



**GEOLOGICAL SURVEY OF CANADA
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**Biogeochemical Surveys in the Bonaparte Lake Area,
South-Central British Columbia**

C.E. Dunn and R.G. Anderson

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ABSTRACT

Exploration in the Interior Plateau of British Columbia is challenging because of the scarcity of outcrop, poor access, dense forests, and(or) glacial sediment or young basalt cover. Geophysical signatures provide some guidance, but the ore-bearing lithologies in the survey area may not generate a distinctive geophysical signature or it may be masked by that of cover rocks. An additional exploration tool is needed.

The chemical analysis of tree tissues can provide insight to the composition of rocks concealed by overburden. The roots of trees can be perceived as natural drills that 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 – in this case outer bark of lodgepole pine and Engelmann spruce. Chemical signatures are usually subtle and data should be interpreted carefully.

During the course of a mapping programme in the summers of 2007 and 2008, bark and twigs from pine and spruce, and foliage from a few western redcedar were collected on an opportunistic basis in the eastern Bonaparte Lake map area (NTS 92P 09 and 10). In 2009, a brief visit was made to collect more samples from an area of known PGE enrichments (Dum Lake) and to further substantiate the elevated levels of REE detected during the earlier surveys.

More than 500 samples were collected and analyzed for 53 elements. A few were analyzed, also, for all the PGEs and REEs. Not all elements were detectable, and some were too close to the detection limit to be usable as reliable data. However, data with good to excellent precision was obtained for more than 30 elements for all samples. Subtle multi-element trends and associations were sought in the data with the objective of assisting in mapping the concealed bedrock and for providing focus for more detailed mineral exploration. A conclusion is that in the study area, for most elements, pine bark would be the preferred sample medium, because of its ability to concentrate many elements to higher levels than spruce bark.

From this study, we conclude that the careful application of biogeochemical methods used in conjunction with other geological and geochemical data and concepts may assist in the exploration for minerals in this environment by identifying spatially-related multi-element zones of subtle enrichments.

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1. Introduction

The survey area in eastern Bonaparte Lake map area (NTS 92P 09 and 10) has poor bedrock exposure because, in addition to the forest cover, glacial till and(or) glaciofluvial deposits as well as Eocene and Pliocene basalt cover are extensive and locally thick (Tipper, 1971; Plouffe et al., 2009; Dohaney et al., 2010). Quaternary studies provide clear evidence of ice movement directions, and the visual and chemical analysis of rock fragments and heavy mineral concentrates derived from the glacial deposits assist in both mapping the bedrock and determining its mineral potential (Plouffe et al., 2009, 2010). Chemical analysis of the fine fraction of the glacial materials adds another data set of useful information. In areas of complex glacial history this information provides tangible evidence of the substrate and vectors toward the source of materials, but needs to be supplemented by other techniques to more closely define their source. Previous studies indicate that, when paired with till studies, the chemical analysis of plant tissues can assist in achieving this goal (Dunn et al., 1991, 1996; Sibbick et al., 1996).

More than 500 vegetation samples were collected (by one of us (RGA)) over a two year period (2007 and 2008) during the course of bedrock mapping in the Bonaparte Lake area. A brief follow up sample collection program (by CED) in 2009 was aimed at an area of known enrichments of platinum group elements (PGE) near Little Fort (Dum Lake area), and an area of elevated rare earth elements (REE) to the southwest of Lac des Roches. Outer bark from lodgepole pine and Engelmann spruce were the prime sample media, supplemented by a small collection of twigs and foliage from western redcedar (referred to here as 'cedar'). The 2009 collection included twigs, needles and bark of both Douglas-fir and Engelmann spruce from the vicinity of the PGE occurrence to test the relative uptake of all PGE by a range of the common tree species in this environment. Except for the more focused 2009 survey, samples were collected on an opportunistic basis, with the emphasis on the eastern part of the survey area because of the extensiveness of prior logging, road access and degradation of pine trees due to mountain pine beetle infestation. Samples were generally collected above visible outcrop; sites were avoided where thick glacial deposits were observed since thick deposits may subdue a subtle biogeochemical response to underlying strata. An effort was made to collect samples at sites near known mineralization in outcrop (e.g., MINFILE localities). Where available, both spruce and pine bark samples were collected from the same sample station in order to determine if both provide the same information or, if different for some elements, then which species would be more useful for future exploration surveys. Excluding field duplicates, the 2007 and 2008 surveys involved the collection of 198 samples of pine bark and 180 samples of spruce bark. Cedar is less widespread in the survey area and was obtained for comparison at 35 sites. The 2009 sampling comprised 21 samples.

The objective of the biogeochemical survey was to assist in bedrock mapping and to provide focus to areas with broad geochemical 'pathfinder' associations that might be worthy of more detailed investigation. Pattern recognition of spatially related zones of suites of elements that characterize specific styles of mineralization is key to exploration strategies

2. Biogeochemical Methods – General Considerations

The underlying rationale for applying biogeochemical methods to mineral exploration is that trees and shrubs absorb metals present in the ground and transfer these metals via their root systems to the growing plant. Metals are absorbed from soil, groundwater, and locally from bedrock where roots penetrate faults, joints and cleavages. A significant advantage of applying plant chemistry to exploration is that the root system of a tree or shrub may penetrate through many cubic metres of the substrate, and therefore integrate the geochemical signature of a large volume of all soil horizons, the contained groundwater, and the bedrock where covered by a few metres of overburden,. Depth of root penetration is not critical for a biogeochemical response, because local conditions may be favourable for elements to migrate upward from considerable depth in solution, by diffusion, in electrochemical cells, by bacterial movements and in seismically active areas by seismic pumping (i.e., release of metals due to earth tremors) to be accessed by root systems. Consequently, there is commonly not a good correlation between plant and soil chemistry.

Most plants require mycorrhizal fungi on their root surfaces to effectively transfer nutrients into their structures, and the soil/root microenvironment can be highly corrosive (as low as pH 1). Furthermore, roots will take the path of least resistance and first accept elements in gaseous form, and then those in solution, then seek out additional requirements by selectively extracting labile elements – i.e., those loosely bonded to soil surfaces – such as the amorphous manganese and iron oxide coatings to which metals are known to be adsorbed, and which form the basis of various selective extraction techniques applied to soils. Once the above elemental sources have been exhausted, then further requirements of the plants will be met by their roots attacking the less labile components of the substrate – the crystalline phases of soils and bedrock.

Many texts suggest that for biogeochemical exploration to be successful there should be a high correlation between the metal content of the soil and that of the plant. This is a valid concept for some parts of the world where there are residual soils. However, a good positive correlation between plant and soil compositions may not always occur, especially where exotic overburden such as glacial deposits, lacustrine clays or wind-blown loess has been deposited on mineralized bedrock. This situation may be further complicated by elements being dissolved in groundwater, and not, therefore, reflected in the soil chemistry where elements are neither absorbed by, nor adsorbed on, soil particles. This is particularly true of highly soluble elements (e.g., some U complexes) that can remain in solution until intercepted by the root zone of a tree. Furthermore, some elements may be absorbed directly from the interaction of their roots with the groundwater and/or the capillary fringe of the water table, whereas others such as Hg may be taken up in gaseous form. Even where the physicochemical environment of the soil may not be conducive to element absorption from groundwater, plant roots can absorb elements in solution and concentrate them in their various tissues. A further consideration is that many plants establish barriers to metal uptake so that the metal content of a plant may not be proportional over a wide range of concentrations to the metal content of the soil (Kovalevsky, 1987, 1995).

Although plant to soil coefficients can be established in laboratory experiments, the real world is rarely that simple. In attempting to determine the correlation between the composition of soil and that of a tree, the usual procedure is to collect a bag of soil and a bag of tree tissue. However, there arise some fundamental questions:

- which soil horizon should be collected?
- which size fraction of the soil should be analysed?
- which type of tree tissue (and from which part of a tree, top or bottom, north or south) should be collected for comparison with the underlying soil?

Typically, each soil horizon has a different metal content, as does each size fraction of that soil. Similarly, each vegetation tissue type has a different ability to collect and store metals, and concentrations in living tissue change with the seasons. The problem is compounded by the fact that a soil sample is usually no more than a handful of a single soil horizon from which a small portion of fine-grained material is sieved, and as such represents a miniscule sample compared to the volume of material sampled by the root system of a large tree. Studies have demonstrated that the correlation between plant tissues and C-horizon soil compositions is commonly stronger than between the plant and other soil horizons, indicating that the majority of the elements in plants are derived from well beneath the surface rather than from the top few centimetres of soil (Dunn, 1992, 2007).

Plant species have different chemical tolerances, hence knowledge of metal accumulation characteristics of the different species is key to interpretation of biogeochemical data. For example, Douglas-fir trees are capable of accumulating high concentrations of As (Warren et al., 1968). Interpretation of results also requires some understanding of the chemical requirements of the many plant species. For example, Zn is an element essential for plant metabolism and therefore high concentrations do not necessarily indicate the presence of mineralization. However, Cd has a strong geochemical affinity for Zn, but it is not involved in a plant's metabolism and is therefore a better indicator of Zn mineralization than Zn itself. Similarly, B and Cu are essential elements, but they are required in differing concentrations by each plant species. Conversely, Au is not required for plant growth so the presence of high Au concentrations in plant tissue may indicate enrichment in the substrate. Nickel and Mo are involved in enzymic reactions that enhance plant growth (Kabata-Pendias and Pendias, 1992)

Many factors are involved in distributing metals among the diverse components of soils and trees. Some comprehensive accounts are given by Brooks (1983), Kovalevsky (1987), Brooks et al. (1995) and Dunn (2007). In many situations the information supplied by the tree composition is different from that derived from soils or glacial deposits - each provides its own 'layer' of geochemical information in the same way that different geophysical measurements provide different information on the physics of the Earth.

In addition to great differences in the uptake of metals by different species of plant, within a single tree or shrub there are substantial differences in the element content of its various components. For example, in some species the highest Au enrichment is in the outer bark and in others it may be in the leaves or twigs (Dunn, 2007).

In short, plants are complex structures that apply extraordinarily sophisticated mechanisms to select those elements that they require for efficient metabolic function, while tolerating other elements and sequestering them out of harm's way, and excluding other toxic elements. Each species of plant is unique in its chemical composition and, therefore, its value for biogeochemical exploration.

3. Location and Geological Summary

3.1 *Survey Location and Geological Framework*

The survey area occurs within two 1:50,000 map sheets, NTS 92P-09 and 92P-10, west of the North Thompson River and Cariboo Mountains. Figure 1 shows the regional topographic, cultural, and geological setting of the survey area (black rectangle) within the Interior Plateau of south-central British Columbia.

Recent bedrock mapping of the Thuya Batholith has indicated a complex multi-episodic Late Triassic and Early Jurassic intrusion of heterogeneous and homogeneous phases. Clinopyroxene-phyric volcanoclastic and sedimentary rocks of the Upper Triassic (Carnian) Nicola Group are intruded by the Thuya Batholith with associated deformation and metamorphism.

Batholithic suites include the Eakin Creek suite in the east, comprising diorite, monzodiorite, quartz monzonite and alkali feldspar megacrystic monzogranite phases which underlie most of the eastern half of the batholith, and, in the north, host many of the base metal Cu-rich showings. Ultramafic and minor diorite and syenitic rocks (Dum Lake suite) occur mainly along the north-eastern flank of the batholith and host Au vein and PGE occurrences. The younger, high level, unaltered, felsic and apparently unmineralized biotite monzogranite of the Bonaparte Lake phase underlies much of the western and central areas, near Bonaparte Lake.

The Rayfield River suite comprising hornblende-biotite syenite, in the western part of the batholith, is the host for the Cu-Au gold deposit of the same name. In the Rayfield River area, north- and east-trending brittle faults localize some alteration and base-metal mineralization and apparently were remobilized to localize Neogene basanite and nephelinite centres which contain mantle xenoliths.

The composite Mt. Hagen stock along the south-eastern flank of the batholith is mainly underlain by texturally heterogeneous biotite syenite phases which intruded micro-diorite. A bladed, alkali feldspar porphyry pegmatite variant of the syenite phase hosts copper-gold showings near the summit of Mt. Hagen, located in the far south-eastern corner of the survey area.

Phases with the most potential for base metal veins include the Eakin Creek mafic phase diorite, and the Rayfield River and Mt. Hagen syenite phases.

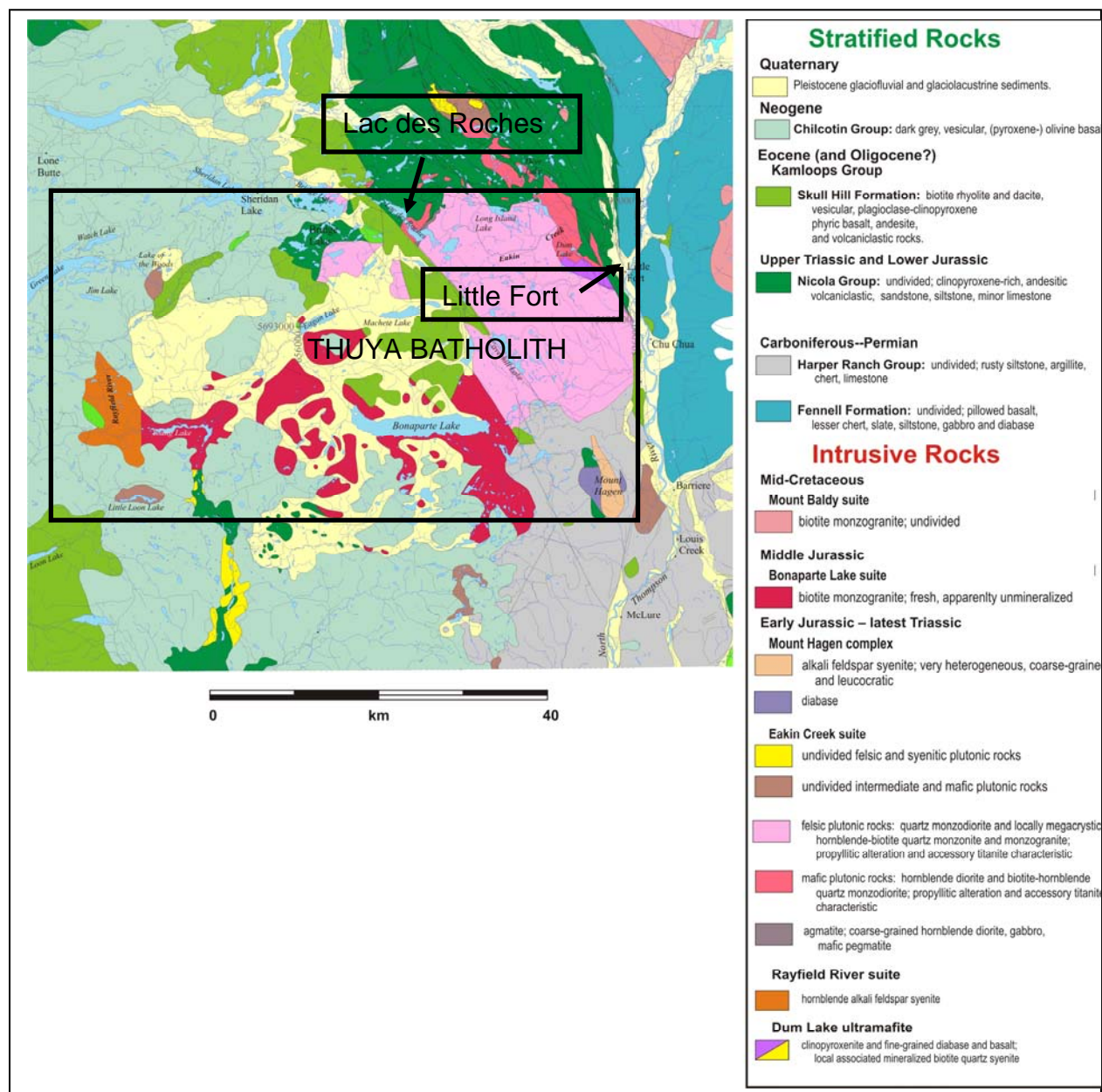


Figure 1: Geology of the survey area. Black rectangle indicates limits of the biogeochemical survey.

