the deposits and also affect the development of the associated geochemical signature in the surficial media. These variations result in a unique set of conditions for each porphyry system and even for individual deposits in a single porphyry system. Therefore, in order to develop usable and appropriate geochemical exploration models, deposits can be categorized based on a limited number

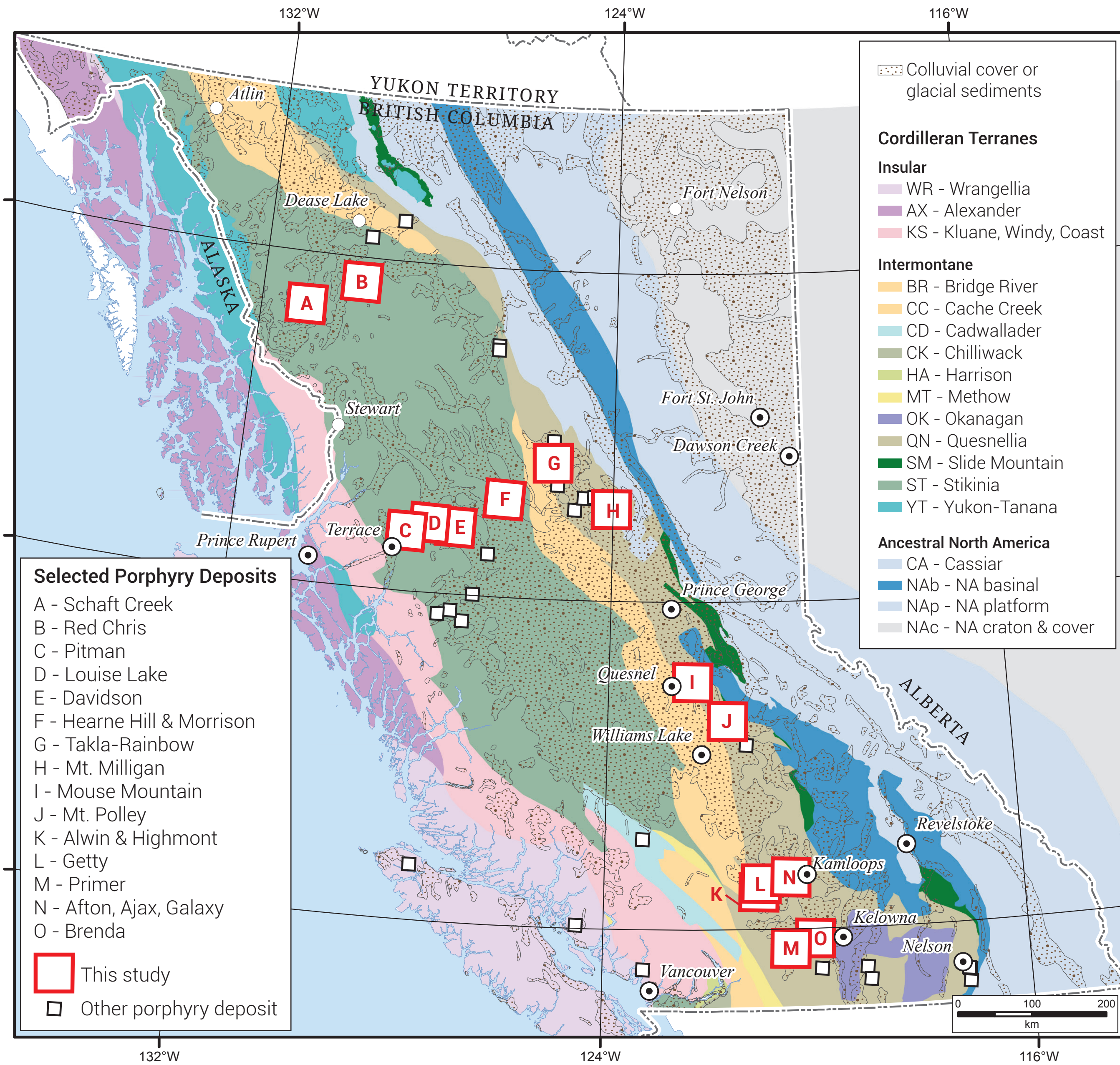

Figure 1: British Columbia porphyry deposits evaluated (white squares with black or red borders) and those selected for geochemical-data compilations (white squares with red border), shown with respect to the distribution of Quaternary glacial deposits and older cover, as well as major terrane boundaries (Colpron and Nelson, 2011). Label refers to the legend key and to the name of the geochemical-data compilation associated with this project (e.g., Schaft Creek is package 2016-15-A).

Table 1: : Distribution of sample type within the Assessment File Indexing System (ARIS) and other publicly-available datasets digitized for each porphyry deposit in the GIS map packages. Abbreviation: BLEG, bulk leach extractable gold.

Compilation	Porphyry	Data Source	Sample Type										
			Soil	Silt	Stream Sediment	Moss Mat	Lake Sediment	Till or Outwash	Rock	Grab	Vegetation	BLEG	Unclear
A	**Schaft Creek**	ARIS	183						17				
		RGS (Lett, 2011)			278								
B	**Red Chris**	ARIS	2463										
		RGS (Lett, 2011)			425								
C	**Pitman**	ARIS	872										
		RGS (Lett, 2011)			790								
D	**Louise Lake**	ARIS	1101	534									
		RGS (Lett, 2011)			438		22						
E	**Davidson**	ARIS	446										
		RGS (Lett, 2011)			331		50						
F	**Hearne Hill &**	ARIS	807					1228					
	Morrison	RGS (Lett, 2011)			714		803						
G		ARIS	19701		1978	165		1275	1751				8
	Takla-Rainbow	RGS (Lett, 2011)			841								
H	**Mt. Milligan**	ARIS	2519	32	59							33	
		RGS (Lett, 2011)			394		606						
		Other sources						121			133		
I	**Mouse Mtn**	ARIS	3403						1	15	2		2
		RGS (Lett, 2011)			692		31						
J	**Mt Polley**	ARIS	5625					85					
		RGS (Lett, 2011)			829								
		Other sources	105								100		
K	**Alwin &**	ARIS	712										
	Highmont	RGS (Lett, 2011)			266								
L	**Getty**	ARIS	4298										
		RGS (Lett, 2011)			212								
		Other sources											318
M	**Primer**	ARIS	1151										
		RGS (Lett, 2011)			377								
N	**Afton, Ajax &**	ARIS	2403		27		3	341					
	Galaxy	RGS (Lett, 2011)			186								
O	**Brenda**	ARIS	3788										

of dominant external controls and physio-chemical processes that produce unique geochemical signatures at each deposit. These processes can be broadly categorized into primary, secondary and post-secondary processes. Categorization of the deposits is based on the external controls that regulate these processes; classification of the selected porphyry deposits by these controlling factors can be found in Table 2.

Processes Responsible for Geochemical Signals

Primary Processes

For use within this document, primary processes are deposit-specific mechanisms that control the geochemical distribution of elements within the deposit itself and relate to ore-deposit forming processes/ mineralization styles. These primary processes control the inherent geochemical signature of the deposit itself and any associated alteration, which is subsequently modified or redistributed by secondary processes. For this study, to address primary processes, deposits are classified based on the porphyry-type classification developed by the BCGS (Lefebure and Ray, 1995) that categorizes porphyries into Alkalic, Calc-Alkalic and Porphyry Mo deposits. It is recognized that this is a generalization and individual deposits will vary within these groupings. Whenever possible, the characteristics of individual deposits that can affect the resulting surficial geochemistry will be discussed.

