Adding Value to Regional Till Geochemical Data through Exploratory Data Analysis, TREK Project Area, Central British Columbia (parts of NTS 093B, C, F, G)

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Introduction

The most efficient use of resources in mineral exploration is to add value to existing data products. The utility of existing geochemical data can be greatly improved by first order interpretation, because derivative data products (which are common in geophysics) account for surficial processes. These derivative data products can spur interest in areas that may have been otherwise overlooked.

Over the past 11 years, Geoscience BC has supported the continued collection and chemical analysis of till geochemical samples in efforts to promote mineral exploration throughout British Columbia (BC). The TREK (**T**argeting **R**esources through **E**xploration and **K**nowledge) project was initiated in 2013 to generate new information on BC's northern Interior Plateau region, an area which is highly prospective for mineral resources and may also have some geothermal potential. However, the area is underexplored for these resources due to overburden of variable thickness covering complicated and poorly understood bedrock geology. Across the TREK project area almost 3000 samples were collected by the British Columbia Geological Survey (BCGS), Geological Survey of Canada (GSC) and Geoscience BC (Figure 1). Samples from the BCGS and GSC campaigns were reanalyzed as part of the TREK project (Jackaman et al., 2015) to ensure state-of-the-art data quality.

The geochemical interpretation presented in this study has three main steps, the deliverables of which will contribute to Geoscience BC's mandate to stimulate mineral exploration:

1) All available till geochemical analyses in the TREK area were evaluated and assessed for comparability and utility on an element by element basis. Data artefacts were visible between original survey areas, but their effects were suitably circumvented during the remainder of the interpretation.
2) A thorough interpretation of the till geochemical data selected in the first step was accomplished using exploratory data analysis (EDA) techniques, including cluster analysis to determine till signature. Further geochemical techniques, such as regression analyses to account for secondary surficial processes, were also employed.
3) Robust, second order, geochemical derivative products (compared to known mineral occurrences where possible) that delineate areas of increased mineral potential based on ranked multi-element anomalies were provided.

Keywords: *British Columbia, geochemistry, exploratory data analysis, till, anomaly, mineral exploration, provenance*

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Data Validation and Assessment

Before data analysis can be properly undertaken, it is necessary to assess the quality and distribution of the available geochemical data. The data quality was assessed using ioGAS software and common data format issues were addressed, such as replacement of below-detection values, 'no-data' values (in this dataset no-data was listed as "-9999") and zeroes with null values to allow further statistical analysis. The full dataset (number of samples [n] = 2970) comprises 1259 new till survey samples and 1711 reanalyzed till samples from previous campaigns in the area (Jackaman et al., 2015), data from which will be included as an appendix in the final report. The newly collected and reanalyzed samples were all subjected to the same analytical method at the same lab (aqua-regia digestion with inductively coupled plasma–mass spectrometry [ICP-MS] finish at Bureau Veritas Minerals [Vancouver, BC]) eliminating the need for data processing to remove lab method effects. Normal probability plots were used to evaluate the distributions of each element and to flag those elements with limited quality and precision. The TREK till geochemistry dataset was generally of very good quality, with the exception of a few elements (W, S, Se, Te, Ge, Ta, In, Re, Pd, Pt, B, Na), and a group of 255 samples that contained null values for all elements. Also, a handful of samples (n = 6) were omitted from