Two dominant directions of ice-flow have been recognized (Tipper, 1971; Paulen et al., 1999; Plouffe et al., 2009) and are depicted on Figure 2. At the onset of the last glaciation, glaciers from the Cariboo Mountains advanced in westward and south-westward directions, with the dominant direction in the present survey area toward the southwest (yellow arrows on Fig. 2). The development of the ice divide to the north caused a shift of ice flow toward the south and south-east (Plouffe et al., 2009) (green and blue arrows on Fig. 2).

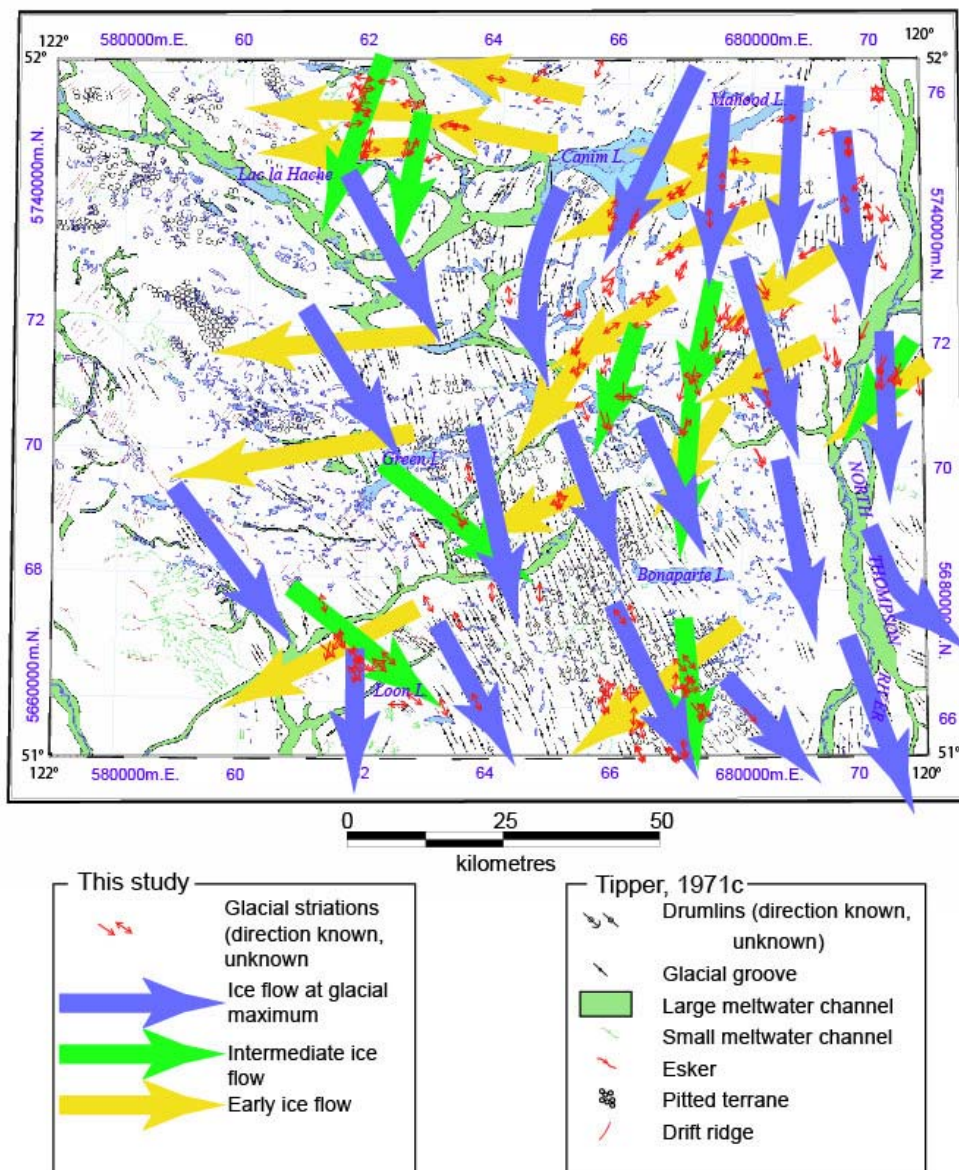


Figure 2. Ice-flow history of the Bonaparte Lake map area reconstructed from the glacial striation record. Surficial geology by Tipper (1971) is depicted in the background. Reproduced from Plouffe et al. (2009).

4. Environment and Sample Collection

The survey area encompasses a number of biogeoclimatic zones but the generally dry conditions support a vegetation cover dominated by lodgepole pine (*Pinus contorta*) and Engelmann spruce (*Picea engelmannii*), with cedar (*Thuja plicata*) in valleys and moister areas. Douglas-fir (*Pseudotsuga menziesii*) is relatively rare, except in the east near Little Fort. There is a wide range in topographic elevation in the survey area, and samples were collected from elevations of 500 m to 1550 m.

Previous biogeochemical surveys have made extensive use of lodgepole pine outer bark as a sample medium for mineral exploration, because of its ability to selectively absorb and accumulate certain trace metals (e.g., Dunn and Hastings, 1998). Other studies have demonstrated the value in using Engelmann spruce bark in defining its response to base metal mineralization (e.g., the Sullivan mine; Dunn, 2000).

Using a hardened steel paint scraper, at each sample station (located a minimum of 50 m from a road or trail) the outer bark scales were scraped from around the circumference of a single tree at chest height (for both consistency and practical purposes) and collected in a dustpan with a semi-circle cut out (to rest against the curve of the tree trunk and facilitate the efficient collection). About 50 g of bark scrapings were then poured into a standard 'kraft' paper bag of the type used for collecting soils. This amount more than half-filled each bag. There are substantial differences between the compositions of the outer bark ('rhytidome') and the inner bark ('bast'), so care was taken in the field not to dig into the inner bark. The latter has lower concentrations of most elements of economic significance (Dunn, 2007).

For the cedar sampling, at each sample station 25cm lengths of twigs with attached foliage were collected. Each sample comprised 5 to 7 twigs of similar diameter, snipped from around the circumference of a single tree using Teflon-coated anvil-type pruning snips (Fig. 3).



Figure 3: Typical sample of western redcedar (cedar) foliage collected for analysis (left); photo on right shows the dried foliage separated from the twig tissue.

For the few Douglas-fir and Engelmann spruce twigs that were collected, the sampling procedure was much the same as that for the cedar.

Throughout much of southern British Columbia this amount of twig growth typically has a maximum diameter of 4 to 5 mm. Consistency in twig diameter is quite critical, because many trace elements concentrate in the bark part of the twig, while the woody tissue (the cortex) has lower concentrations of most elements. Consequently, unless there is consistency in the diameters of the twigs that are collected, any analysis of twig tissue can result in variability among samples simply because of the differing ratios of woody tissue to bark. Such inconsistency in sampling can be likened to mixing populations of A horizon and B horizon soil and expecting to obtain meaningful data. For the cedar in the current survey, the potential problems that might ensue were not of particular significance because the foliage, and not the twigs, was to be targeted for analysis. However, for the 2009 follow-up survey a few samples of both twigs and needles of Douglas-fir and Engelmann spruce were analyzed. As a general principle it is wise to follow this practice of consistency in sampling in order to minimize factors controlling metal accumulations that might simply be related to plant growth. Unseparated twigs and foliage were placed into porous polypropylene bags (Hubco Sentry II) and sent to Vancouver Island for preparation prior to chemical analysis.

5. Sample Preparation and Analysis

5.1 *Washing, drying and milling*

There is on-going debate among practitioners of biogeochemical exploration methods as to whether or not samples should be washed prior to analysis (Dunn, 2007). In general, in Canadian forests far from dusty roads washing is redundant. Whereas it might be argued that washing should be carried out as a matter of course, regardless of local conditions, there are potential problems from doing so. For example, any rigorous swirling of samples can break down the outer cells of the plant surfaces and potentially release some elements into the washing medium. In other words, the washing medium could act as a partial extractant. Consequently, the bark samples were not washed as part of the sample preparation procedure.

The samples were oven-dried at 75°C for 24 hours, still in their original bags (paper for bark and fabric for the twigs), in order to remove all moisture. This temperature is convenient but not critical and could be anywhere between 60°C (at which temperature drying would take much longer) and 100°C above which Hg may start to partially volatilize, although tests have indicated that little or none of the Hg contained within plant structure is lost until between 120-150°C (Dunn, 2007). By drying at 75°C the chemical integrity of the plant tissues is not affected with respect to the inorganic components which constitute the targets for an exploration biogeochemical survey. Once the bark samples were completely dry they were reduced to a powder by milling. For the cedar samples, the foliage was separated from the twigs before milling the foliage (Fig. 3). Twigs were retained as archive samples.

For the follow-up work in 2009 there was the requirement to determine all of the REE. In dry tissue, concentrations of many of the REE are usually below the level of detection by quadrupole ICP-MS. Consequently, for this suite of samples, after drying, they were reduced to

ash by controlled ignition at 475°C for 24 hours thereby removing all organic compounds and concentrating the inorganic elements to levels that were detectable for all REE for most of the samples, except those near the Dum Lake PGE occurrence.

5.2 *Quality Control*

Quality control was monitored on several levels:

- **Field duplicates:** after every 20th sample, a second tree was sampled.
- **Controls of known composition:** within each batch of 20 samples one control vegetation sample was inserted 'blind'; additional control samples were inserted by Acme (one control in each tray of 33 samples as part of their systematic quality control procedures)
- **Sample preparation duplicates:** within each batch of 20 samples a duplicate split of one sample was prepared and both splits submitted for analysis.
- **Laboratory duplicates:** duplicate analyses were undertaken by Acme Laboratories at a frequency of 1 in 33 samples, because samples were analyzed in trays of 33 samples.
- **Analytical 'blanks':** inserted by Acme Laboratories.

5.3 *Analysis*

The analytical protocol used for all the 2007 and 2008 samples was that devised by Acme Laboratories Ltd. (Vancouver), involving a preliminary digestion of 1g of dry tissue with nitric acid, followed by complete digestion in aqua regia for a prescribed time. For vegetation, this procedure results in almost complete extraction of most elements. The analytical package that was selected (Group 1VE-MS) provides data for 53 elements and involves analysis by ICP-MS (inductively-coupled plasma mass spectrometry).

The procedure for the 2009 samples was to digest the ashed material in aqua regia followed by a 53 element ICP-MS analysis. All Hg was volatilized during the ashing procedure, so there was a maximum of 52 elements for which, potentially, data might be available. This included data for the La and Ce, but not for the remaining 12 REE. Consequently, a request was made for analysis of all 14 REE (La to Lu).

For the 2009 samples from the PGE occurrence, a relatively new technique was employed at Activation Laboratories (method 2F-PGE) permitting the detection of all the PGE in dry tissue to sub-ppb levels. This involves microwave digestion of 0.5 g of dry, powdered tissue, followed by an ion-exchange procedure and determination by high resolution ICP-MS (HR-ICP-MS). The method eliminates interferences from isotopes of other elements, which is a common and complex problem for PGE determinations by other less sophisticated methods.

6. Quality Control and Data Handling

6.1 *Data listings and quality control*

Details on the quality control protocol are provided in section 5.2. All field observations are shown in Appendix 1, with a separate spreadsheet for each year of sample collection. Appendix 2 shows all analytical data, merged for the sample collections in 2007 and 2008, and sorted by species/tissue. Separate spreadsheets list data from the 2009 collection.

Results on the control samples are presented in Appendix 3, which contains several spreadsheets detailing:

- Control samples (for assessing both analytical accuracy and precision) – included are ‘blind’ controls (V6 – a pine used by the Geological Survey of Canada for the past 20 years), and vegetation controls inserted by Acme
- Analytical duplicates
- Field duplicates
- Sample preparation duplicates
- Acme’s internal ‘blank’ controls, of which one is a flour with very low trace element contents

In addition to the data listings, each Excel spreadsheet has an embedded chart that can be scrolled across the elements to obtain a visual assessment of the data quality. This can be done by clicking on the graph then dragging the green and blue boxed areas in the spreadsheet to the element of interest. Colour codes for the bars on these charts are as follows:

- **Black bar** - (first bar on the left) indicates detection level
- **Blue bars** - 'blind' control samples
- **Red bar** - average value
- **Dark Blue bar** - standard deviation
- **Magenta bar** – ‘target’ value (accepted value based on several hundred analyses by this analytical method)

The over all reproducibility of most elements in the control standards was very good, and the data showed good accuracy with respect to values previously obtained. Exceptions were elements where concentrations were at or close to detection levels. A measure of the reproducibility is the Relative Standard Deviation (RSD), expressed as a percentage. The RSD for most elements in each of the controls was less than 10%. Table 1 summarizes the data shown in Appendix 3 for the control samples.

		RSD%-2007	RSD%-2008	RSD%-2007	RSD%-2008	RSD%-2008
		V6	V6	V14 - Acme	V14 - Acme	V16 - Acme
Ag	ppb	9	9	10	7	5
Al	%	11	8	5	7	0
As	ppm	58	40	2	5	6
Au	ppb	65	66	13	48	39
B	ppm	14	15	6	11	10
Ba	ppm	7	5	38	9	14
Be	ppm					
Bi	ppm			4	8	
Ca	%	5	4	4	5	4
Cd	ppm	8	6	5	6	6
Ce	ppm	7	9	7	16	10
Co	ppm	10	8	4	7	13
Cr	ppm	16	7	7	23	16
Cs	ppm	6	6	5	7	6
Cu	ppm	9	8	5	4	24
Fe	%	7	4	4	5	13
Ga	ppm	34	37		38	36
Ge	ppm					40
Hf	ppm	32	27			38
Hg	ppb	16	10	12	8	14
In	ppm					
K	%	8	5	5	5	5
La	ppm	9	7	0	29	11
Li	ppm	23	11	19	22	25
Mg	%	6	5	5	7	5
Mn	ppm	5	4	4	4	3
Mo	ppm	8	6	14	16	21
Na	%	9	7		25	59
Nb	ppm	12	20			18
Ni	ppm	9	8	8	5	13
P	%	6	4	3	7	6
Pb	ppm	5	5	15	9	4
Pd	ppb					
Pt	ppb					
Rb	ppm	7	7	5	5	3
Re	ppb					
S	%	21	27	35	21	
Sb	ppm	14	31	10	5	22
Sc	ppm	31	21			19
Se	ppm	33	41			
Sn	ppm	16	10	17	34	12
Sr	ppm	6	3	4	6	6
Ta	ppm	22	66			
Te	ppm					
Th	ppm	30	28			
Ti	ppm	6	6	8	24	6
Tl	ppm				12	
U	ppm	9	8			
V	ppm					
W	ppm					
Y	ppm	13	7	11	5	4
Zn	ppm	30	9	13	4	4
Zr	ppm	10	9	22	37	8

Table 1 Summary of the Relative Standard Deviations (RSD%) for each of the control samples shown in detail in Appendix 3.

The only elements to exhibit consistently poor precision (RSD mostly >25%) were Au, Ga, Ge, Hf, S, Se and Ta. Beryllium, Bi, In, Pd, Pt, Re, Te, Tl, V and W were below the levels of detection in all or most samples, so RSD values could not be calculated. Precision for As in the blind control (V6) was poor because levels of As are close to detection. However, the precision for As was very good in controls V14 and V16 which have concentrations an order of magnitude or more greater than in V6. When values are close to detection limit the precision is invariably inferior to values well above detection. Sodium, in particular, suffers from this as can be seen in Table 1 where precision in V6 is good, but in the other controls where concentrations are close to detection limit the precision is far inferior. The generally poor precision for Au is largely a function of the low Au concentration in nearly all samples (<1 ppb): this is the typical variability that must be expected for Au at this level using this instrumentation. It would require analysis by a multi-collector ICP-MS or an Element 2 High Resolution ICP-MS (lower detection levels) in order to obtain better precision. This would increase analytical costs substantially.

The bar chart embedded in the spreadsheet for the control samples shows the precision obtained for each year of sampling (i.e., two analytical batches). For most elements the precision for 2007 and 2008 was similar. There were some inter-year differences for S, Sc, and Na but only B showed a significant difference in accuracy. This is an inter-batch problem that has been encountered previously and no explanation has been found. The RSD obtained for B on the analytical controls was quite good (better than 15%) *within each year of analysis*; consequently, for site comparisons (e.g., field duplicates and comparisons of species) the precision is adequate for meaningful interpretation. However, the inter-year variability for B is too wide for reliably levelling the data to a common base and so no map plot of the data has been made because it would be strongly biased by the different values obtained for B each year of the survey.