Secondary Processes

Secondary processes result in the transfer or modification of the ore deposit material and can include both physical and chemical mechanisms. These processes include the physical transport of material through geomorphological processes (colluvial, alluvial, fluvial, eolian, and glacial processes, etc.) and weathering of the ore deposits and overlying bedrock. Glaciation is the secondary process believed to exert the greatest control on geochemical expression in British Columbia, as much of BC experienced widespread glaciation, most recently during the Late Wisconsinan (maxima ~14500 ybp) (Clague and James,

Table 2: Classification of three major types of British Columbia porphyry deposits based on factors affecting surficial geochemical expression. Climatic factors include temperature (classed by the length of the frost-free period [ffp]), and precipitation (classed by the annual amount of non-snow precipitation [nsp]). Topographic factors include a general expression of relief (steep, moderate or slight). Deposits selected for delivery as geochemical-data compilations for this project are shown in bold text.

Climate		Calc-Alkalic			Alkalic			Molybdenum	
	Topography:	Steep	Moderate	Slight	Steep	Moderate	Slight	Steep	Moderate
Warm (ffp > 50 days)	**Wet** nsp > 500mm	Ok North Hushamu	**Louise Lake**	Gambier Island	Kena Gold Kena (Gold Mountain)	-	-	**Pitman**	-
Warm (ffp > 50 days)	**Dry** nsp < 500mm	**Hearne Hill** Indata, May **Morrison** **Schaft Creek**	**Brenda** HED, Poplar **Highmont** **Alwin**	**Getty South** Jean	**Mt. Polley** **Mt. Milligan** Col	**Getty** **Mouse Mtn.** **Primer**	**Ajax** **Galaxy** Woodjam	Carmi Mo **Davidson** Stewart	Mineral Hill
Cool (ffp < 50 days)	**Wet** nsp > 500mm	Taseko Huckleberry New Nanik Whiting Creek	-	-	-	-	-	-	-
Cool (ffp < 50 days)	**Dry** nsp < 500mm	**Takla-** **Rainbow** Kemess **Red Chris**	Gnat Pass Eaglehead	-	Chuchi Lake	-	-	Storie	-

2002). This glacial event has blanketed large portions of BC with glacial tills and related deposits (Fig. 1), and the nature and distribution of these materials will have a profound effect on the geochemical signature of deposits.

For the purpose of identifying secondary processes, surficial cover can be broadly divided into four categories based upon soil (terrain) mapping by the BC Ministry of Environment (2011). The categories are:

1) Residual soils - Soils developed directly from the weathering of the bedrock on which they reside.

2) Locally derived transported cover (geochemically attached) – These materials have a direct connection to the underlying bedrock and may be developed through glacial weathering and localized transport (a few 10s of meters) or through colluvial processes (colluvium and some till veneers; mass wasting deposits).

3) Transported cover (geochemically detached) – These materials are assumed to have no direct geochemical connection to the underlying bedrock as their source may be distant or sourced from distal materials (i.e. glacial deposits such as till or outwash, glaciolacustrine, fluvial and alluvial deposits).

4) Blind deposits – The current bedrock weathering surface has not reached these deposits and they are overlain either by younger rocks or the rocks in which the deposits are hosted and are therefore blind to surface.

Post-secondary Processes

Post-secondary processes, as defined here, are those processes that further modify or transport a geochemical signature, and are generally independent of the physical transport of the material that hosts the signature. These processes may include hydromorphic, phreatic, vadose zone and gaseous transport, as well as transportation by vegetation. Bio- and cryo-turbation are also included in this category, as they are processes that modify the distribution of material post-deposition.

External Controlling Factors on Geochemical Signal Processes

Climate

The climate in BC during the last post glacial period has been fairly stable, becoming steadily cooler and wetter throughout out the past ~14000 years (Hebda, 2007). However, due to the broad range of climate zones within BC, climatic conditions can vary greatly between deposits. The varied climate conditions between deposits can have a great effect on the generation of geochemical anomalies by controlling the secondary and post-secondary processes (Butt, 2005; Aspandiar et al., 2008) The two dominant climatic controls are temperature and availability of water (precipitation). Climate data for deposit locations (taken from www.minfile.ca) was determined using the ClimateBC model developed by the Faculty of Forestry at the University of British Columbia (2011). ClimateBC is a model based on PRISM by Daly et al. (2002), and can be accessed at http://cfcg.forestry.ubc.ca/projects/climate-data/climatebcwna/. Climate can be important, however, the influence of availability of water and temperature decreases as relief increases; as a result physical transport processes will dominate in areas of steep topography (Butt, 2005).

Temperature

Temperature can affect an ore deposit's geochemical signature in the surficial environment through a number of different mechanisms. Warmer climates promote chemical weathering and increase the availability of elements liberated through weathering. As well, temperature controls the availability of water throughout the year as water is not available during winter months due to freezing. Low temperatures and long periods of frost can also promote frost-induced fracturing, promoting weathering and increased colluvial processes.

Porphyry deposits were classified based on temperature according to their frost-free period (f.f.p.), which is the number of consecutive days that the area has temperatures above freezing. Two classifications are made with deposits falling into categories of greater or less than 50-days frost-free period. Frost-free period was chosen over mean annual temperature, as it was believed to be a better indicator of the potential effects of temperature, highlighting the unavailability of water and frost-driven processes during winter months.

Precipitation

Precipitation or the availability of water is the main factor controlling post-secondary processes and it can have an effect on secondary physical transport mechanisms as well. Seasonality is an important factor as well as the amount of precipitation (Butt, 2005) and therefore the classification of the deposits into two categories is based upon non-snow precipitation (greater or less than 500mm). Precipitation received as snow will more than likely be introduced to the hydrologic system as run-off, increasing alluviation and likely will not be introduced significantly to the local groundwater system where the aforementioned post-secondary processes occur.

Increased availability of water in areas of low to moderate relief will generally cause a higher water table and increase the likelihood of phreatic and hydromorphic processes, whereas in areas with lower water tables the dominant processes will be gaseous transport and vadose zone processes.

Physiography

The relief of the area surrounding a deposit has strong control over physical transport processes and soil development processes. Steep areas will prevent soil formation and result in physical transport (alluvial and colluvial processes) exerting the dominant control on geochemical dispersal. As well, in steep areas rainfall will be more likely to produce run-off, decreasing water infiltration and enhancing alluvial processes. Deposits are classified generally based on topography as slight (<100m elevation change/km), moderate (100-300m elevation change/km) and steep (>300m elevation change/km); however, local variations in relief are common and interpretation is based primarily on local assessment of elevation.