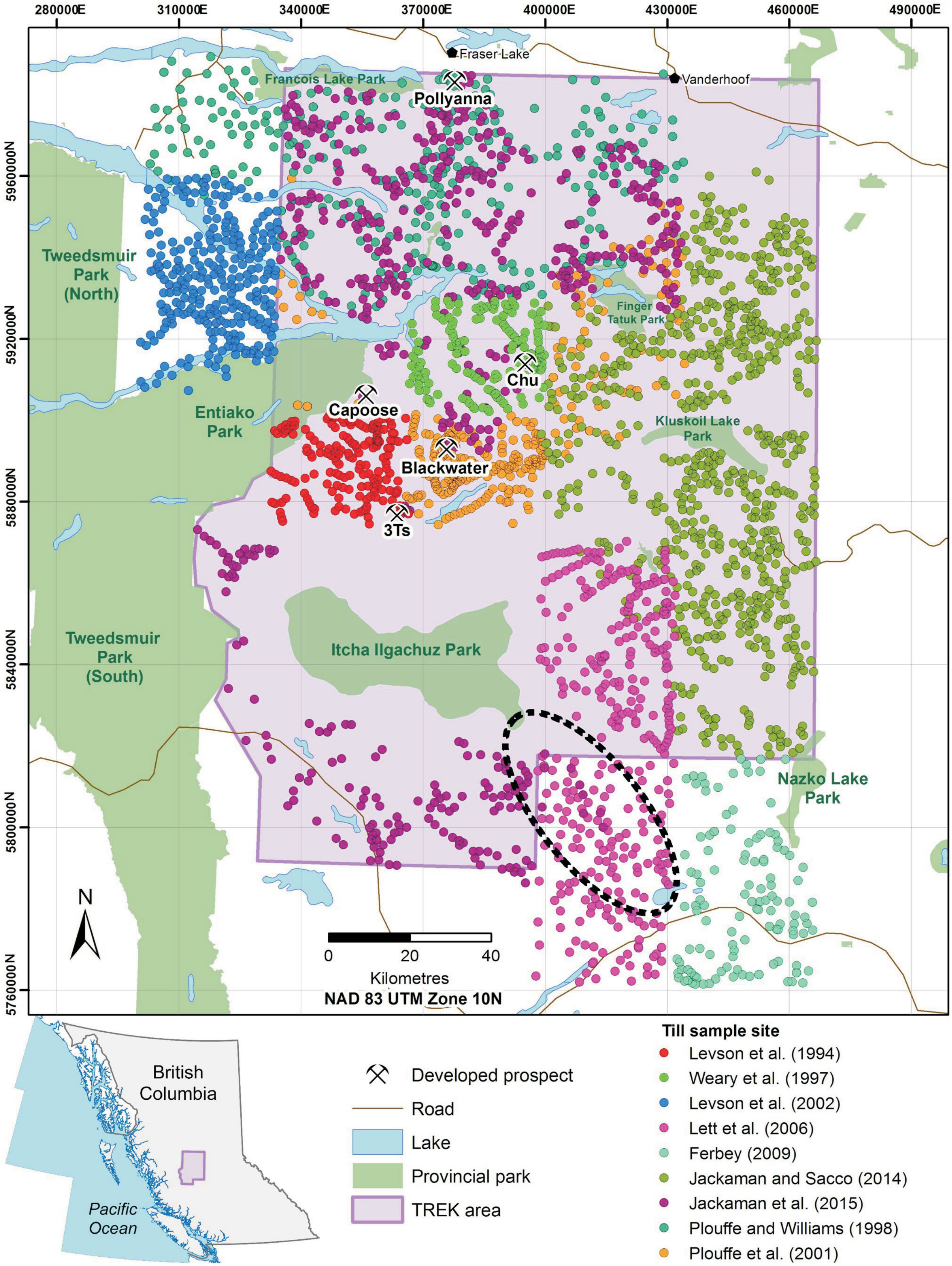

Figure 1. The **T**argeting **R**esources through **E**xploration and **K**nowledge (TREK) project location map with till samples coloured based on the associated geoscience report ('original report'). Note that the black-dashed circle represents the area of survey overlap used to determine spatial versus survey influence in the exploratory data analysis.

the interpretation because of extreme values in elements of secondary interest (Fe, Mn, Na).

In total, the interpreted dataset (n = 2709) spans nine survey areas, including five zones where spatial sample collection overlap. To investigate whether changes in elemental concentrations were influenced by the survey area ('original report'), these five zones were isolated and then all element ranges were evaluated. If the ranges of element concentrations vary significantly when only looking at data from within one zone, it can be confidently surmised that the data variation is due to some other factor than original report (i.e., changes in slope or underlying geology rather than survey effect). Four of the five zones showed acceptable variation when comparing the immobile elements, but one zone (Figure 1) showed considerable differences (up to three times greater median values in immobile elements between areas), between Jackaman et al. (2015) and Lett et al. (2006), and this variation will be addressed in further interpretations.

The main concern with the variation of data between survey areas is actually the quality of the till sample collected. Jackaman et al. (2015) re-evaluated the basal till potential (BTP) for the historic till samples and found large degrees of variation between survey years. Jackaman et al. assigned a BTP score to all samples, and 2581 till samples were classified "basal till or very likely basal till", whereas 389 samples were classified "unlikely to be basal till". The latter samples require more careful interpretation because they were likely transported farther from their protolith.