In total, of the elements determined about a quarter were either present at concentrations that were too low to be determined by ICP-MS, or their precision was inadequate for further consideration. Fortunately, data for most of the elements of particular interest in the study area were at concentrations well above detection, and the analytical precision of these data was excellent.

The precision of the data from the sample preparation and the analytical duplicates was extremely good. Figure 4 presents a few examples and details for all elements can be found in Appendix 3.

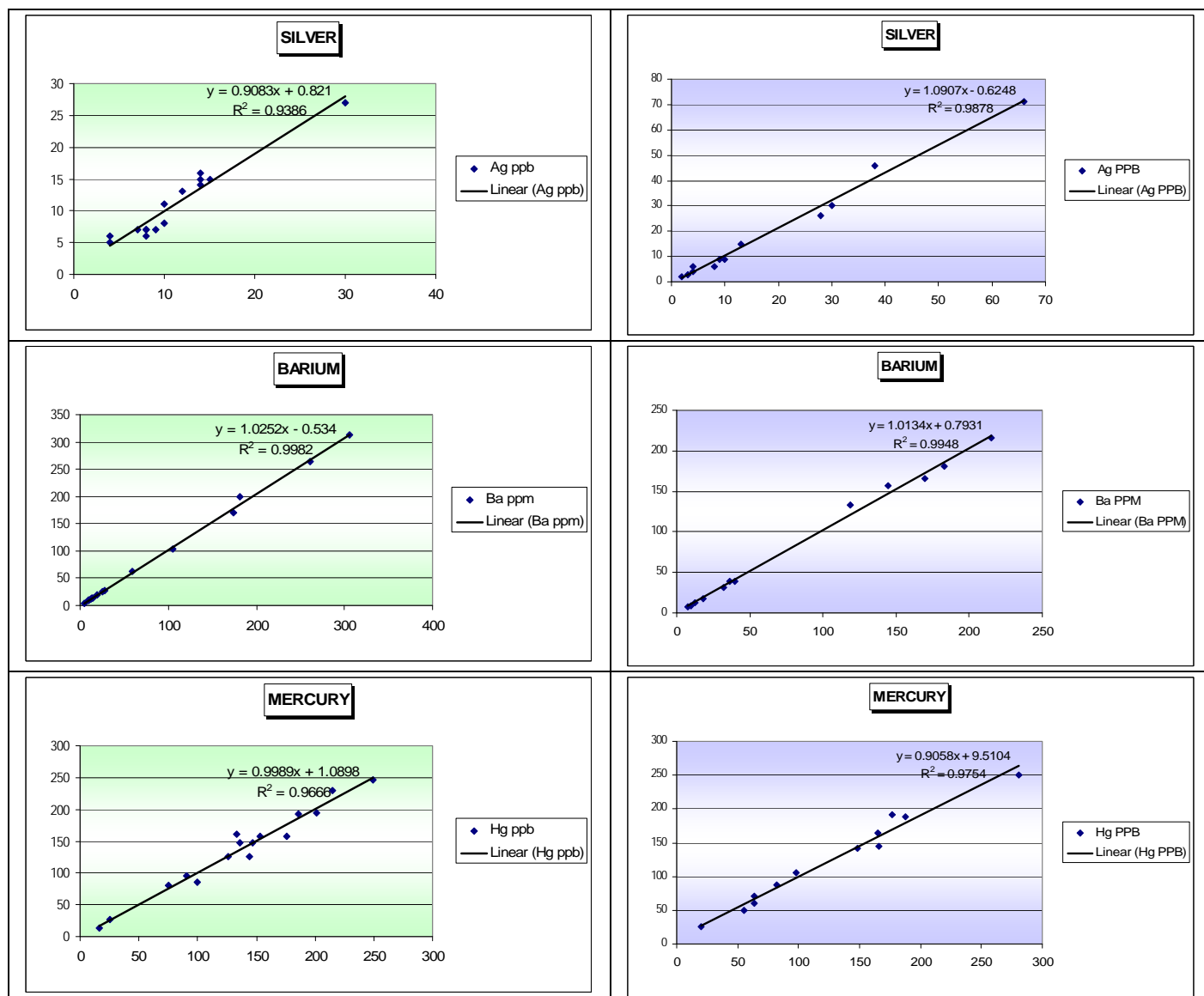


Figure 4 Analytical and sample preparation precision

Left column: Scatter plots of analytical duplicate pairs ($n = 16$) for Ag, Ba, Hg.

Right column: Scatter plots of preparation duplicate pairs ($n = 12$) for Ag, Ba and Hg.
Source data for all elements are shown in Appendix 3.

Reproducibility of the data for field duplicates (paired trees within a few metres of one another, Appendix 3) was less precise than for either the sample preparation or analytical precision. This is typical of field duplicates for almost any type of geochemical dataset, with some elements exhibiting better precision than others. Figure 5 shows scatter plots of field duplicate results for the same elements as those shown in Fig. 4, plus a plot of Pb.

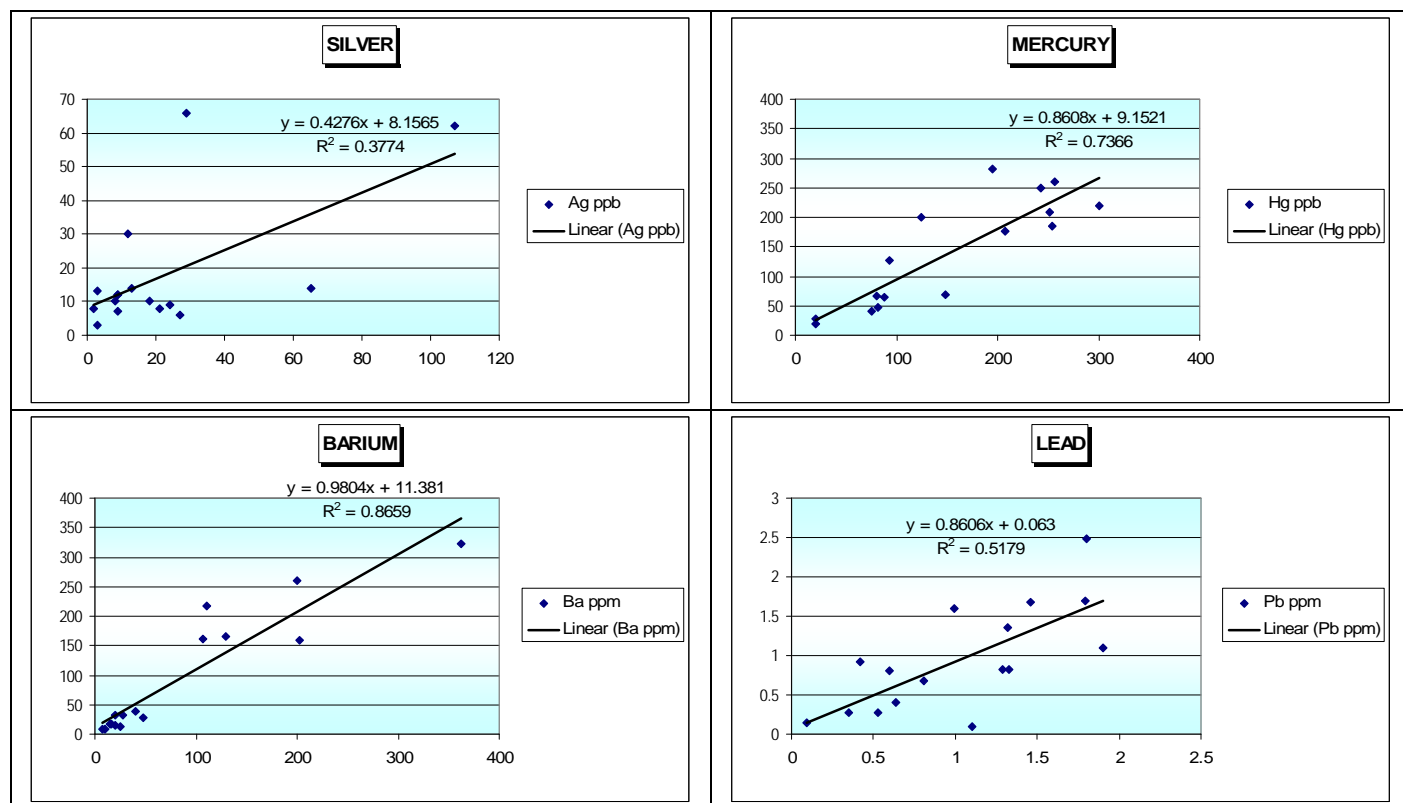


Figure 5 Field duplicate precision – Ag, Hg, Ba and Pb. Data for all elements in Appendix 3.

As a result of the differing levels of precision obtained, data need to be evaluated on a ‘fit for purpose’ basis (Bettany and Stanley, 2001) - i.e., since perfect precision for all 53 elements at the levels present is virtually impossible, consideration must be given to the question ‘are these data adequate for the task at hand?’. Duplicate samples showed that for the most part the precision was acceptable and ‘fit for purpose’ and geochemical data can be plotted with confidence that distribution patterns are dominantly natural variations. The over all quality of the data is considered acceptable with remarkably good precision for many elements, given the low levels present, especially for the sample preparation and the analytical reproducibility.

6.2 Data Handling

The following software programmes were used in analysis and plotting of the data:

- Spreadsheets in Microsoft Excel
- Statistics using SPSS software
- Map plots using the software ‘Surfer’ v.9 (Golden Software, Colorado)

On receipt of the analytical data they were entered into Excel files, and cross-reference information (sample sites, field observations, and quality control [QC] samples) was added. QC

samples were extracted into separate tables (see Appendix 3) and the data were evaluated. Subsequently, data sets were extracted as sub-files for statistical analysis and plotting of maps.

A standard set of statistical parameters was obtained for all elements. These included minimum, maximum, mean, standard deviation and the 50th, 60th, 70th, 80th, 90th and 95th percentiles. For examining the relative concentrations of elements in the survey area, the initial approach in this report was to plot 'image' (gradational colour contour) maps of each sample population (pine and spruce bark). There were too few cedar samples to warrant similar map plots.

Using the software program 'Surfer', the data were kriged prior to plotting maps. Kriging is a regression technique used in geostatistics to approximate or interpolate data. In order that false extrapolations are not shown, areas with no sample control have been blanked out. In some parts of the survey area (especially west and northwest of Bonaparte Lake) there is very little sample control. Kriging extrapolates the colour images thereby generating a false impression of the data distribution. Consequently, the few samples present are shown as large dots coloured in accord with the relative concentrations shown in the colour bar. The maps should be viewed with consideration of the sample distributions.

Each map has been prepared in a similar manner of gradational colours following a spectrum from red for highest values, through orange, yellow, green, blue, pale mauve and white for lowest concentrations. These are 'image' maps in the Surfer nomenclature. Colour changes have been adjusted to the percentile intervals and trimmed to the 95th percentile as the maximum. By so doing, extreme values do not unduly distort the contour patterns of the remainder of the dataset, because all values greater than the 95th percentile are given the same colour code. The colour changes are at the following percentile levels:

- >95th percentile – red
- 90-95th percentile - orange grading to red
- 80-90th percentile - yellow grading to orange
- 70-80th percentile - green grading to yellow
- 60-70th percentile - blue grading to green
- 50-60th percentile - lilac grading to blue
- <50th percentile - white grading to lilac

Above the colour code bar to the right of each plot, the maximum value can be found. In addition to the gradational contours, each map has superimposed on it the sample sites, the principal drainage features, roads and trails and a UTM grid.

The nature of the sample collection, described above, results in irregular sample coverage such that the data do not lend themselves well to meaningful kriging. There are large areas with no sample coverage and where a sample or samples on the margins of such areas have elevated levels, the colour is extrapolated into these areas where there is no sample control. This effect is

particularly pronounced for Ce, Th, Cu, Mo and U (amongst others). To avoid providing misleading information on the distribution of these elements, the areas with no sample control have been blanked out with pale grey polygons. Fig. 6 shows this situation using Co in pine as an example.

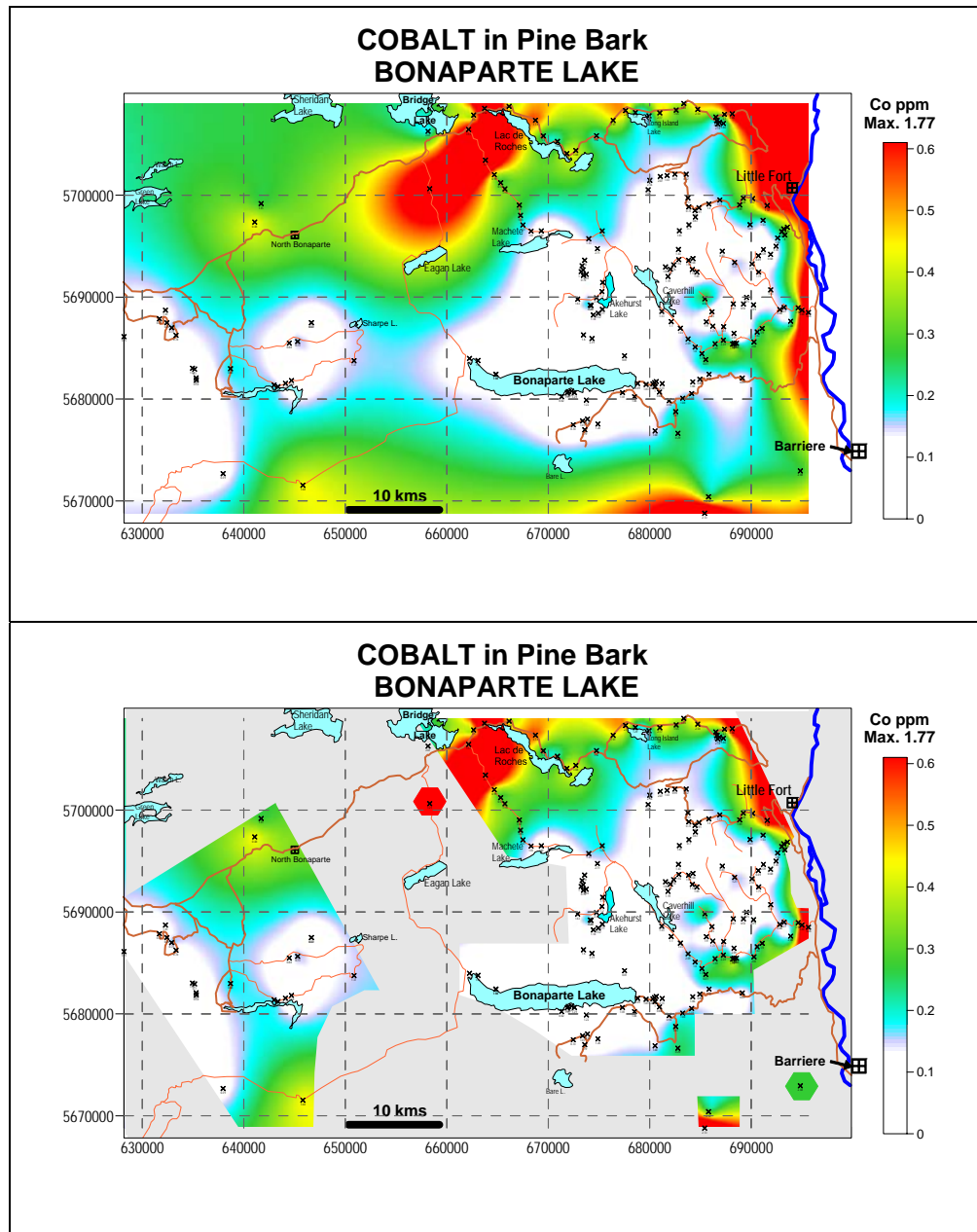


Figure 6: Cobalt in pine bark. Upper figure shows a plot of the kriged data; the lower figure is a plot of the same data, but with the areas having no sample coverage blanked out.

This procedure of blanking out areas with no sample control has been followed for all relevant elements.