DEVELOPMENT OF GEOCHEMICAL EXPLORATION MODELS

Geochemical exploration models are developed by determining the element associations and their distribution between sampled media and mineralization and linking those distributions to the process generating the geochemical pattern. Relating the geochemical expression to mineralization and/or geology and relating the expression to a process is a necessary exercise for each deposit and within each deposit. At project completion, these models are incomplete and are also beyond the full scope of the project. Geochemical expressions and related processes for several deposits are discussed below, to highlight both the importance of this study, and the importance of having readily-available geochemical data from historical assessment reports integrated into exploration models and practices. The products of this report (summarized in Products section), including the maps and data packages, can be further utilized by future users to produce new interpretations of the relationships between geochemical signals and controlling factors for deposits not discussed herein.

Preliminary interpretations of observed geochemical behaviour is discussed below for the Mount Milligan, Mount Polley, and Galaxy porphyry deposits, over which substantial B-horizon surveys were conducted. The deposits and surveys are summarized in Table 3. The results discussed here show that there are a broad range of potential anomaly formation mechanisms, even in a limited number of deposits illustrating the necessity of properly mapped surficial units and interpreting the geochemistry based on this mapping. Many of the elements analyzed show an association with underlying geology, but this association will not be discussed in this paper.

Shallow Locally-derived Cover

The simplest case for interpreting geochemical signatures, aside from residual soils, is where the deposits are concealed beneath shallow, locally derived cover such as basal till veneers where the dominant till sediment is locally derived. In this case the soils are developed directly from material transported from the deposit and, as a result, the geochemical signature can be preserved and detected in B-horizon soils. Two deposits where this is interpreted to occur are the Galaxy deposit and areas within the Mount Polley deposit.

At the Mount Polley deposit, in areas covered by a shallow till veneer (~1m or less), there are elevated (Cu, Mo, Au) and reduced (As) soil geochemical signatures coincident with the mineralization. This area is also bounded by elevated Pb and Zn in soil forming a halo around the mineralized bedrock (Fig. 2).

At Galaxy, the cover is slightly deeper (up to two to three

Table 3: Summary of B-horizon soil surveys at Mount Milligan, Mount Polley and Galaxy porphyry deposits.

Deposit	Galaxy	Mount Polley	Mount Milligan
ARIS Report Number	29628 (Carron, 2007)	16040 (McNaughton, 1987)	12912 (Heberlein et al., 1984)
Availability of water	Dry	Dry	Dry
Temperature	Warm	Warm	Warm
Topography	Slight	Variable - Steep	Variable - Steep
Surficial Material	Simple Transported Till veneer/Blanket	Varible – Simple to Complex Transported Till veneer Till Blanket w Colluvium	Varible – Simple to Complex Transported Colluvium Till Blanket Glaciofluvial
Geochemical Survey	B-Horizon Soils, 80 Mesh Aqua Regia Digest, ICP-OES finish	B-Horizon Soils, 80 Mesh Aqua Regia Digest, ICP-OES finish	B-Horizon Soils, 80 Mesh Aqua Regia Digest, ICP-OES finish
Elements Analyzed	La, P, Bi, Al, Zn, Na, Ba, Au, Cu, Ag, Mo, Co, Cd, Fe, Ni, Cr, As, Ca, Mg, V, Sr, Ti, Sb	Ag, As, Au, Cd, Co, Cr, Cu, Fe, La, Mg, Mo, Mn, Ni, Pb, V, W, Zn	Cu, Ti , P, K, Cr, La, B, Mg, Ca, Mo, Sr, Zn, Pb, Al, Sn, Cd, Th, U, Bi, V, Ba, W, Ni. Fe, Ag, Mn, Sb, As, Co, Au

meters) and elevated Cu, Mo and Au in soil are coincident with the mineralized zone (Fig. 3). Barium depletion in soil is also coincident with the mineralized zone, but this may be an effect related to the low solubility of some Ba minerals (e.g. barite) in the aqua regia digestion of the soil samples.

Glacial Dispersal Fans

Associated with the coincident soil geochemical anomalies discussed above at Mount Polley and Galaxy are glacial dispersal fans extending the soils anomaly in the direction of glacial transport. At Mount Polley (Fig. 2) the glacial dispersal fan shows elevated Cu, Au and Mo with the highest values coincident with mineralization. At Galaxy the dispersal fan shows elevated Cu and Au, but with no conclusive evidence for glacial dispersal of Mo (Fig. 3).

Gravity-transported Anomalies/Colluvial Fans

Areas of steep elevation around Mount Polley and Mount Milligan show evidence of gravity-transported anomalies in the soil overlaying colluvial material (Fig. 2 and 4). Geochemical analysis of B-horizon soils show elevated Cu, Au, +/- Mo and +/- Co values in soils overlying colluvium developed from mineralized zones.

Complex Multi-provenance Cover

Areas of Mount Polley and Mount Milligan are covered in complex multi-provenance till blankets, and at Mount Polley the till is intermixed with colluvium. In most cases, B-Horizon soils are inadequate to determine the location of mineralization and there is no conclusive coincident elevated geochemical signature in soil relating to the mineralization at these deposits. However, at Mount Milligan there is evidence of geochemical haloes in the B-horizon soils showing elevated levels of As, Zn and Pb surrounding mineralization with lower levels coincident over mineralization (Figure 4).

Transported or Displaced Anomalies

Although there are no coherent coincident geochemical indicators within the B-horizon soils overlying the thicker, complex transported cover at Mount Polley and Mount Milligan there are patchy, elevated concentrations of Cu, Mo and Au in soil in the direction of glacial dispersal at both deposits that may be related to the up-ice mineralization (Fig. 2 and 4). These elevated values could be indicative of lenses of locally-derived material in the till blankets or small windows to the underlying till veneer.

Vegetation and Tills

The lodgepole pine (Pinus contorta) bark vegetation survey conducted at Mount Milligan by Dunn et al. (1997) was successful at identifying areas of mineralization under areas of complex cover (Fig. 5) and shows elevated Au, Cu, Mo and As in bark directly overlying or immediately adjacent to mineralization. A till survey by Sibbick et al. (1997) conducted at the same time as the lodgepole pine bark sampling, also found similar element distribution patterns. The maximum Au value in bark on Figure 5 is located over the north-eastern area of mineralization and this may reflect transported cover material from the southern mineralized area and may not be an in situ anomaly, this possibility also applies to Cu, As and Mo.

Hydromorphic Anomalies

Hydromorphic anomalies are anomalies formed through transport and concentration of elements by aqueous transport