Exploratory Data Analysis - Methodology

Exploratory data analysis is well documented in geochemical literature, and has been used in mineral exploration for the past 50 years. Grunsky (2007) describes it as the process of detecting trends or structures within the data, which can "provide insight into the geochemical/geological processes". By having a greater understanding of the processes that create, channel and ultimately control geochemical anomalies that are expressed at surface, the likelihood of correctly interpreting these anomalies is drastically increased and therefore the likelihood of discovering buried mineralization. Exploratory data analysis (EDA) was performed on the 2709 till samples selected from the full dataset of 2970 samples based on data quality.

Part I: Cluster Analysis to Define Till Provenance

Till geochemical samples, even if they are basal till and a first derivative of the underlying bedrock, are still the product of a surficial process and thus their data must be treated accordingly. Assigning a protolith unit to a till sample based on its actual sample collection location is inappropriate because the till may have been derived from bedrock as much as tens of kilometres away (Ferbey et al., 2014). The provenance of these till samples was determined by a multivariate analysis of both immobile and trace elements, and initially five different till types were identified using a hard-partitioning k-means cluster analysis. This method aims to partition a number of observations into k-clusters in which each observation is assigned to the most similar group based on a subset of variables. The optimum number of clusters will have the smallest sum of squares between observations and the cluster's central node. The purpose of this analysis is to minimize the within-cluster variation and maximize the between-cluster variation based on the selected elements of interest.

The elements used in the first pass clustering analysis were (Na+K)/Al, Ca, Ti, Zr, Y, Th and Nb. The (Na+K)/Al term can be used as a proxy for till evolution; more evolved, or distal, till samples will have a lower (Na+K)/Al value because they are more weathered and therefore more of the Na or K has been mobilized and removed from the till sample (Figure 2). The dark green group has been identified as evolved due to its lower relative (Na+K)/Al values, and also its higher Zr and Ti values (Zr can be correlative to the sand fraction of the till sample, also indicating a higher degree of transport). The till samples were analyzed using an aqua-regia digestion, which is an incomplete digestion method that does not dissolve certain silicates, oxides, and some of the minerals that contain high-field strength elements (HFSE), meaning that the results for many elements are only partial, and elements such as Zr will have poorer data quality. The blue group is likely derived from carbonate materials, inferred from their high Ca content.

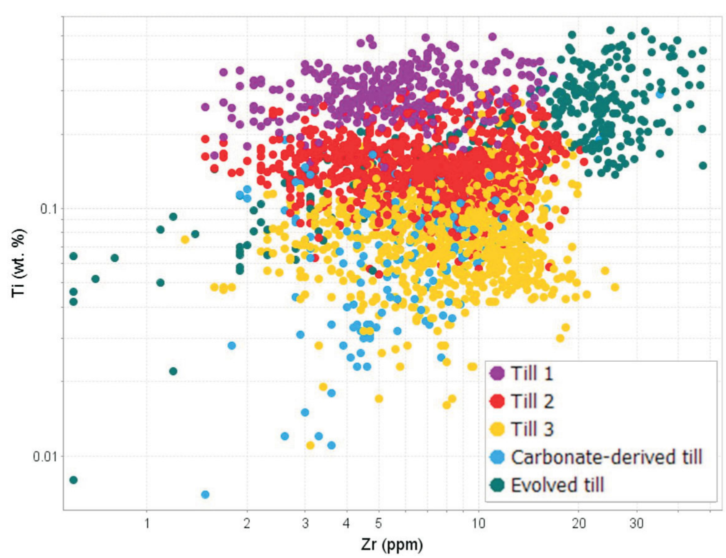

Figure 2. Biplot of Ti as a function of Zr, coloured by first pass clustering analysis using immobile and trace elements to separate till types, **T**argeting **R**esources through **E**xploration and **K**nowledge [TREK] project area, central British Columbia.

The carbonate-derived and evolved tills were then temporarily removed from the dataset and the remaining three till groups were further separated into five groups based on the distributions of major elements and a selection of trace elements (Ti, Al, Fe, Mg, Mn, Ca, Na, K, Cr, U, Ni; Figure 3) resulting in a total of seven chemically distinct till compositions or types in the TREK area (Figure 4). These till types were spatially coherent but do not correspond with the original report areas, which indicates the influence of survey area has been overcome. Till signature was assigned based on differences in till geochemistry and the lithological affinity of major and trace elements.

Part II: Regression Analysis (by Provenance) to Identify Outliers

Regression analysis predicts the behaviour of a response variable relative to an explanatory variable, and also allows the calculation of a residual value, which is the difference between the predicted value and the observed value of the dependent variable. The linear equation resulting from a regression analysis models the relationship between the predictor and response variables. A robust regression analysis down-weights the influence of outliers, thus the robust regression equation most closely approximates the majority of the data, and allows outliers to be identified more clearly. The algorithm used is the least median of squares (LMS) method described in Rousseeuw and Leroy (1987).