7. Results

7.1 General Comments

No geochemical data set should be viewed in isolation. It is strongly recommended that the data be evaluated in conjunction with geological and geophysical evidence before final mineral exploration implications are made. The data presented here are interpreted on the basis of:

- the patterns of element distributions;
- the spatial relationships of these distributions among associated elements;
- knowledge of plant requirements of, and tolerances for, certain elements;
- the relationships of these patterns to the presumed underlying geology.

For statistical computations and for plotting maps, only one value for each pair of preparation duplicates has been used. Also, for computational purposes, values below detection have been reduced to half the detection limit prior to computing statistics and plotting maps.

7.2 Element Concentrations

7.2.1 Cedar Foliage vs. Pine Bark vs. Spruce Bark

Cedar foliage was collected at 35 sample stations. At 20 of these stations both pine and spruce bark were collected in order to undertake a multi-species/tissue comparison, and thereby provide information of potential value for optimizing future surveys. Table 2 compares the average concentrations in all three tissues. Details of the analytical results are shown in Appendix 3 along with an embedded chart for scrolling across the spreadsheet for a visual comparison of the element concentrations patterns.

From Table 2 the following information is of relevance to biogeochemical exploration in general:

- **Cedar foliage:** Highest concentrations of B, K, Mg, Mo, Ni, P and Sr.
- **Spruce bark:** Highest concentrations of Ba, REE, Co, Cs Cu, Mn, Th, U and Zn.
- **Pine bark:** Highest concentrations of Ag, Al, As, Cd, Hg and Sb.
- **Spruce and pine bark:** both had considerably more Hg than the cedar foliage
- **Spruce bark and cedar foliage:** both had considerably more Ba than the pine bark
- **Cedar foliage:** Slightly more Au than the bark of either species
- **Cedar foliage:** Considerably less Fe than the bark of either species

		Cedar	Spruce	Pine
		Foliage	Bark	Bark
Ag	ppb	3.7	16.4	21.8
Al	%	0.008	0.019	0.037
As	ppm	0.06	0.13	0.20
Au	ppb	0.31	0.26	0.2
B	ppm	10.6	6.8	5.4
Ba	ppm	56	227	23
Be	ppm	<0.1	<0.1	<0.1
Bi	ppm	<0.01	<0.01	<0.01
Ca	%	1.30	1.40	0.67
Cd	ppm	0.01	0.15	0.28
Ce	ppm	0.11	0.35	0.23
Co	ppm	0.08	0.24	0.17
Cr	ppm	2.1	1.98	1.76
Cs	ppm	0.011	0.025	0.019
Cu	ppm	2.5	4.8	3.8
Fe	%	0.014	0.028	0.023
Ga	ppm	0.058	0.065	0.063
Ge	ppm	0.009	0.008	0.008
Hf	ppm	0.002	0.004	0.003
Hg	ppb	26	173	227
In	ppm	<0.02	<0.02	<0.02
K	%	0.62	0.14	0.13
La	ppm	0.06	0.17	0.11
Li	ppm	0.09	0.11	0.09
Mg	%	0.15	0.05	0.06
Mn	ppm	211	340	173
Mo	ppm	1.3	0.07	0.06
Na	%	0.001	0.002	0.003
Nb	ppm	0.010	0.025	0.020
Ni	ppm	4.3	1.08	0.805
P	%	0.137	0.022	0.022
Pb	ppm	0.2	1.0	1.5
Pd	ppb	<2	<2	<2
Pt	ppb	<1	<1	<1
Rb	ppm	2.2	1.9	1.7
Re	ppb	<1	<1	<1
S	%	0.05	0.04	0.04
Sb	ppm	0.024	0.018	0.039
Sc	ppm	0.17	0.16	0.19
Se	ppm	0.16	0.17	0.17
Sn	ppm	0.028	0.027	0.023
Sr	ppm	77	57	18
Ta	ppm	<0.002	<0.002	<0.002
Te	ppm	0.013	0.015	0.012
Th	ppm	0.01	0.06	0.02
Ti	ppm	10	14	11
Tl	ppm	0.01	0.01	0.01
U	ppm	0.006	0.014	0.008
V	ppm	1.05	1.25	1.4
W	ppm	<0.1	<0.1	<0.1
Y	ppm	0.04	0.10	0.08
Zn	ppm	12	75	38
Zr	ppm	0.05	0.10	0.09

Table 2: Comparison of average concentrations of elements in cedar foliage, spruce bark and pine bark at 20 sample stations where all three were collected. Elements significantly more enriched in one medium are high-lighted in green.

7.2.2 *Pine bark vs. Spruce Bark*

In general, the trace element concentrations (Table 3) are similar to those typical of pine and spruce outer bark samples from elsewhere on the Interior Plateau of British Columbia (e.g., Dunn and Hastings, 2000). The 50th percentile provides an estimate of background concentrations. When the pine data are compared to those from the spruce it is evident that concentrations of many elements are similar. However, there are some substantial differences.

PINE

		N	Percentiles		Maximum
			50	95	
Ag	ppb	198	13	43	75
Al	%	198	0.04	0.09	0.18
As	ppm	198	0.1	0.6	1.2
Au	ppb	198	0.1	0.7	110
Ba	ppm	198	16	66	135
Be	ppm	198	0.05	0.05	0.1
Bi	ppm	198	0.01	0.01	0.04
Ca	%	198	0.55	1.051	1.37
Cd	ppm	198	0.26	0.82	2.17
Ce	ppm	198	0.17	1.22	4.53
Co	ppm	198	0.13	0.61	1.77
Cr	ppm	198	1.5	3.01	9.3
Cs	ppm	198	0.018	0.079	0.324
Cu	ppm	198	4.1	7.0	9.4
Fe	%	198	0.017	0.094	0.333
Ga	ppm	198	0.05	0.1	0.6
Ge	ppm	198	0.005	0.03	0.07
Hf	ppm	198	0.003	0.017	0.035
Hg	ppb	198	161	281	353
In	ppm	198	0.01	0.01	0.01
K	%	198	0.08	0.16	0.27
La	ppm	198	0.08	0.66	2.22
Li	ppm	198	0.04	0.333	1.37
Mg	%	198	0.041	0.083	0.141
Mn	ppm	198	123	299	404
Mo	ppm	198	0.07	0.19	0.3
Na	%	198	0.002	0.011	0.046
Nb	ppm	198	0.01	0.07	0.39
Ni	ppm	198	0.5	2.1	7.6
P	%	198	0.02	0.032	0.04
Pb	ppm	198	1.32	3.04	8.24
Pd	ppb	198	1	1	4
Pt	ppb	198	0.5	1	3
Rb	ppm	198	1	2.7	8.5
Re	ppb	198	0.5	1	1
S	%	198	0.03	0.061	0.08
Sb	ppm	198	0.03	0.07	0.24
Sc	ppm	198	0.2	0.5	0.8
Se	ppm	198	0.2	0.305	0.5
Sn	ppm	198	0.01	0.05	0.63
Sr	ppm	198	20	46	71
Ta	ppm	198	0.001	0.002	0.006
Te	ppm	198	0.01	0.03	0.06
Th	ppm	198	0.01	0.07	0.57
Ti	ppm	198	8	49	177
Tl	ppm	198	0.01	0.02	0.03
U	ppm	198	0.005	0.031	0.15
V	ppm	198	1	4	9
W	ppm	198	0.05	0.05	0.3
Y	ppm	198	0.06	0.40	1.23
Zn	ppm	198	35	55	91
Zr	ppm	198	0.09	0.53	1.2

SPRUCE

N	Percentiles		Maximum
	50	95	
180	8	21	80
180	0.005	0.05	0.1
180	0.05	0.5	1.1
180	0.2	0.8	5.3
180	185	364	503
180	0.05	0.05	0.1
180	0.01	0.01	0.01
180	1.275	2.019	2.45
180	0.10	0.50	1.83
180	0.11	0.85	2.41
180	0.14	0.63	1.11
180	1.5	4.6	6.7
180	0.024	0.102	0.6
180	4.9	8.2	9.9
180	0.012	0.089	0.218
180	0.05	0.20	0.3
180	0.005	0.03	0.08
180	0.002	0.011	0.039
180	121	243	308
180	0.01	0.01	0.01
180	0.15	0.32	0.45
180	0.05	0.4	1.17
180	0.05	0.35	0.66
180	0.043	0.071	0.119
180	250	530	957
180	0.06	0.17	0.23
180	0.002	0.01	0.029
180	0.01	0.07	0.12
180	0.4	2.8	51
180	0.019	0.033	0.039
180	0.64	1.9	5.2
180	1	1	1
180	0.5	1	2
180	1.7	4.60	5.8
180	0.5	1	1
180	0.03	0.05	0.07
180	0.01	0.04	0.13
180	0.2	0.5	0.7
180	0.2	0.4	0.6
180	0.01	0.05	0.13
180	60	157	249
180	0.001	0.002	0.004
180	0.01	0.04	0.06
180	0.01	0.09	0.7
180	6	44	85
180	0.01	0.019	0.05
180	0.005	0.03	0.27
180	1	3	5
180	0.05	0.05	0.05
180	0.038	0.32	0.66
180	82	122	153
180	0.06	0.427	1.47

Ratio	Ratio
Pine:spruce	Spruce:pine
95th %ile	95th %ile
2.1	0.5
1.8	0.6
1.2	0.8
0.9	1.1
0.2	5.5
1.0	1.0
1.0	1.0
0.5	1.9
1.6	0.6
1.4	0.7
1.0	1.0
0.7	1.5
0.8	1.3
0.8	1.2
1.1	0.9
0.5	2.0
1.0	1.0
1.5	0.6
1.2	0.9
1.0	1.0
0.5	2.0
1.6	0.6
1.0	1.1
1.2	0.9
0.6	1.8
1.1	0.9
1.1	0.9
1.0	1.0
0.8	1.3
1.0	1.0
1.6	0.6
1.0	1.0
1.0	1.0
0.6	1.7
1.0	1.0
1.2	0.8
1.8	0.6
1.0	1.0
0.8	1.3
1.1	0.9
1.1	1.0
1.0	1.0
1.3	0.8
1.0	1.0
1.3	0.8
0.5	2.2
1.2	0.8

Table 3: Spruce and pine bark: 50th and 95th percentile concentrations and maxima for all elements determined in the complete populations of pine and spruce bark. Columns in green show the ratios of elements from the 95th percentiles of the datasets.

Table 4 shows those elements in Table 3 that exhibit the greatest differences between the two tree species. They show the ratios from the 95th percentiles of the datasets; examination of the data in Table 3 shows that similar ratios are evident at the 50th percentile levels. Of particular note are:

- Much higher concentrations of Ba and Sr in the spruce. There is more than 5 times more Ba and more than 3 times more Sr. Associated elements are Ca, Zn, Mn, and Rb, each of which contains more that 1.5 times higher concentrations in spruce than pine.
- Conversely, Ag Al, Cd, La, Pb and Sb are higher in the pine.

		Ratio	Ratio
		Pine:spruce	Spruce:pine
		95th %ile	95th %ile
Ag	ppb	2.1	0.5
Al	%	1.8	0.6
Ba	ppm	0.2	5.5
Ca	%	0.5	1.9
Cd	ppm	1.6	0.6
La	ppm	1.6	0.6
Mn	ppm	0.6	1.8
Pb	ppm	1.6	0.6
Rb	ppm	0.6	1.7
Sb	ppm	1.8	0.6
Sr	ppm	0.3	3.4
Zn	ppm	0.5	2.2

Table 4: Elements with significant difference in uptake by pine vs spruce bark.

These differences emphasise the differing abilities of the two tree species in accumulating elements and clearly demonstrate why data from more than one species should not be mixed. It may be that the spruce has higher (metabolic) requirements for the former suite of elements than the pine; or, less likely, it is possible that the spruce has a greater tolerance to them. It is noteworthy that the higher the ratios, the more *dissimilar* the distribution patterns are for these elements between the two species – there are few similarities between Ba and Sr patterns derived from the pine when compared to the spruce (see Appendix 4).

By contrast, elements that are present at similar levels in the two species commonly exhibit similar distribution patterns. In these cases, the robustness of the biogeochemical method is evident and the patterns can be interpreted with enhanced confidence; i.e., the patterns are substantiated by both species. It is for these reasons that interpretation of biogeochemical data needs to be approached with some knowledge of the requirements of plants for certain elements. For example, Zn is required for plant metabolism, and it is shown that Zn is present in higher concentrations in spruce bark than in pine bark (Table 4). Cadmium, however, which has a strong geochemical affinity for Zn in rocks, is not *required* for plant metabolism and better reflects the presence of Zn in the substrate than Zn itself. The plots of Cd (Appendix 4) show greater similarities between pine and spruce than those of Zn.

7.3 *Element Distribution Patterns*

7.3.1 *General Observations*

The plots in Appendix 4 each show two maps with a single element per page. The map of element distribution in pine bark is shown first, followed by that for spruce bark. It should be noted that whereas both species were collected at most sites, there are some sites where one or the other tree was absent (e.g. at the north-western end of Bonaparte Lake), therefore some differences in distribution patterns are attributable to absence of samples from some sites.

From the abundance of data and elemental plots some consistent correlations emerge. In some cases they are similarities of element distribution patterns; in others they are apparent relationships to the mapped lithologies. Table 5 summarizes these features.

Element	Chemical symbol	Higher in		Element distribution patterns	Relationships to known or interpreted underlying lithologies	Comments
		Pine	Spruce			
Aluminium	Al	X		Similar	Nicola (& Skull Hill?)	
Antimony	Sb	X		Similar	Nicola (& Skull Hill?)	
Arsenic	As			Similar	Nicola (& Skull Hill?)	
Barium	Ba		X	Different	Fairly similar over Eakin Ck. Pluton	
Cadmium	Cd	X		Similar	N. edge of Eakin Ck. Pluton	
Calcium	Ca		X	Similar	E. edge of Eakin Ck. Pluton	
Cerium	Ce	X		Similar	Nicola (& Skull Hill?)	
Cesium	Cs			Similar	Bonaparte Lake suite	Low over Eakin Ck. Pluton
Chromium	Cr		X	Similar	Nicola (& Skull Hill?)	
Cobalt	Co			Similar	Nicola (& Skull Hill?)	
Copper	Cu			Similar	Bonaparte Lake suite	Low over Eakin Ck. Pluton
Iron	Fe			Similar	Nicola (& Skull Hill?)	
Gold	Au			Similar	N. edge of Eakin Ck. Pluton	
Hafnium	Hf			Similar	Nicola (& Skull Hill?)	
Lanthanum	La	X		Similar	Nicola (& Skull Hill?)	
Lead	Pb	X		Variable	Nicola in east	
Lithium	Li			Similar	Nicola (& Skull Hill?)	
Magnesium	Mg			Similar	Ultramafics and Nicola in east	
Manganese	Mn		X	Similar	Zoned over Eakin Ck. Pluton	
Mercury	Hg			Similar	East side of Eakin Ck. Pluton	
Molybdenum	Mo			Similar	Bonaparte Lake suite	Low over Eakin Ck. Pluton
Nickel	Ni			Similar	Ultramafics and Nicola in east	
Niobium	Nb			Similar	Nicola (& Skull Hill?)	
Phosphorus	P			Different	Zoned over Eakin Ck. Pluton	
Potassium	K		X	Different		No similarities
Rubidium	Rb		X	Variable	Zoned over Eakin Ck. Pluton	
Selenium	Se			Variable	Zoned over Eakin Ck. Pluton	
Silver	Ag	X		Different	High over Eakin Ck. Pluton	Few similarities
Sodium	Na			Similar	Nicola	Low over Eakin Ck. Pluton
Strontium	Sr		X	Similar	Few similarities	Low over Eakin Ck. Pluton
Sulphur	S			Variable	Zoned over Eakin Ck. Pluton	
Tellurium	Te			Similar	Southeast and east (Mt. Hagan?)	V. low concentrations
Thorium	Th			Similar	Nicola (& Skull Hill?)	
Tin	Sn			Different	Zoned over Eakin Ck. Pluton	
Titanium	Ti			Similar	Nicola (& Skull Hill?)	
Uranium	U			Similar	Nicola (& Skull Hill?)	
Vanadium	V			Similar	Nicola (& Skull Hill?)	
Yttrium	Y			Similar	Nicola (& Skull Hill?)	
Zinc	Zn		X	Different		No similarities
Zirconium	Zr			Similar	Nicola (& Skull Hill?)	