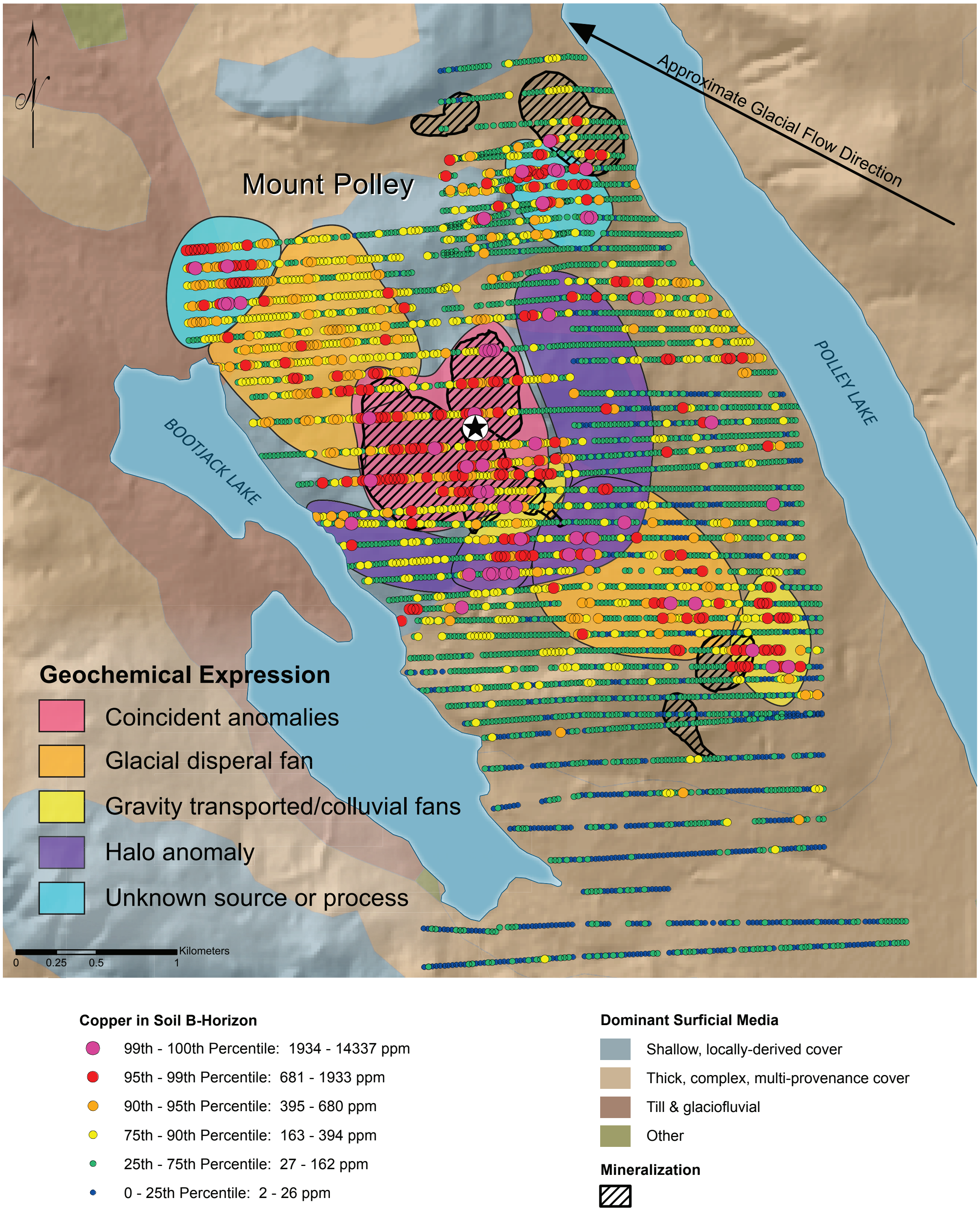

Figure 2: Copper distribution in B-horizon soils at the Mount Polley porphyry deposit showing the resulting interpretation of geochemical expressions/distribution processes. This is an example of the type of interpretations made possible by interrogating the combination of archival geochemical data and modern spatial datasets in the frameworks provided as project deliverables.

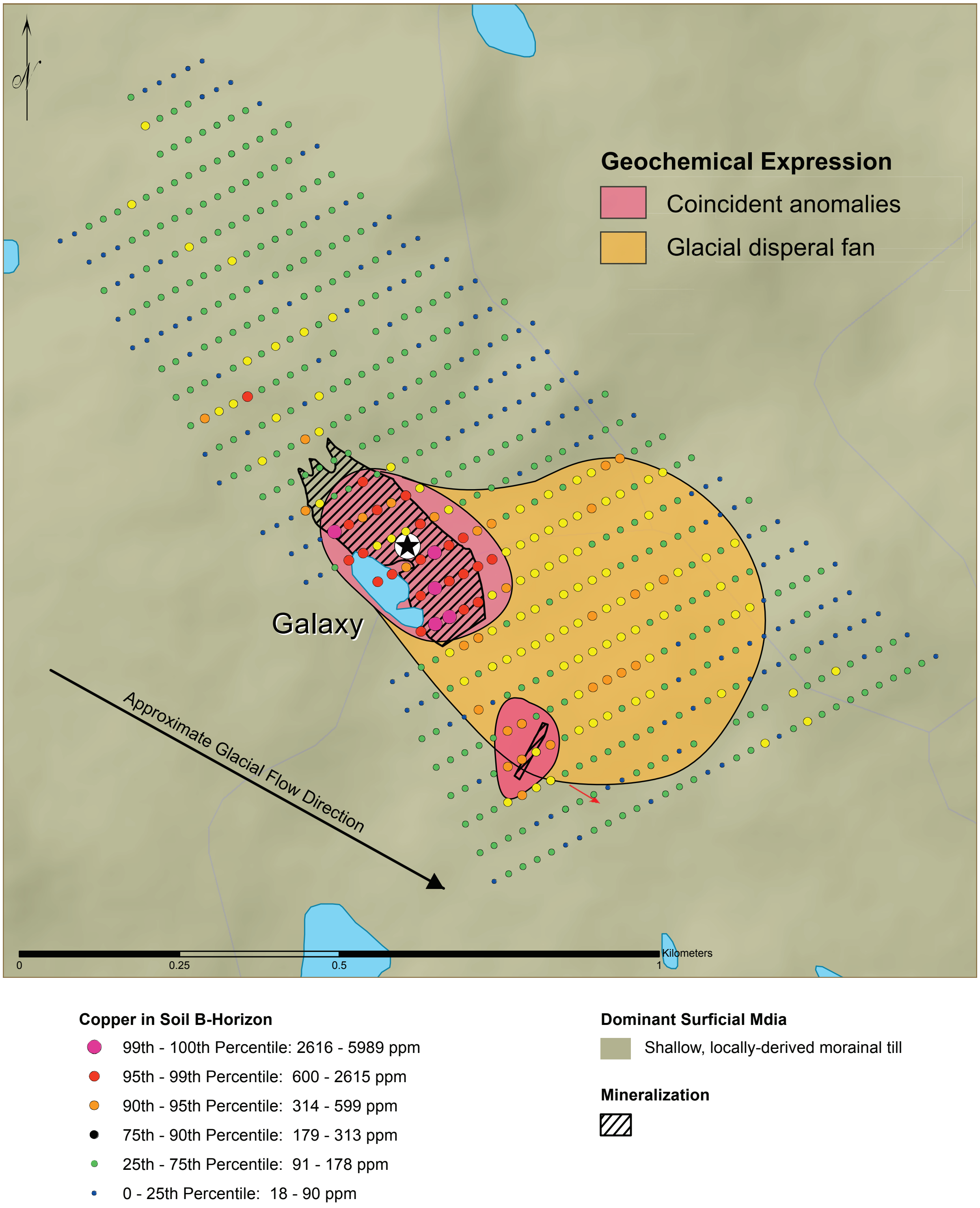

Figure 3: Copper distribution in B-horizon soils at the Galaxy porphyry deposit showing the resulting interpretation of geochemical expressions/distribution processes. This is an example of the type of interpretations made possible by interrogating the combination of archival geochemical data and modern spatial datasets in the frameworks provided as project deliverables.