In this regression analysis, the predictor variables used were Fe and Al. Iron oxides in the surficial environment are very efficient at binding mobile chalcophile elements (e.g., Cu, Zn, Pb, Ag, As) and Al can be used as a proxy for clay content in till samples because mobile elements can be adsorbed onto clay particles. In this interpretation, the regression analysis was carried out by till type, meaning that outliers were identified for each different till type as defined and separated by signature. This is significant because some till types naturally contain more chalcophile elements based on their protolith. The example in Figure 5 shows that the mafic-signature (high Fe) till type has the highest proportion of Cu, so by calculating a regression analysis by till type the effect of varying signatures can be levelled out at the same time a robust residual is calculated. Of note is the elevated Fe content coinciding with the elevated Cu content in the mafic-signature (high Fe) till type; this alludes to either Fe control on hydromorphic dispersion of Cu, or that Fe and Cu have a common source in this till type.

Residuals are the measure of the difference between the observed value and the expected value (of the response variable, i.e., Cu) compared to the predictor or explanatory variable, in this case Fe (Figure 6). Robust standardized residual values (residual divided by the standard deviation of the residuals) were then calculated for the pathfinder elements (Cu, Mo, Zn, Pb, As, Ag) as a function of both Fe and Al (independently), as well as per till type and plotted on the map along with known developed prospects to validate the results (Figure 7, Cu as a function of Fe). Calculated robust standardized residuals for all pathfinder elements are presented with the data compilation as an appendix to the final report.

The results of the interpretation show excellent spatial relation of residual values with known developed prospects (Blackwater [MINFILE 093H 037, BC Geological Survey, 2016], 3Ts [MINFILE 093F 055], Pollyanna [MINFILE 093F 15W], Chu [MINFILE 093F 07E]) in the TREK area. One exception is the Capoose prospect (MINFILE 093F 06E), which is just outside the till sampling coverage area. Even though these observations are helpful in validating the method, the more important results of the interpretation are the several new areas that have been highlighted by this approach of second-order geochemical data interpretation. These prospective areas, which have not yet been identified as areas of mineralization, may warrant follow-up by more detailed fieldwork in the future (Figure 7).

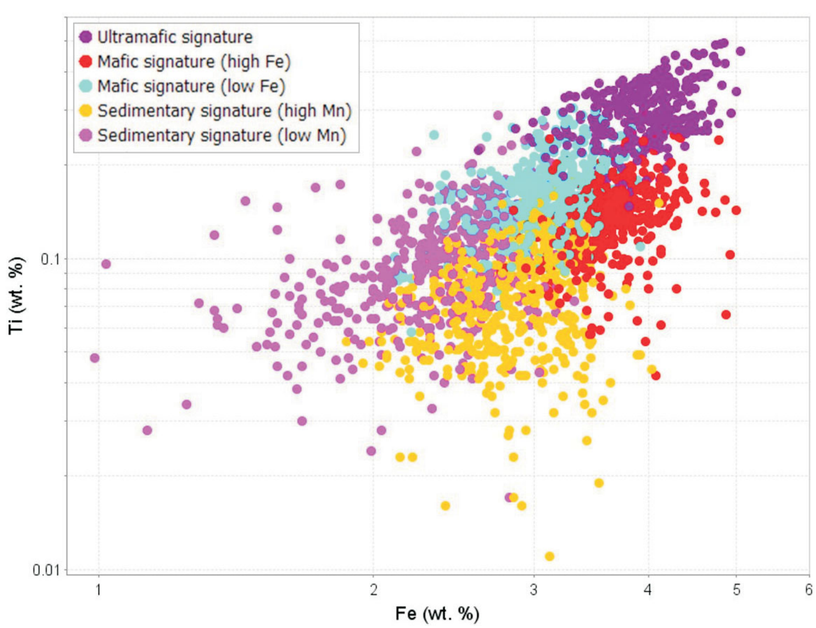

Figure 3. Biplot of Ti as a function of Fe, coloured by the second iteration of clustering analysis to differentiate the five till types, **T**argeting **R**esources through **E**xploration and **K**nowledge (TREK) project area, central British Columbia (note that carbonate-derived and evolved tills are omitted from this diagram for clarity).