Table 5: Summary of possible correlations to bedrock type derived from plots of element distributions – pine and spruce bark (see Appendix 3 for plots).

7.3.2 Gold

A single sample of pine bark from a site in the east, half-way between Barrière and Little Fort near the North Thompson River, yielded 110 ppb Au (Fig. 7, pine - E694618, N5688950). This highly anomalous value was not reproduced from the analysis of a second split of this sample, nor were there any of the classic pathfinder elements present and it is probably therefore an analytical artefact. Furthermore, neither spruce bark nor cedar foliage from the same sample station yielded anomalous levels of Au; consequently this high Au in pine value has been excluded from statistical analyses of the data. Geologically the bedrock is not anomalous nor are there nearby MINFILE occurrences containing Au as a commodity.

Of note are subtle enrichments of Au in the north-eastern part of the survey area (Fig. 7) in an area where several Au prospects have been identified. As typically occurs in exploration geochemistry, the patterns of element distributions are commonly of greater relevance than the absolute values – especially if a deposit is buried. Furthermore, this zone of slight enrichment is coincident with the area of elevated levels of Au grains and gold concentrations in till (Plouffe et al., 2009, 2010) – Fig. 8.

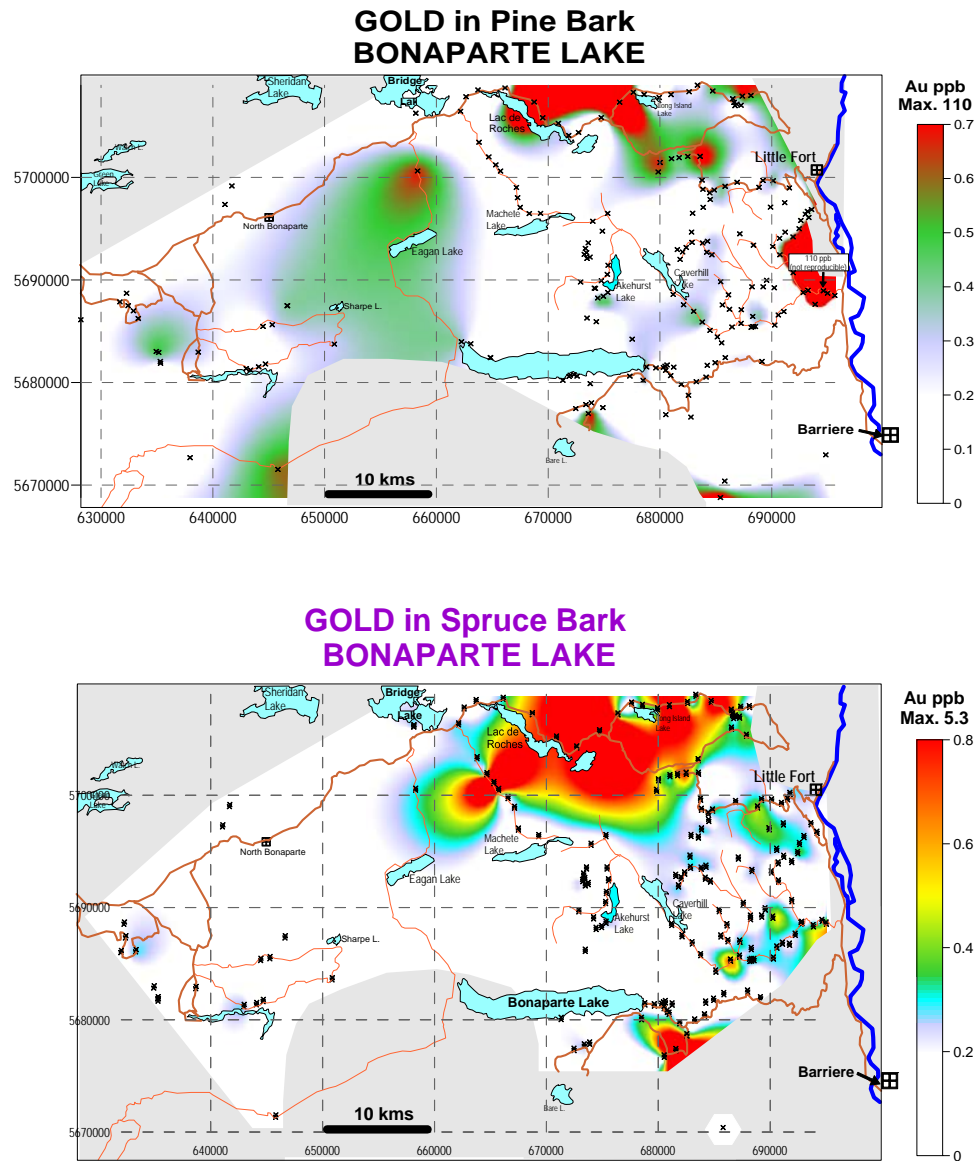


Figure 7: Distribution of Au in pine and spruce bark. See Section 6.2.1 Data Handling for further comments on the interpretation of the data image maps.

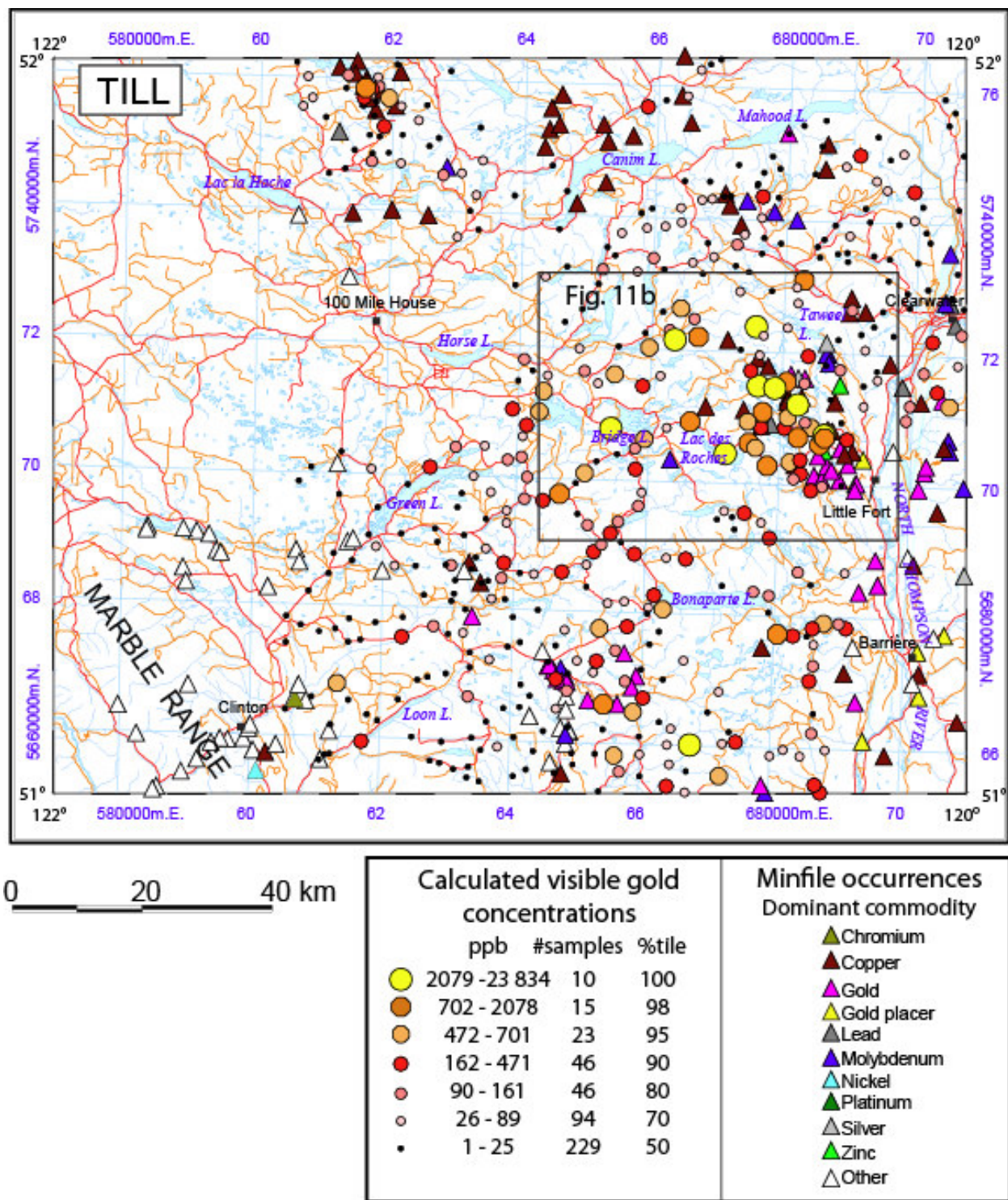


Figure 8: Gold in till (from Plouffe et al., 2009; area marked as Fig. 11b is detailed in that publication)

7.3.3 Thorianite

An interesting and potentially important observation of heavy mineral concentrates from the till study was the discovery of an abundance of the rare mineral thorianite (Fig. 9), south of Green Lake (Plouffe *et al.*, 2009). Thorianite (ThO_2) can contain several percent of both U and/or the rare earth elements (notably the LREE), as well as lesser amounts of Pb and Fe.

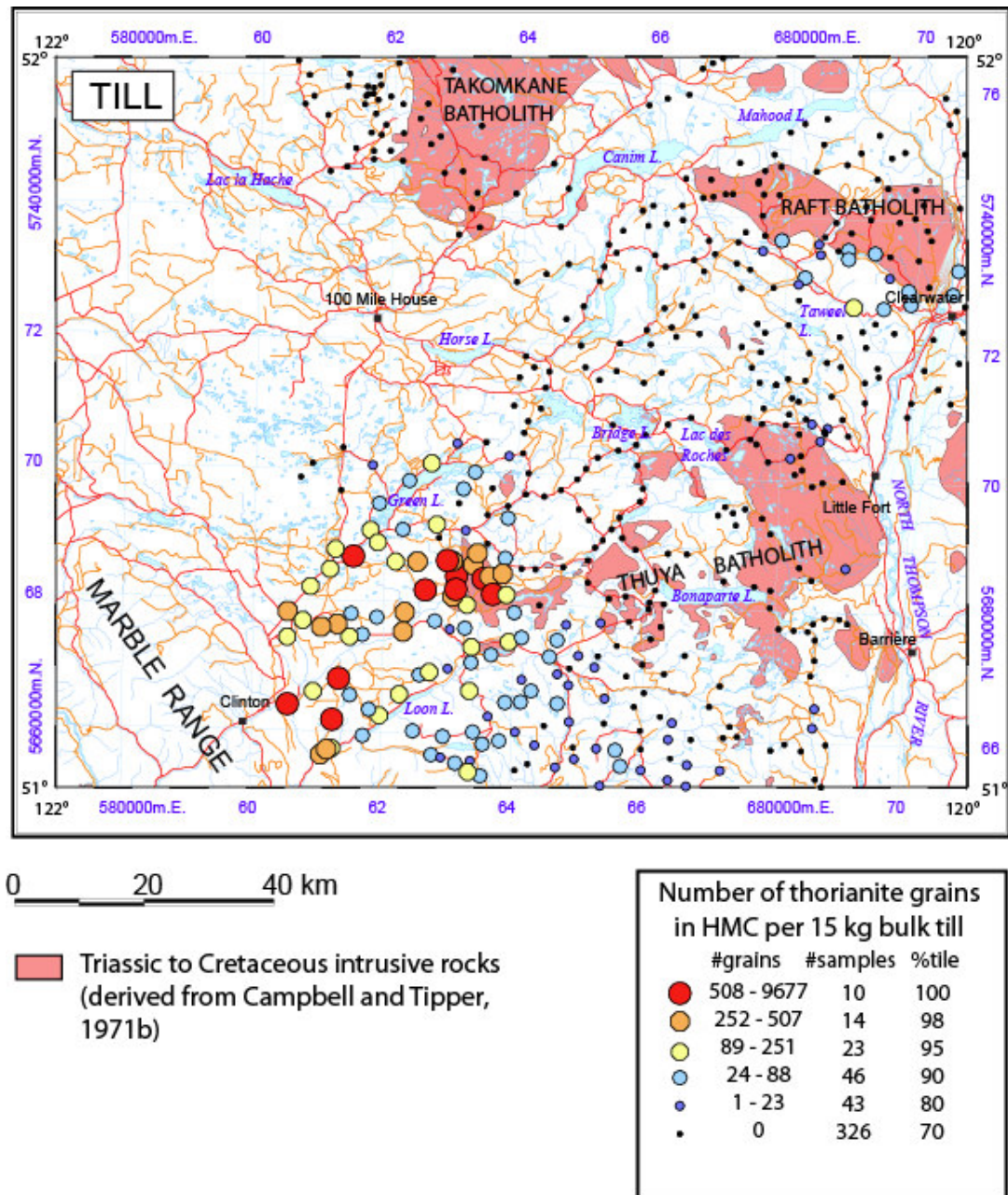
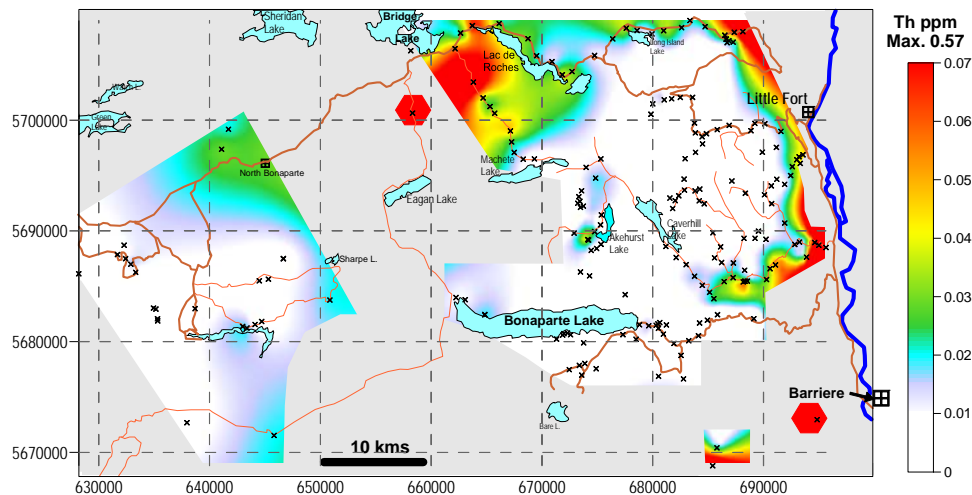


Figure 9: Distribution of thorianite grains in heavy mineral concentrates from till (from Plouffe *et al.*, 2009).

The greatest abundances of grains (up to almost 10,000 per 15 kg till sample) were clustered over, and to the southwest from, the Rayfield River syenite phase in the Thuya Batholith (Fig. 9). Bark samples from both species indicated some slightly elevated levels of Th, U and REE to the northeast of the area with thorianite (areas coloured red in Figs. 10, 11, 12). This could be reflecting the source of the thorianite, possibly from the Rayfield phase, since the first phase of dispersion from the last glaciation was from that direction modified by subsequent dispersal toward the south (Fig. 2).