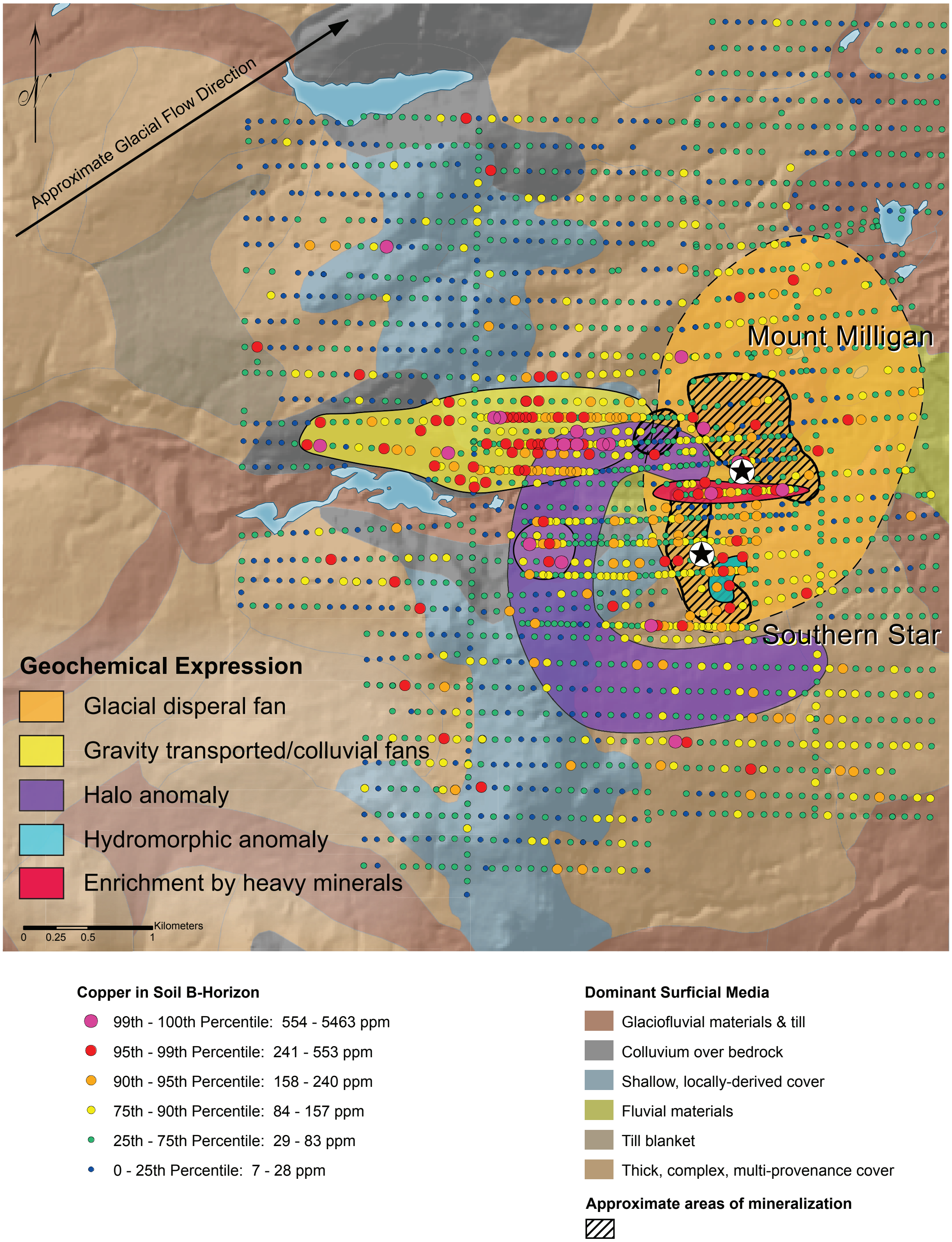

Figure 4: Copper distribution in B-horizon soils at the Mount Milligan porphyry deposit showing the resulting interpretation of geochemical expressions/distribution processes. This is an example of the type of interpretations made possible by interrogating the combination of archival geochemical data and modern spatial datasets in the frameworks provided as project deliverables.

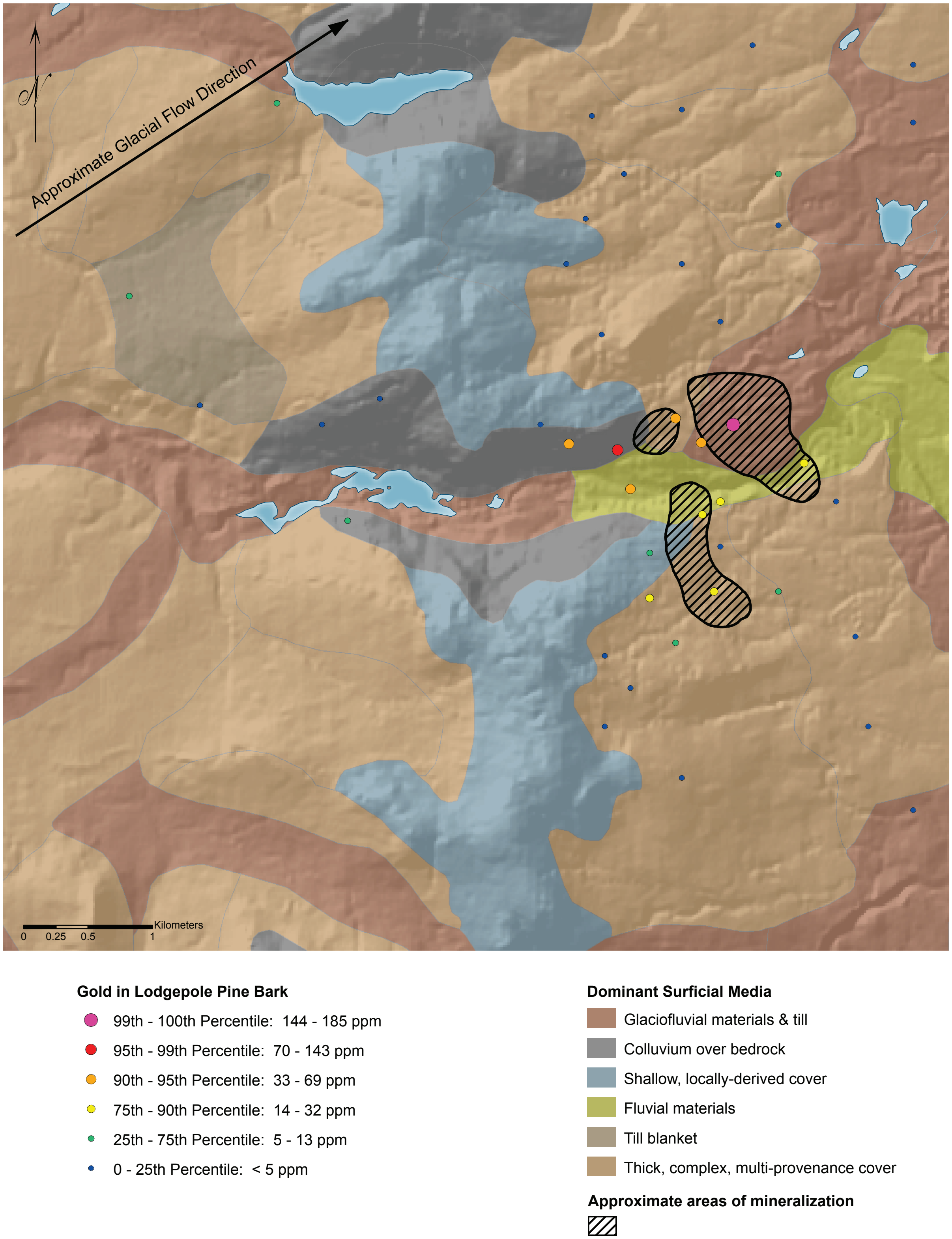

Figure 5: Gold distribution in lodgepole pine (Pinus contorta latifolia) bark at the Mount Milligan porphyry deposit showing the resulting interpretation of geochemical expressions/distribution processes. This is an example of the type of interpretations made possible by interrogating the combination of archival geochemical data and modern spatial datasets in the frameworks provided as project deliverables.