Discussion

In the initial stages of EDA, two main observations about the structure of the data

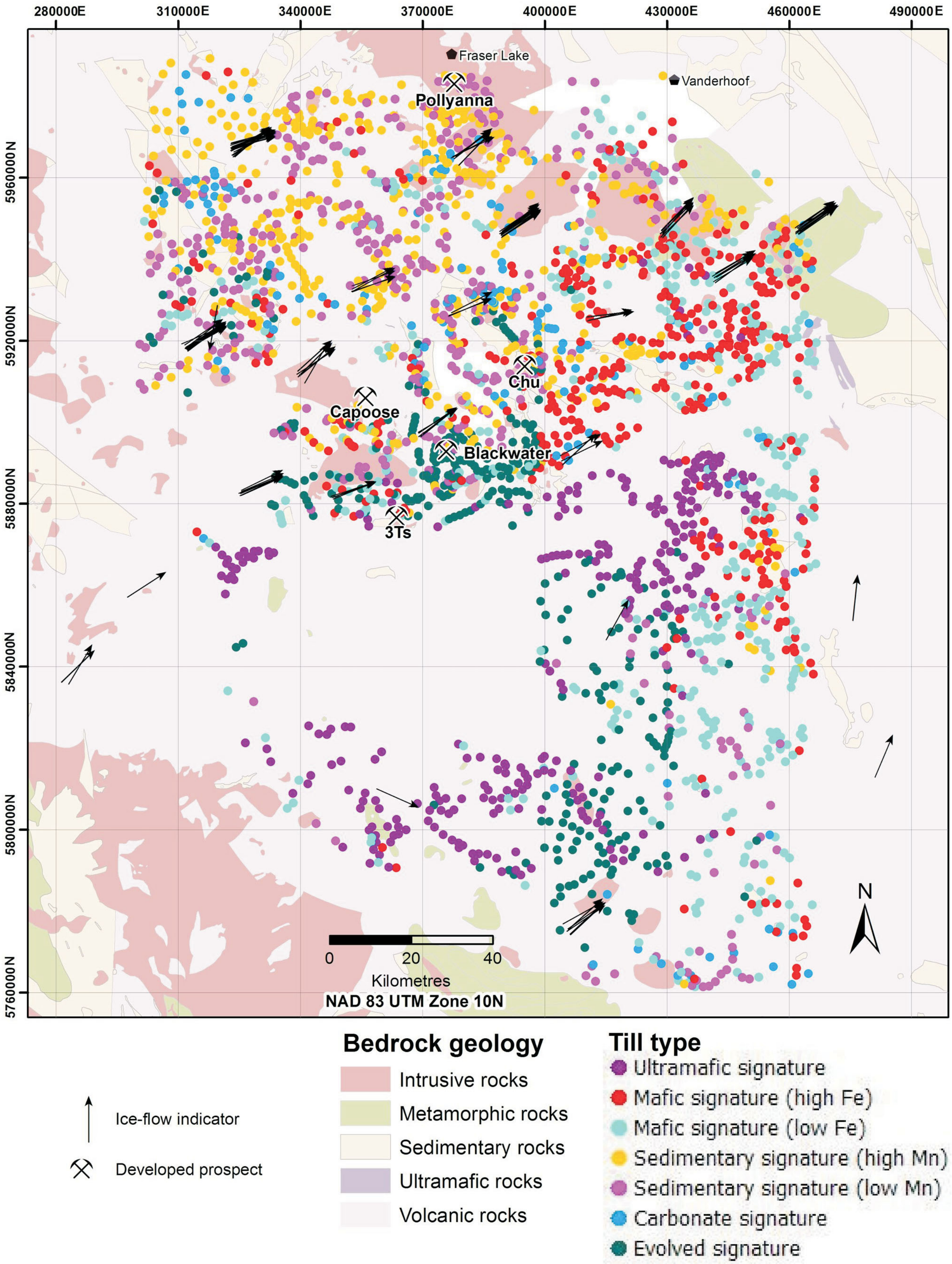

Figure 4. Map of till geochemical samples, colour is based on till type (signature), **T**argeting **R**esources through **E**xploration and **K**nowledge (TREK) project area, central British Columbia. Bedrock geology modified from Massey et al. (2005).