THORIUM in Pine Bark BONAPARTE LAKE



THORIUM in Spruce Bark BONAPARTE LAKE

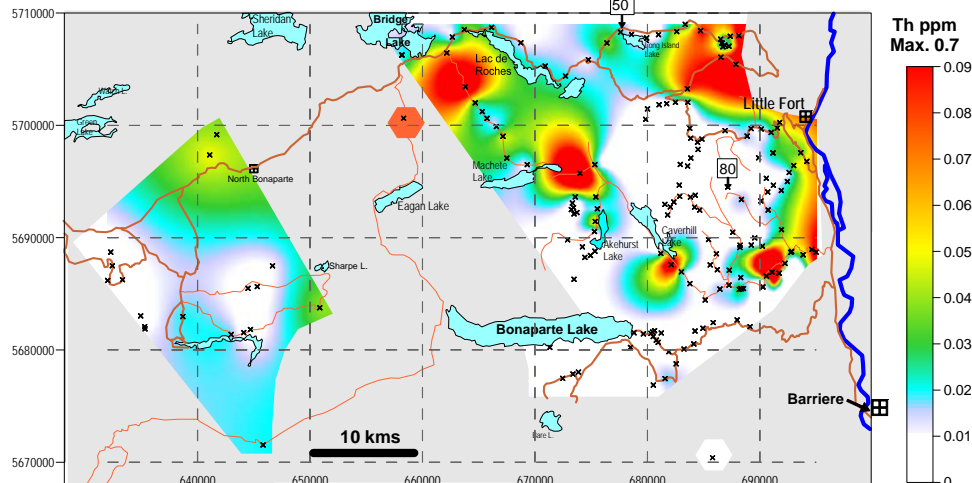
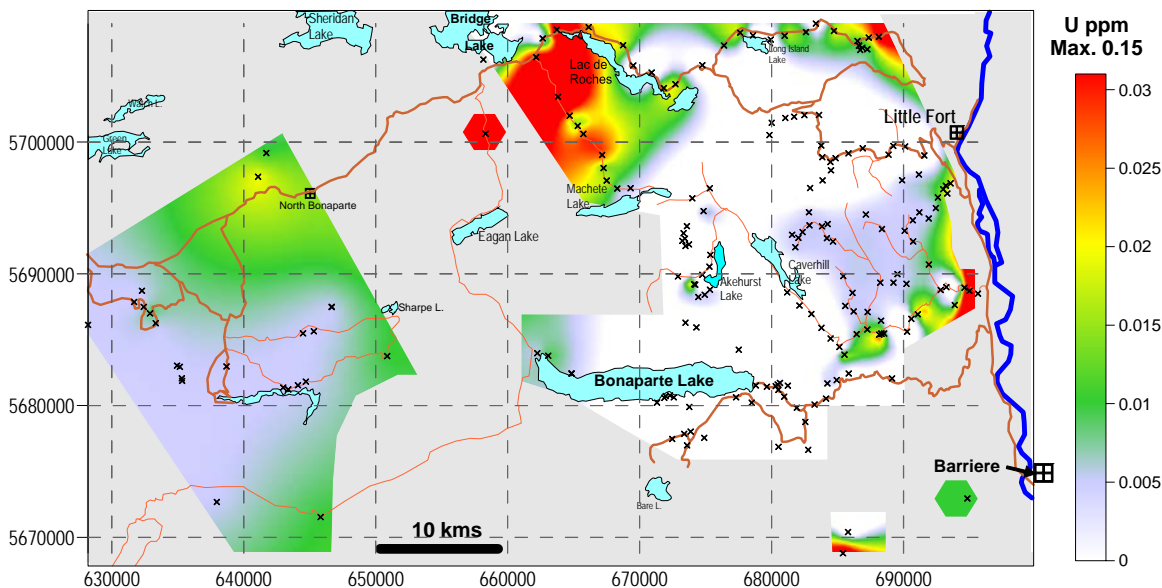


Figure 10: Thorium in pine and spruce bark. See Section 6.2.1 Data Handling for further comments on the interpretation of the data image maps.

URANIUM in Pine Bark BONAPARTE LAKE



URANIUM in Spruce Bark BONAPARTE LAKE

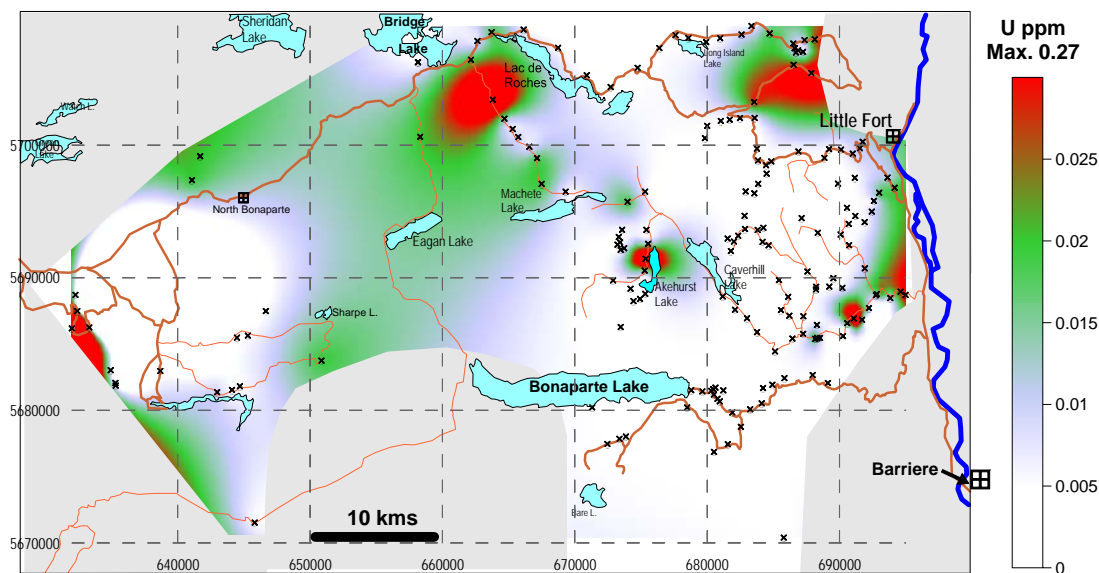
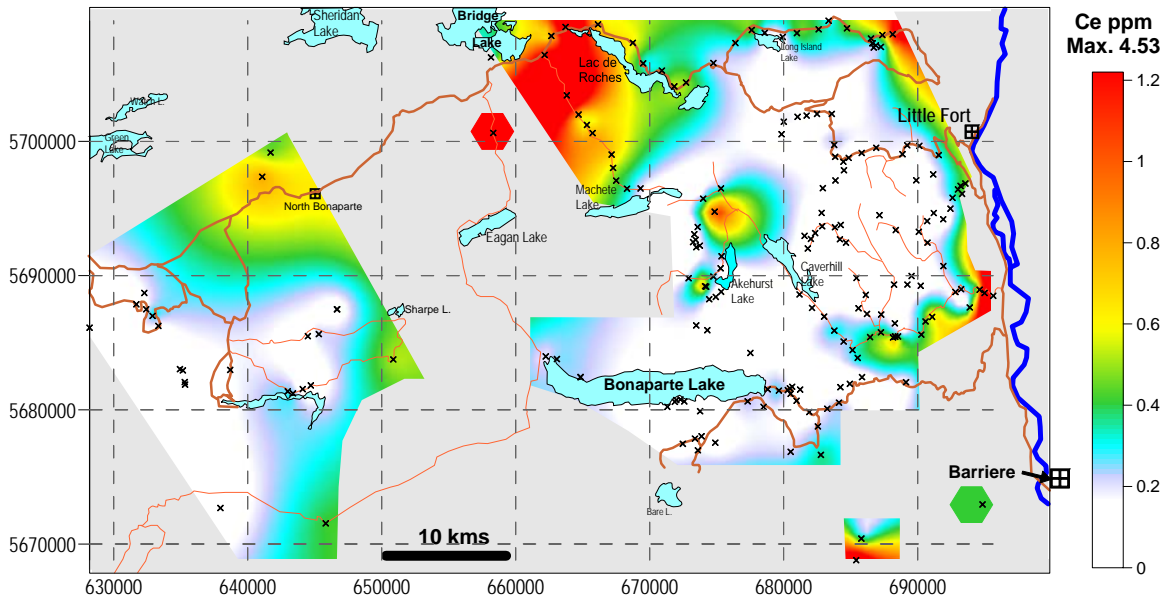


Figure 11: Uranium in pine and spruce bark. See Section 6.2.1 Data Handling for further comments on the interpretation of the data image maps.

CERIUM in Pine Bark BONAPARTE LAKE



CERIUM in Spruce Bark BONAPARTE LAKE

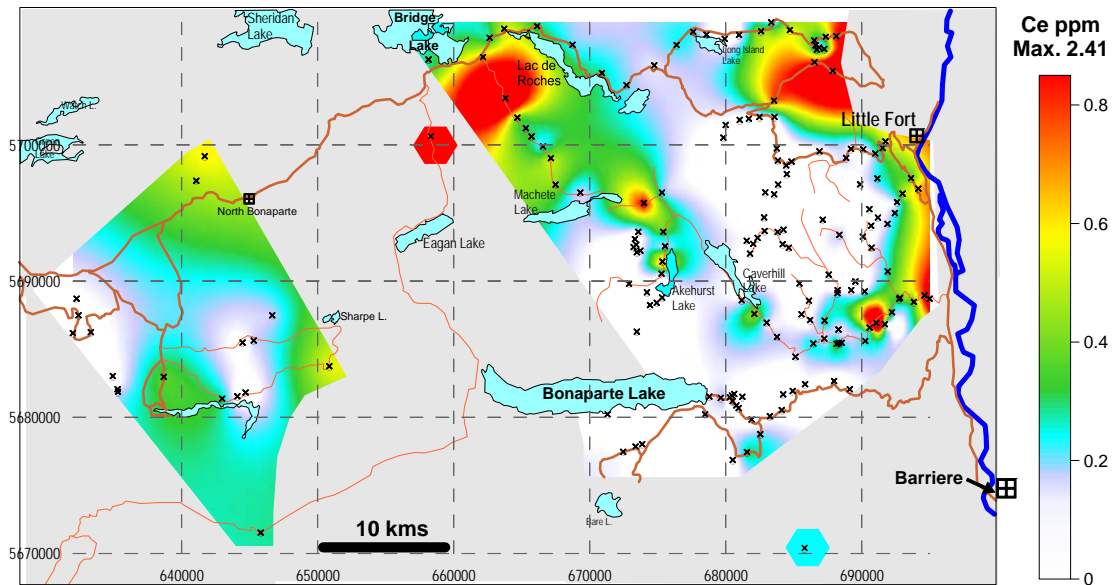


Figure 12: Cerium in pine and spruce bark. See Section 6.2.1 Data Handling for further comments on the interpretation of the data image maps.

These patterns are not definitive, because the distribution of samples is sparse and several additional elements exhibit similar patterns – Al, Hf, Fe, Li, Nb, Ti, V and to a lesser degree Co, Cr, Mg, Ni and Zr. More detailed sampling would be required to substantiate these patterns.

Samples collected in 2007 and 2008 collected south and west of Lac des Roches contain elevated levels of REE. During a brief visit to the area in 2009, additional samples of lodgepole pine and Engelmann spruce bark were collected at a few easily accessible sites on the Eagan Lake and Machete Lake roads, south of Lac des Roches (Fig. 12). The purpose was to substantiate the elevated levels of REE obtained during the earlier survey periods and to establish the concentrations of all the REE elements. In order to obtain these data the samples were reduced to ash prior to analysis, thereby concentrating the traces of REE to above detection levels. The results are shown in Fig. 13 as chondrite normalized plots, along with the a few samples from farther east (Dum Lake, near Little Fort) that had many values below detection.

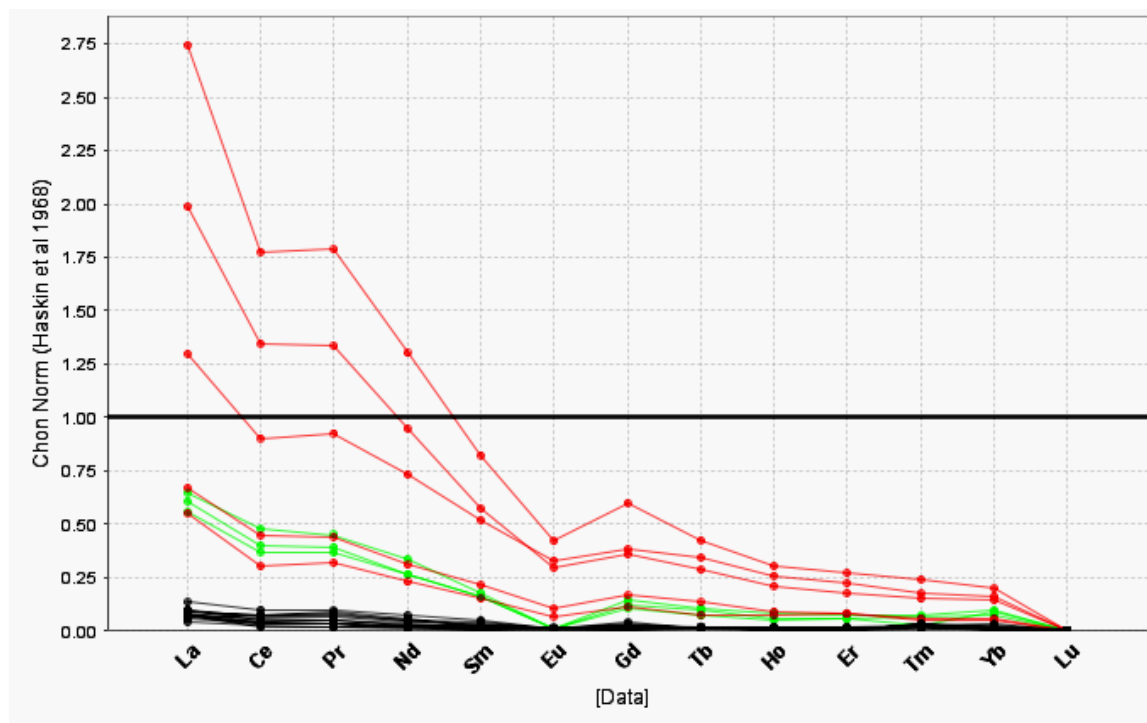


Figure 13 Chondrite normalized plots of REE in tree tissues.

Red: Lodgepole pine bark – Bonaparte Lake

Green: Engelmann spruce bark – Bonaparte Lake

Black: Douglas-fir and Engelmann spruce bark, twigs and needles – Dum Lake
ultramafic rocks (see section on PGE)

The data in Fig. 13 show that the highest concentrations of REE occur in the lodgepole pine bark. Also, the higher the total REE content, the steeper is the slope of the LREE (i.e. enrichment is mostly in the LREE). Negative anomalies for Ce and Eu indicate that they are present in their reduced state. These data confirm that an area of REE enrichment occurs southwestward from Lac des Roches. Samples of Douglas-fir and Engelmann spruce from over

ultramafic rocks near Little Fort have substantially lower concentrations. The data obtained on all these samples are shown in Table 6. Concentrations were reported in ash and have been levelled to a dry-weight equivalent as ppb.

Easting	Northing	Sample #	Tissue	Species	La	Ce	Pr	Nd	Sm	Eu	Gd	Tb	Dy	Ho	Er	Tm	Yb	Lu
					ppb	ppb	ppb	ppb	ppb	ppb	ppb	ppb	ppb	ppb	ppb	ppb	ppb	ppb
LAC DES ROCHES AREA																		
663203	5705065	BL09-ES03	Bark	Spruce	214	420	51	203	33	0.9	36	5.1	26	6.0	15.4	2.1	19.3	2.14
663659	5704020	BL09-ES04	Bark	Spruce	201	354	44	159	29	0.8	30	4.4	20	4.0	10.8	2.0	14.9	2.01
664005	5702927	BL09-ES05	Bark	Spruce	183	326	41	159	29	0.7	27	3.3	18	3.7	11.4	0.7	17.2	2.20
681014	5708280	BL09-LP01	Bark	Pine	183	267	36	137	27	4.7	28	3.7	20	5.1	16.1	1.5	10.2	2.19
662124	5706420	BL09-LP02	Bark	Pine	906	1562	200	781	149	29.0	149	20	104	21	54	7	40	7.25
663659	5704020	BL09-LP04	Bark	Pine	656	1185	150	568	104	20.4	89	13	71	15	36	4	29	3.80
650517	5693104	BL09-LP06	Bark	Pine	429	795	104	440	94	22.8	96	16	81	18	45	5	33	5.94
635381	5693553	BL09-LP07	Bark	Pine	221	395	49	185	39	7.2	41	6.3	28	6.5	16.1	1.8	12.0	1.48
ULTRAMAFIC ROCKS - DUM LAKE AREA																		
691330	5699802	DLU09-DF04	Twig	Douglas-fir	26	49	5	22	3	0.5	4.9	0.5	3.6	0.8	2.8	0.5	1.8	0.51
691518	5699616	DLU09-DF05	Twig	Douglas-fir	33	42	5	18	4	1.0	2.8	0.3	2.3	0.7	1.2	0.3	1.7	0.33
691648	5699453	DLU09-DF06	Twig	Douglas-fir	30	68	10	33	3	0.6	6.3	0.6	5.1	1.2	2.7	0.6	2.7	0.60
690840	5700240	DLU09-DF01	Needles	Douglas-fir	13	21	2	13	1.3	0.5	0.5	0.5	0.5	0.3	0.5	0.5	0.54	0.54
690945	5700185	DLU09-DF02	Needles	Douglas-fir	23	32	4	13	0.9	0.9	4.6	0.9	2.3	0.5	0.9	0.9	0.93	0.93
691125	5700063	DLU09-DF03	Needles	Douglas-fir	19	31	3	15	2	0.8	3.5	0.8	1.9	0.4	0.8	0.8	0.77	0.77
691330	5699802	DLU09-DF04	Needles	Douglas-fir	21	38	4	13	4	0.8	5.1	0.8	3.4	0.4	0.8	0.8	3.4	0.85
691518	5699616	DLU09-DF05	Needles	Douglas-fir	21	64	8	28	5	0.9	4.7	0.9	4.3	0.4	2.1	0.9	3.0	0.85
691648	5699453	DLU09-DF06	Needles	Douglas-fir	26	36	4	13	3	1.0	4.1	1.0	1.0	0.5	1.0	1.0	4.1	1.03
691330	5699802	DLU09-ES04	Bark	Spruce	33	59	7	26	6	0.7	9.1	0.7	4.2	0.7	2.6	0.7	4.6	0.65
691518	5699616	DLU09-ES05	Bark	Spruce	44	89	11	45	9	0.9	5.8	0.9	7.1	1.3	3.1	0.9	6.6	0.89
691125	5700063	DLU09-ES03	Twig	Spruce	30	67	9	32	8	0.6	9.7	0.6	6.4	0.9	3.3	0.6	3.6	0.61
691125	5700063	DLU09-ES03	Needles	Spruce	24	15	2	7	1	1.0	1.0	1.0	1.0	0.5	1.0	1.0	1.95	0.98

Table 6: REE concentrations (dry weight) in different tissues from two areas.