and are generally recognized through the common association of elements that are enriched during these processes. An example of a hydromorphic anomaly interpreted from the soils geochemical data at the Mount Milligan deposit is shown in Fig. 4. Here a small soil Cu anomaly overlying a mineralized area has formed in a topographic depression with elevated Mn, Fe and Co; elements which are generally found associated with hydromorphic anomalies.

Fluvial Concentration of Heavy Minerals

The elongated area of elevated Cu, Co and Fe concentration in soil in Figure 4 for Mount Milligan—labelled “concentration by heavy minerals”—lies along a valley bottom overlying fluvial sediments. It should be noted that the linear appearance of this anomaly is somewhat exaggerated due to a sight baseline shift in the geochemistry between the main survey lines and the infill lines. However, it is still evident when comparing this anomaly to the adjacent infill lines. Elevated Cu, Co and Fe in the soil is an association typical of a hydromorphic anomaly, but Mn is not elevated and there are elevated Ti and V. The higher Ti and V can be indicative of elements concentrated by accumulation of heavy minerals. The proximity of the soil anomaly to the fluvial sediments where heavy minerals (e.g. magnetite) might accumulate also supports this possibility.

DATA PRODUCTS

The products associated with this project are intended to form a dynamic framework upon which users can visually and spatially interrogate geochemical data and the geologic data layers that influence dispersion processes at each porphyry deposit. As in the examples presented in the previous section, users can test their own hypotheses of geochemical signal modification and model transport mechanisms.

For these products, available geologic and physiogeographic datasets were integrated with the geochemical data and packaged as self-extracting ArcGIS® map packages (.mpk), an industry standard format that facilitates sharing and visual reproduction of maps and data (e.g. see Figure 6). This allows users to undertake their own interpretations of geochemical signatures based on interrelated influences of physiography, geology, mineralization, surficial materials and glacial history at each porphyry deposit.

The packages open as a fully symbolized ArcGIS map project at a fixed scale (between 1:24 000 and 1:75 000), and display in a format suitable for printing on ledger/tabloid (11 by 17 inch) paper. Metadata for each layer are populated according to the ISO 19139 Metadata Implementation Specification. For each package, all GIS layers have been clipped to an area of 50 by 50 km around the deposit or group of deposits, but the maps are best displayed at the scale that incorporates the range of compiled soil-geochemical data. Users ultimately have the flexibility to view at whatever scale they wish.

Additional layers for each map package vary depending on availability of data at the highest level of detail, and may include

- digital elevation data and rendered hillshade images built from 30 m images resampled to 12 m resolution (Alaska Satellite Facility, 2015);
- National Topographic System (NTS)1:50 000 scale gridlines and UTM zones);
- bedrock geology and faults (Colpron and Nelson, 2011; Cui et al., 2015);
- surficial geology (Fulton, 1995; Hashmi et al., 2015; Plouffe and Ferbey, 2015);
- glacial indicators (Ferbey et al., 2013);
- soils (BC Ministry of Environment, 2015);
- hydrologic features (British Columbia Ministry of Forests, Lands and Natural Resource Operations, Fresh Water Atlas (FWA), 2016);
- geophysical imagery from various sources;
- scanned geological maps from assessment reports; and
- cultural and transportation information sourced from OpenStreetMap contributors (2016).

Packages are accompanied by

1) tabulated files (.xlsx) of geochemical data with map co-ordinates for manipulation outside ArcGIS;
2) Geological Survey of Canada (GSC) fonts and layer files for third-party reproduction of symbologies in map packages;
3) a PDF and georeferenced TIFF versions of the map depicting each property and the distribution of geochemical data; and
4) this report summarizing the work conducted on the project, with a full list of ARIS reports and references for each map package. These files are available for download from the Project 2009-048: Geochemical Models for BC Porphyry Deposits: Outcropping, Blind and Buried Examples page of the Geoscience BC website.

Please note that, although reasonable efforts have been made to ensure that the data presented are of the highest quality, there may be errors due to the historical nature of the data, transcription and OCR errors, and spatial re-projections necessary to provide the data in modern GIS formats. Neither Geoscience BC, MDRU nor the authors assume any liability for the correctness of the data or decisions based upon its use.

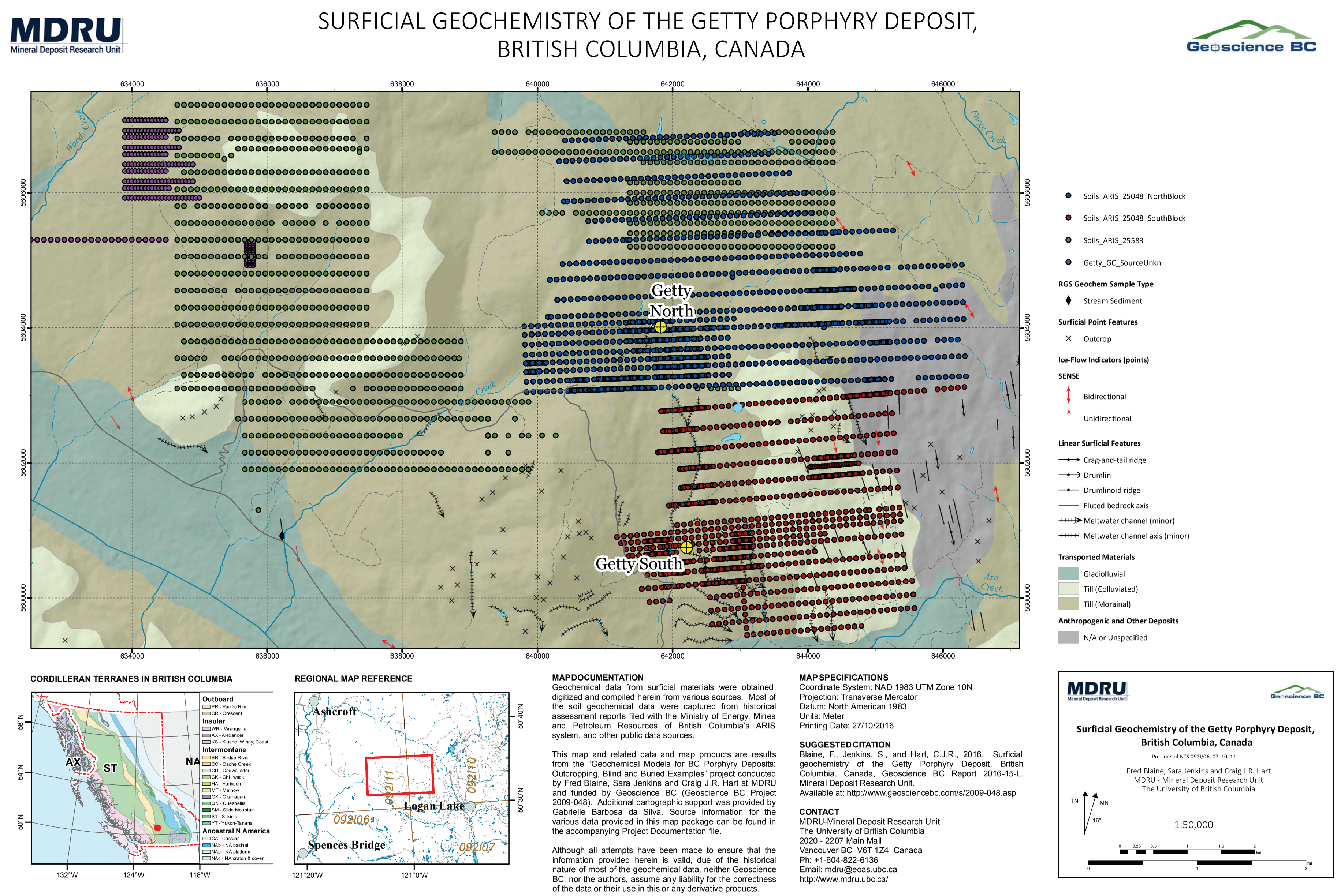

Figure 6: Surficial geochemistry of the Getty porphyry deposit, as an example of a self-extracting map package that is designed to be displayed or printed in 11 x 17 inch format. Features and text displayed here are representative and not intended to be utilized

SUMMARY

Available data from multiple sources including; government, GeoscienceBC, academic institutions but mostly industry sources have been compiled to support the generation of empirically-derived geochemical exploration models. This compilation includes geochemical data for over 50 000 industry-collected, surficial media samples that were previously public available, though in a largely unusable, PDF format. These data have been collected and are available within the 15 .mpk map packages, and as stand-alone tabular data files for each property. These datasets or stand-alone data should be used—along with additional information such as known mineralization, surficial-media mapping, digital elevation models, climate models, geology and geophysics—to generate geochemical exploration models showing generalized or expected geochemical dispersion and dispersal patterns for porphyry deposits in BC. These models are climatic environment-specific models and provide the framework for geochemical exploration program design and data interpretation in areas without proper orientation surveys, maximizing potential success in areas with limited information.

The success or failure of a geochemical exploration program designed to discover a porphyry Cu system can depend on the practitioner's ability to interpret the data and effectively drill targets. Understanding how geochemical signatures respond and are modified according to various physiographic, glacial, pedogenic, climatic and related features is essential to effective exploration decision-making. Without this integration it can be easy to exclude an area based on perceived negative results or upgrade an area based on false positive results. Datasets provided as part of this project offer the ultimate, made-in-BC opportunity for geologists to discover and understand the various controlling features related to surficial geochemical responses and patterns.

ACKNOWLEDGEMENTS

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APPENDIX 1: Data collection quality summary and georeferencing parameters

Much of the data contained within this data package were obtained from historical assessment reports filed with the Ministry of Energy, Mines and Petroleum Resources of British Columbia and other public data sources; neither GeoscienceBC nor the authors assume any liability for the correctness of the data submitted to these sources.

Some of the data contained within these packages were collected from historically scanned pdf reports through a combination of optical character recognition (OCR) with manual checking and/or manual entry. Although every possible effort has been made to ensure the accuracy of the information contained in this report, however the data are likely to contain transcription errors. Geoscience BC and the authors do not assume any liability for unrecognized errors that may occur and any decisions that may result from these errors. Source references are included in the report and users should verify critical information. If errors of consequence are encountered please notify Geoscience BC or the authors and attempts will be made to correct these errors.

The following table summarizes the data source, quality and data collection techniques for the geochemical data contained within the included map packages. Also included is the means of obtaining spatial (UTM coordinate) information for the data, when conversions were done and location maps were available sample location were checked against the map. As noted below, for specific deposits, points were manually adjusted to match the sample location maps.

To ensure that the data was as accurate as possible in all cases where OCR was used, the data was checked manually after OCR processing. Where data was questionable best attempts were made at determining the values. However, when data reproduction quality was too poor to determine the values these data were excluded and will be a null in the reports

Deposit Name/ARIS	Quality	Data Capture	GRID and Origin info	Detection Limits	Comments
PRIME – AR30033	Excellent+	OCR	UTMs from report	As reported, less than DL (<X) changed to negative DL (-X)	
North Brenda – AR30902	Excellent	OCR	UTMs from report	As reported, less than DL (<X) changed to negative DL (-X)	
Alwin – AR01028					Maps only
Alwin – AR28783	Good	OCR	Local to UTM Conversion: **Conversion Parameters:** Local: 0N, 0E NAD83: Lat 50.48473236 Long -121.11014971 Bearing: 000	As reported, less than DL (<X) changed to negative DL (-X)	
Alwin – AR30283					Maps only
Alwin – AR23151					Maps only
Getty – AR28072					Maps only
Getty – AR22481					Maps only
Getty – AR20232					Maps only

Getty – AR23340					Maps only
Getty – AR23712					Maps only
Getty – AR25048	Fair	OCR/Manual	Local to UTM Conversion: Change in North grid bearing between north half and southern half of survey Grid split into two parts North Block >2600N, South Block <=2600N North Block – coordinates used for generation of Lat-Long L4775N, 3000E Lat 50.57969263 Long -120.98335338, Bearing 359.5 South Block L800S, 3000E Lat 50.52949134 Long -120.98088484, Bearing 357 Above used for general location and manually adjusted to georeferenced location map	As reported, less than DL (<X) changed to negative DL (-X)	
Getty – AR25583	Fair	OCR	Local to UTM Conversion: **Conversion Parameters:** Easting = Local E +639871 Northing = Local N +5600000		
Getty – Other data EMPR non published data, provided by Ray Lett	Excellent +	Digital Data files	UTM coordinates provided	As reported	
Iron Mask – AR29628					
Iron Mask – AR29795	Excellent	OCR	Both local grid and UTM given in Assessment report	As reported, less than DL (<X) changed to negative DL (-X)	
Iron Mask – AR29950	Excellent	OCR	Both local grid and UTM given in Assessment report	As reported, no “<” or negative numbers	
Mount Polley – GeoscienceBC 2007-10	Excellent+	Digital Files	UTMs provided in report	As reported, no “<” or negative numbers	
Mount Polley – AR28270	Good	OCR	UTMs provided in report	As reported, less than DL (<X) changed to negative DL (-X)	
Mount Polley – AR16040	Fair to Good	OCR and Manual entry	All data points adjusted onto georeferenced location map	As reported, less than DL (<X) changed to negative DL (-X)	See supplementary data below
Mount Polley – AR30667	Excellent+	Digital Files	UTMs provided in report	As reported, less than DL (<X) changed to negative DL (-X)	
Mouse Mountain – AR19096	Poor to fair	OCR and Manual entry	Local to UTM Conversion: **Conversion Parameters:** Local: L10800N 9800E	As reported, no “<” or negative numbers	Only limited geochem data collected .pdf file