7.3.4 Bonaparte Lake Suite

Relative enrichments of Mo and Cs (Fig. 14a and b) and to a lesser degree Cu are present in trees overlying intrusive rocks (coloured crimson in Fig.1) in the centre of the survey area around Bonaparte Lake. In Figure 14a and b, in addition to the shaded image maps, classed post maps (proportional dots of increasing size with element concentration) have been superimposed. These are plotted using the equal sample binning method, such that there are 5 classes, each representing a 20% fraction of the sample population and shown by dots of the same colour and size. Thus, all values greater than the 80th percentile value are shown as purple dots. They provide additional information to assist in interpreting the patterns.

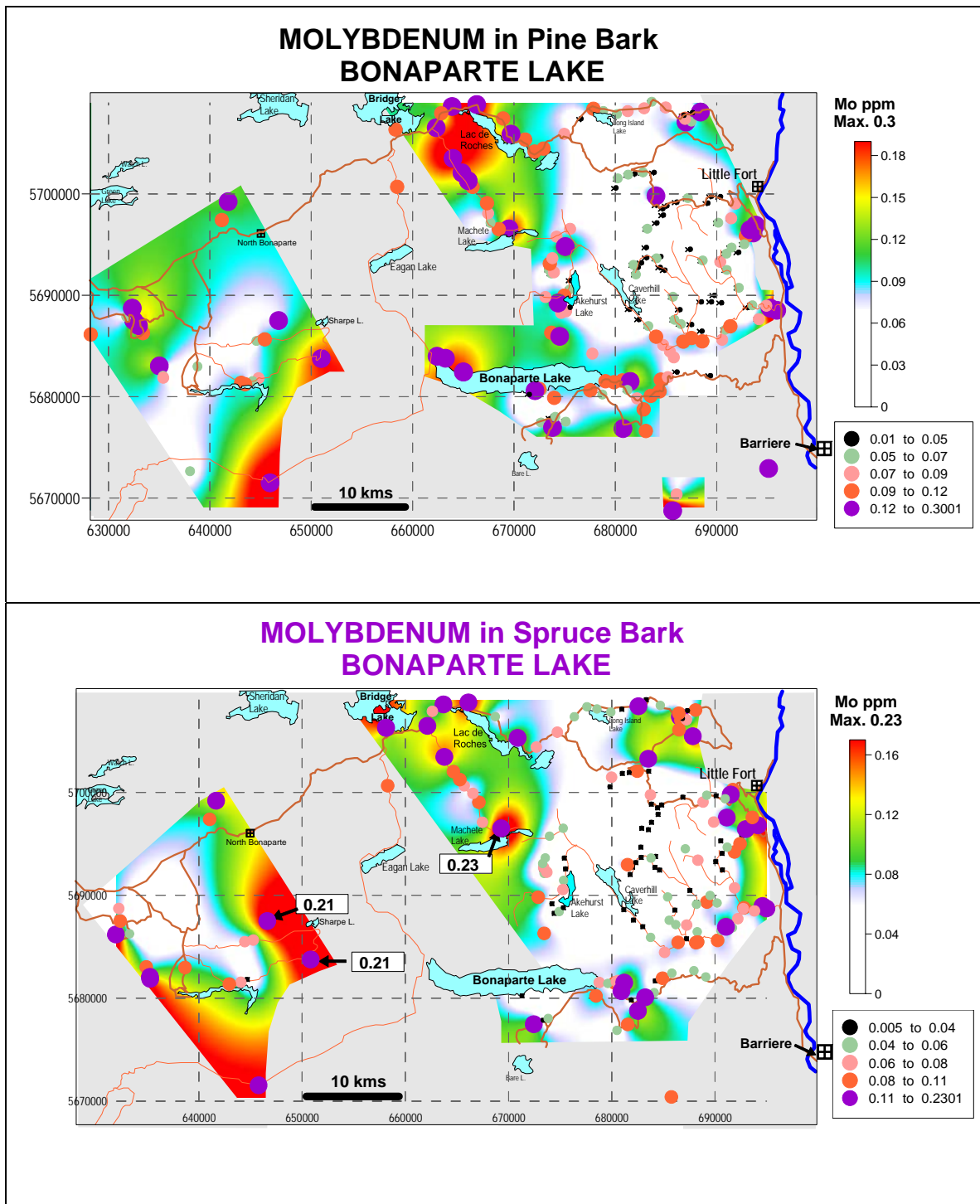


Figure 14a: Mo in pine and spruce bark. See Section 6.2.1 Data Handling for further comments on the interpretation of the data image maps.

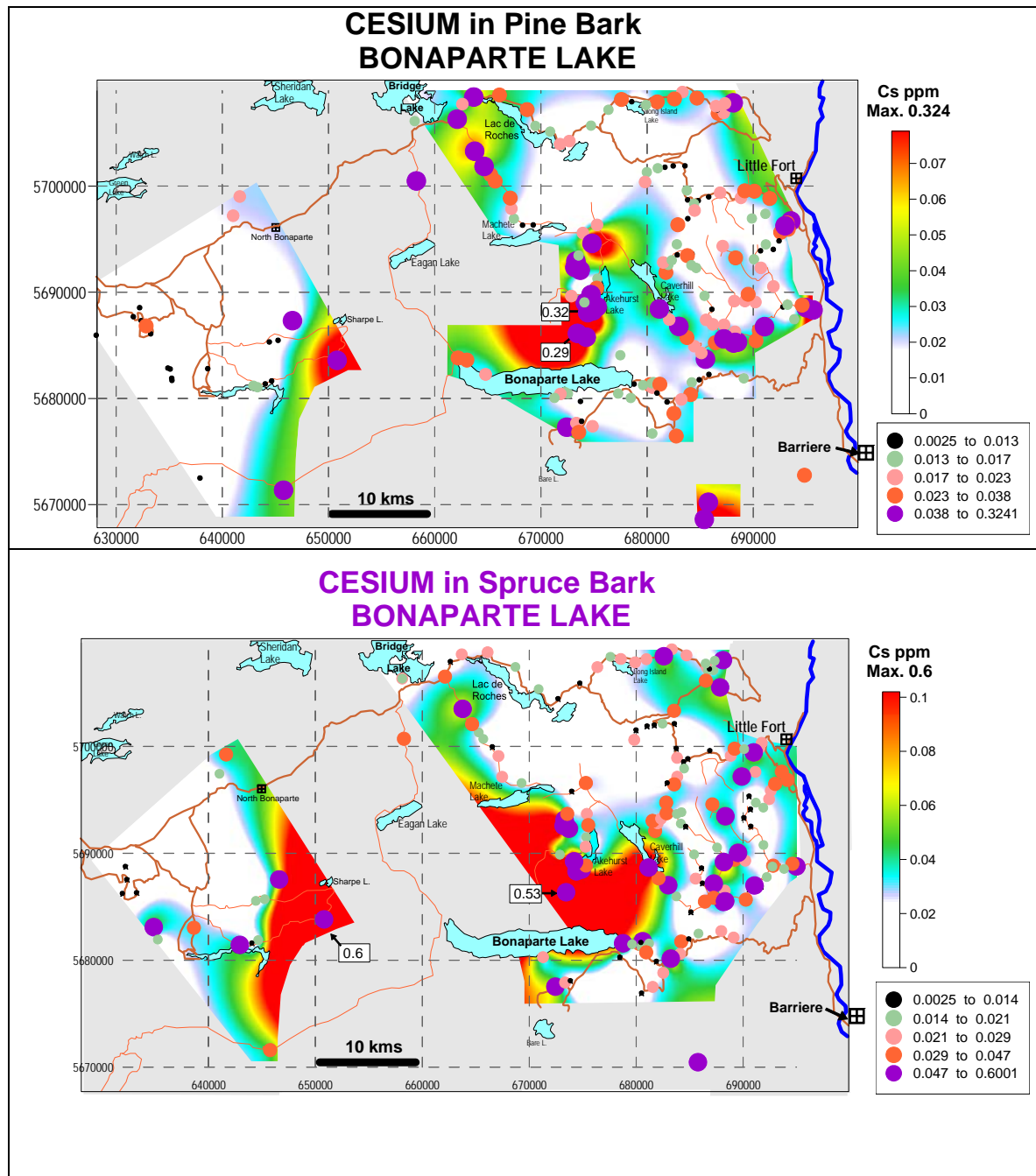


Figure 14b: Cs in pine and spruce bark. See Section 6.2.1 Data Handling for further comments on the interpretation of the data image maps.

There are very few control points for the red-coloured zones shown in Fig. 14a and b and it is, therefore, probable that these zones would be greatly modified from more detailed sampling. However, it is of interest that these are the only elements that have elevated values in

the area of the intrusive rocks of the Bonaparte Lake Suite suggesting that these rocks may be defined by having some enrichment of Mo, Cs and Cu. Most of the highest values of both Mo and Cs (labelled) within the entire survey occur in this area.

7.3.5 Eakin Creek Suite

The predominantly felsic plutonic rocks to the west of Little Fort (Fig. 1) exhibit patterns of element depletion and possible zoning.

Elements that are relatively depleted over this pluton, compared to much of the remainder of the survey area include Al, As, Cd, Ca, REE, Cs, Cr, Co, Cu, Fe, Li, Mo, K, Na, Sr, Th, Ti, U and Zn. An example of this depletion is that of Mo in Fig. 14.

Other elements suggest some zonation of this pluton: Ag, Rb, Pb and S (Fig. 15). Potassium in pine bark (Appendix 4) is elevated toward the outer parts of the pluton compared to the core and is consistent with the radiometric maps for potassium distribution in this area (Dumont et al., 2007). However, this is not apparent in the plot of the spruce bark. Perhaps the pine, with only half the concentrations of spruce, is more sensitive to potassic phases of the heterogeneous Eakin Creek suite. Similarly, Sn has higher levels in pine than spruce in the core of the pluton.

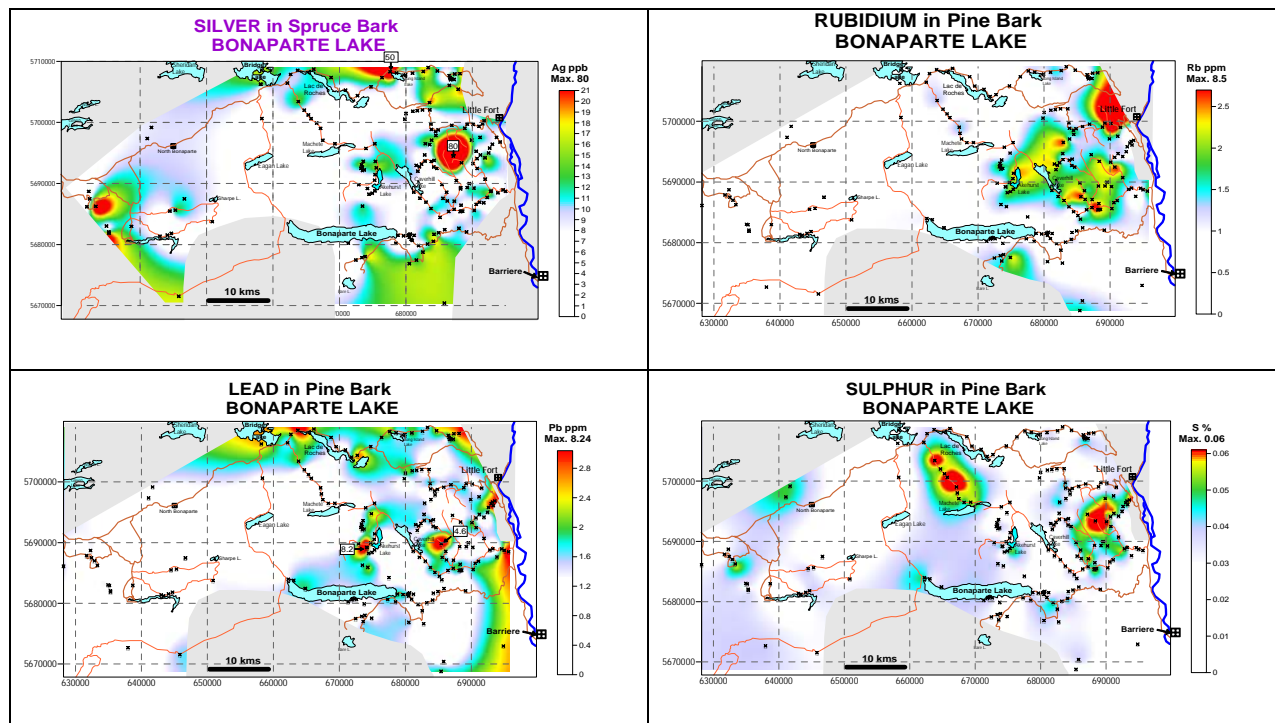


Figure 15: Elements exhibiting possible zoning in the Eakin pluton west of Little Fort. See Section 6.2.1 Data Handling for further comments on the interpretation of the data image maps.

Plots in Appendix 4 show that enrichments at the southern margin of the pluton include Hg, As, Sb, Fe, REE, Pb, Mn, Se, and traces of Au.

7.3.6 *Mafic Rocks*

Along the eastern margin of the survey area, west of Little Fort, rocks comprising the Dum Lake ultramafite include clinopyroxenite, diorite and monzodiorite and fine-grained diabase, basalt and local occurrences of mineralized biotite quartz syenite.

Plots of typical ultramafic related elements (i.e., Co, Cr, Mg, Ni) all yield relatively high concentrations in this area with a single sample of spruce bark containing 51 ppm Ni 10 km west of Little Fort, and an additional 3 sites yielding between 5-10 ppm Ni in that general area (background levels are 0.4 ppm Ni). Figure 16 shows classed post maps (equal number binning method) of the relative concentrations of Ni and Cr, and emphasises those sites with highest levels.