			NAD83: Lat 53.04087471 Long -122.3290335 Bearing: 360		for full multi-element data was of poor quality
Mouse Mountain – AR27902	Very good	OCR	Local to UTM Conversion: **Conversion Parameters:** Easting = Local E +540000 Northing = Local N +5870000	As reported, less than DL (<X) changed to negative DL (-X)	
Mouse Mountain – AR29178	Excellent	OCR	Local to UTM Conversion: **Conversion Parameters:** Easting = Local E +540000 Northing = Local N +5800000	As reported, less than DL (<X) changed to negative DL (-X)	
Mouse Mountain – AR30166	Excellent	OCR	Local to UTM Conversion: **Conversion Parameters:** Easting = Local E +540000 (G-South) +560000 (Moustique) Northing = Local N +5800000	As reported, less than DL (<X) changed to negative DL (-X)	
Davidson – AR29651	Good	OCR	Local to UTM Conversion: **Conversion Parameters:** Easting = Local E +600000 Northing = Local N +6000000	As reported, less than DL (<X) changed to negative DL (-X)	
Davidson – AR30657					Maps only
Louise Lake – AR28077	Fair	OCR	UTMs provided in report	As reported, less than DL (<X) changed to negative DL (-X)	
Louise Lake – AR30665	Very Good - Excellent	OCR	UTMs provided in report	As reported, less than DL (<X) changed to negative DL (-X)	
Pitman – AR30900	Excellent	OCR	UTMs provided in report	As reported, less than DL (<X) changed to negative DL (-X)	
Babine – AR30986	Very good - Excellent	OCR	UTMs provided in report	As reported, less than DL (<X) changed to negative DL (-X)	
Babine – AR21722	Good	OCR	Manual assignment of coordinates from map **Conversion Parameters** **LB-1 Grid:** Easting = Local E +661127 Northing = Local N +6110896.6 **MD-7 Grid:** Easting = Local E +661595 Northing = Local N +6111229	As reported, no "<" or negative numbers	
Babine – AR25287	Good	OCR	Local to UTM Conversion: **Conversion Parameters:** Local: L10000S, 10000W NAD83: Lat 55.18309725 Long -126.28412582 Bearing: 359	As reported, less than DL (<X) changed to negative DL (-X)	
Babine – AR25574	Good	OCR	Local to UTM Conversion: **Conversion Parameters:** Local: L10000S, 10000W NAD83: Lat 55.18309725 Long -126.28412582 Bearing: 359	As reported, less than DL (<X) changed to negative DL (-X)	
Babine – AR24376	Good	OCR	Local to UTM Conversion: **Conversion Parameters:**	As reported, less than DL (<X)	

			Local: L10000S, 10000W NAD83: Lat 55.18309725 Long -126.28412582 Bearing: 359	changed to negative DL (-X)	
Takla-Rainbow – AR28264	Excellent+	Digital File	UTMs provided in report	As reported	
Takla-Rainbow – AR29011					Maps only
Takla-Rainbow – AR29891					Maps only
Mount Milligan – BC EMPR OF1996-17	Excellent+	Digital FIles	UTMs provided in report		
Mount Milligan – AR12912	Excellent	Digital File	UTMs provided in report	As provided	Provided in collaboration with GeoscienceBC PIP project
Mount Milligan – AR28210	Very good	OCR	UTMs provided in report	As reported, less than DL (<X) changed to negative DL (-X)	
Mount Milligan – BC EMPR OF1996-22	Excellent+	Digital FIles	UTMs provided in report		
Schaft Creek – AR30682	Very good	OCR	UTMs provided in report	As reported, less than DL (<X) changed to negative DL (-X)	
Red Chris – AR23834					Maps only
Red Chris – AR24615	Good	OCR	Converted from drillhole data from AR27479: Local E Local N UTM_E UTM_N 51394 99984 453297 6395503 51798 99985 453700 6395489	As reported, no “<” or negative numbers	
Red Chris – AR24453	Good	OCR	Converted from drillhole data from AR27479: Local E Local N UTM_E UTM_N 51394 99984 453297 6395503 51798 99985 453700 6395489	As reported, no “<” or negative numbers	
Red Chris – AR03044	Fair	OCR	Local to UTM Conversion: **Conversion Parameters:** Local: 0N 0E NAD83: Lat 57.72245192 Long -129.77405860 Bearing: 008	As reported, less than DL (<X) changed to negative DL (-X)	

APPENDIX 2: References for ARIS reports used for this project, and whose digitized data are contained within the associated ArcGIS map packages

ALWIN

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BRENDA

Greig, C (2009): 2006 and 2007 Exploration Programs on the North Brenda Property; Ministry of Energy, Mines and Petroleum Resources, ARIS report # 30902, 168 p. URLs http://aris.empr.gov.bc.ca/ArisReports/30902A.PDF, http://aris.empr.gov.bc.ca/ArisReports/30902B.PDF

DAVIDSON

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GETTY

Evans, G and Hewson, C (2006): Geological Mapping, Linecutting and Geophysical Surveys on the Getty Copper Option; Ministry of Energy, Mines and Petroleum Resource, ARIS report # 28072, 109 p. URLs http://aris.empr.gov.bc.ca/ArisReports/28072A.PDF, http://aris.empr.gov.bc.ca/ArisReports/28072B.PDF

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Gower, S (1994): Drilling and Metallurgical Report on the Getty Copper Claims; Ministry of Energy, Mines and Petroleum Resource, ARIS report # 23340, 99 p. URL http://aris.empr.gov.bc.ca/ArisReports/23340.PDF

Northcote, K., Grower, S., and Udumala, P (1995): Remote Sensing Analysis, Geophysical Follow-up and Ground Checking of the Getty and GTY Claims; Ministry of Energy, Mines and Petroleum Resource, ARIS report # 23712, 79 p. URLs http://aris.empr.gov.bc.ca/ArisReports/23712A.PDF, http://aris.empr.gov.bc.ca/ArisReports/23712B.PDF

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Perry, B (1998): Geochemical Report on the Getty Copper Property; Ministry of Energy, Mines and Petroleum Resources, ARIS report # 25583, 135 p. URL http://aris.empr.gov.bc.ca/ArisReports/25583A.PDF

HEARNE HILL and MORRISON

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http://aris.empr.gov.bc.ca/ArisReports/29950.PDF

LOUISE LAKE

Shulze, C. (2006): NI 43-101-Compliant Report on the Year-2005 Diamond Drilling Program On the Louise Lake Property North American Gem Inc. and Firestone Ventures Inc. ; BC Ministry of Energy, Mines and Petroleum Resources, ARIS report #28077, 213 p. URL http://aris.empr.gov.bc.ca/ArisReports/28077.PDF

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http://aris.empr.gov.bc.ca/ArisReports/30665.PDF

MOUNT MILLIGAN

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