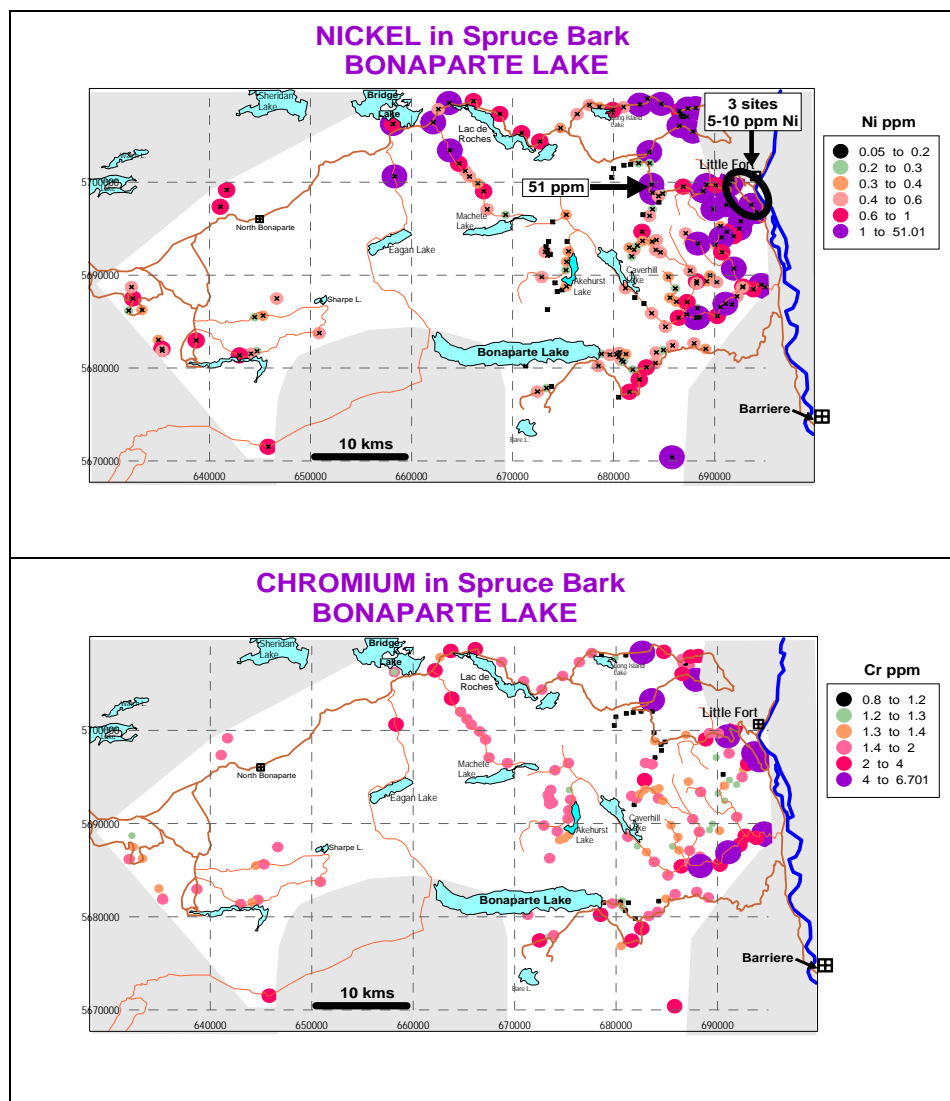


Figure 16: Classed post plots of Ni and Cr in spruce bark

The image plots in Appendix 3 show that the patterns of Co, Cr, Mg and Ni are similar in both the pine and spruce bark samples. Chromium in the pine bark exhibits some enrichment (up to 7.7 ppm Cr [Appendix 4]) in the south and may be related to the diabase phase of the Mount Hagen Complex. No spruce sample was collected from this area.

The Golden Loon Platinum or Clearwater Platinum occurrence (BC MINFILE number 092P 043) is located 2.5 kilometres west of Little Fort. A sample of highly oxidized ultramafic material cut by chromite stringers yielded an analysis of 13,798 ppb Pt, 25 ppb Pd and 23 ppb Au. A second highly anomalous sample of dark peridotite with chromite veins from about 1 kilometre to the north yielded 483 ppb Pt, 10 ppb Pd and 2 ppb Au. These two samples were

from a group of 150 samples collected under a separate project in 1999 of ultramafic rocks from the Dum Lake Intrusive Complex (MINFILE, 2009; <http://minfile.gov.bc.ca/Summary.aspx?minfilno=092P++043>).

Platinum in the bark samples was barely above the detection level of 1 ppb Pt in most samples and analytical precision at that level is poor. However, plots of the sites with detectable Pt levels (Fig. 17) are noticeably more clustered in the northeast around the mafic and ultramafic phases (mafic rocks of Eakin Creek suite, Dum Lake ultramafite and Nicola Group). No samples were taken from close to the Golden Loon occurrence.

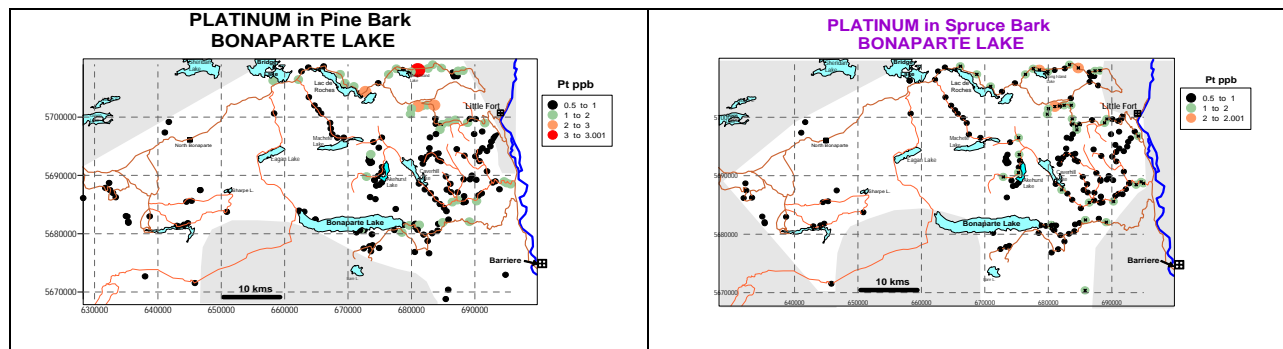


Figure 17: Platinum in pine and spruce bark.

In 2009 a few tree samples were collected near the trail some 400 m southwest of the Golden Loon occurrence (Fig. 18), where the dominant species is Douglas-fir intermixed with relatively sparse Engelmann spruce. The scope of the survey was limited by constraints on time, access and the high cost of the analytical work.

After drying and separation of twigs from needles, samples were ground to a fine powder and submitted for analysis by an ultra-sensitive method developed by Activation Laboratories Ltd. (Ancaster, Ontario; see section 5.3). Results for all the PGE are shown in Table 7. Figure 18 shows plots of the concentrations of Pd, Ru and Rh in dry Douglas-fir twigs. All samples yielded <0.2 ppb Ir, and <0.3 ppb Pt.

Sample #	Control	Tissue	Species	Easting	Northing	Unit	Ir	Pt	Pd	Rh	Ru
						<i>D.L. Limits</i>	ppb 0.2	ppb 0.2	ppb 0.1	ppb 0.1	ppb 0.2
DLU09-DF01		Twigs	Douglas-fir	690840	5700240	DLU-1	< 0.2	0.2	1.2	0.5	0.6
DLU09-DF02		Twigs	Douglas-fir	690945	5700185	DLU-2	< 0.2	< 0.2	1	0.4	0.7
DLU09-DF03		Twigs	Douglas-fir	691125	5700063	DLU-3	< 0.2	< 0.2	1.4	0.3	0.6
DLU09-DF04		Twigs	Douglas-fir	691330	5699802	DLU-4	< 0.2	< 0.2	1	0.3	0.7
DLU09-DF05		Twigs	Douglas-fir	691518	5699616	DLU-5	< 0.2	< 0.2	1.5	0.4	0.6
DLU09-DF06		Twigs	Douglas-fir	691648	5699453	DLU-6	< 0.2	0.3	1.1	0.3	0.7
Golden Loon PGE occurrence				691688	5700077						
DLU09-DF01		Needles	Douglas-fir	691330	5699802	DLU-7	< 0.2	< 0.2	0.8	0.2	0.3
DLU09-DF02		Needles	Douglas-fir	691518	5699616	DLU-8	< 0.2	< 0.2	0.6	0.2	0.4
DLU09-DF03		Needles	Douglas-fir	691648	5699453	DLU-9	< 0.2	< 0.2	0.9	0.2	0.4
DLU09-ES03	An. duplicate	Twigs	Engelmann spruce	691125	5700063	DLU-10 (1)	< 0.2	< 0.2	1	0.3	0.5
DLU09-ES03	An. duplicate	Twigs	Engelmann spruce	691125	5700063	DLU-10 (2)	< 0.2	< 0.2	1.1	0.3	0.5
DLU09-ES04		Bark	Engelmann spruce	691330	5699802	DLU-11	< 0.2	< 0.2	0.7	0.3	0.5
DLU09-ES05		Bark	Engelmann spruce	691518	5699616	DLU-12	< 0.2	0.2	0.7	0.3	0.5

Table 7: PGE concentrations in dry plant tissues

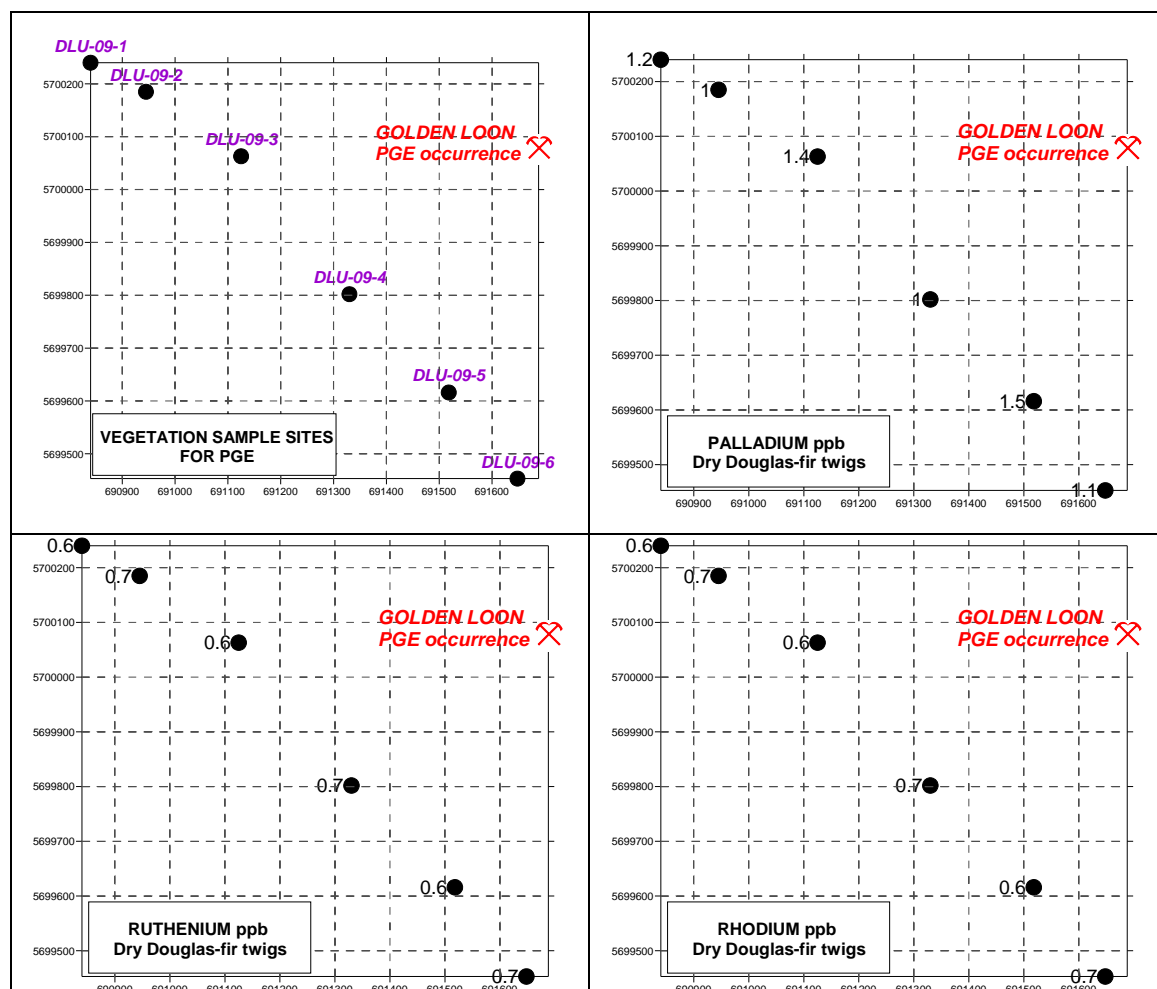


Figure 18: Location of sample sites, and concentrations of Pd, Ru and Rh in dry Douglas-fir twigs. The dashed line grid is at 100 m spacing.

This small study of PGE shows the following:

- Douglas-fir twigs yield marginally higher concentrations of Pd, Ru and Rh than Douglas-fir needles and Engelmann spruce bark.
- A single sample of Engelmann spruce twigs (duplicate analysis) yielded similar levels of Pd, Rh and Ru to the Douglas-fir twigs.
- Two samples of the spruce outer bark had slightly less Pd but similar levels of Rh and Ru to the fir twigs.

The low levels of PGE in these samples indicate that more detailed sampling would be required over well-defined targets to warrant the application of this expensive, but sensitive method of analysis when exploring for PGEs. The data obtained for Pt and Pd from a multi-element ICP-MS analysis is a good first step in defining exploration targets, but further refinement of targets (based, for example, on geological concepts and geophysics) is required before this more expensive analytical method is applied on a set of follow-up biogeochemical samples.

8. Summary and Conclusions

Ideally, a geochemical exploration survey should have samples collected in a grid pattern in order to obtain optimal information on element distribution patterns. However, this approach requires a dedicated survey. In the present situation, bark samples could be collected on an opportunistic basis at minimal additional field cost. Consequently, an additional layer of geochemical information could be obtained to assist in lithological mapping and to provide focus for detailed follow up in prospecting for mineral deposits. More statistically rigorous biogeochemical sampling in this part of the Interior Plateau is hindered by extensive previous logging, road access and degradation of pine trees due to the effects of Mountain Pine Beetle infestation.

The opportunity was taken to collect outer bark from the two most common tree species of the area – lodgepole pine and Engelmann spruce, and twigs and foliage from a few cedars. In total, approximately 500 samples were collected including field duplicates. The analytical data provided a basis for comparing and contrasting the geochemical signatures of the two media and defining those elements that generated the same or similar signatures while establishing other elements that generated different distribution patterns because of tolerances to, or requirements for, those elements. Most elements generated 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. Elements that tended to show different patterns (e.g., Ba, Sr) were those that were significantly more concentrated in a particular sample medium. In summary, the pine bark was significantly more enriched than the spruce in Ag, Al, Cd, La, Pb and Sb. Conversely, spruce was more enriched in Ba, Ca, Mn, Rb, Sr and Zn. The cedar foliage had the highest concentrations of B, K, Mg, Mo, Ni, P and Sr.

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. Also in the till, a recent survey disclosed unusually high concentrations of thorianite grains in the heavy mineral concentrates. Plots of thorianite related elements – Th, U and REE – in the conifer bark samples indicate an area of subtle enrichment that is located up-ice from the high thorianite grain counts in till. Limited follow-up work confirmed the relative enrichments of REE in the bark from near Lac des Roches, and established the concentrations of all the REE of which the light REE proved to be the more common.

The Bonaparte Lake Suite comprising biotite monzogranite in the centre of the survey area has elevated levels of Mo, Cs and Cu in the few samples that were collected from that area. Conversely, the Eakin Creek Suite dominated by felsic plutonic rocks has low concentrations of most elements in bark attesting to its generally barren nature, although metal enrichments (e.g. Ag, Pb) do occur locally; around the margins of this pluton several elements are relatively enriched (e.g., Hg, As, Sb, Fe, REE, Pb, Mn, Se and Au along the southern margin)

Bark samples from trees on the mafic to ultramafic rocks of the Dum Lake complex and the Nicola Group in the eastern and northeastern parts of the survey area yield relatively high concentrations of Co, Cr, Mg and Ni. Similarly, Pt is only detectable at sites on these lithologies. Detailed analysis of a few tree tissues from this area for all the PGE indicated that levels are low, and sampling would need to be closely spaced to a PGE target of this mineralogical type to warrant using the biogeochemical method to assist in locating concealed mineralization.

It is concluded that careful application and interpretation of tree chemistry can add a further useful data set to a mapping and exploration programme in this part of British Columbia.

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