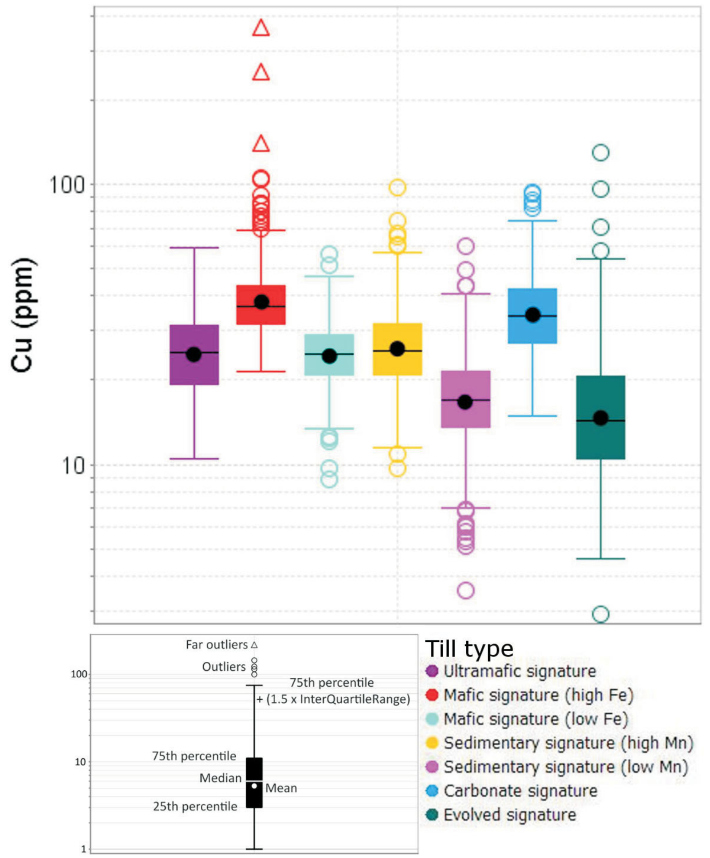

Figure 5. Boxplot of Cu content of till samples grouped by till type (signature), **T**argeting **R**esources through **E**xploration and **K**nowledge (TREK) project area, central British Columbia.

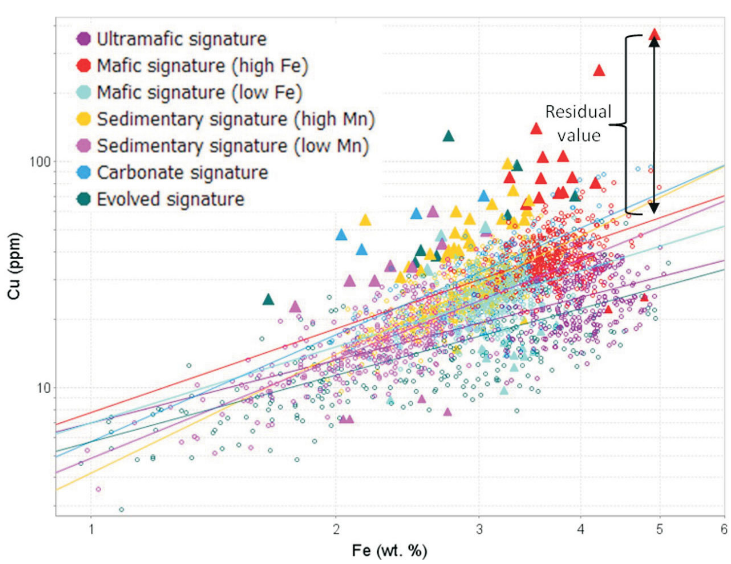

Figure 6. Regression analysis of Cu as a function of Fe (till samples from **T**argeting **R**esources through **E**xploration and **K**nowledge [TREK] project area, central British Columbia). Samples with standardized residual values >3 are presented as large filled triangles. Residuals are the value of the difference between the observed and the expected result. Standardized residuals = residual / standard deviation of the residuals by till type.

were obvious. Firstly, several elements of interest, including the porphyry pathfinder and immobile elements, were incomparable between the original reports, and this effect had to be investigated more closely. Secondly, the main changes in the BTP score (Jackaman et al., 2015) were coincident with survey boundaries. This is not surprising because earlier surveys were not as rigorous about the type of till collected, which became important in later surveys, so in many cases ablation or supraglacial flow tills were collected rather than basal tills. Since the collected material differed in origin, differences in trace and immobile element chemistry were also incomparable by their BTP. This is a boon for the interpretation because it is possible to account for either of those factors and the influence of the other will also be accounted for.

To investigate the original report effect more closely, five small areas containing samples from two spatially overlapping reports were selected and that data was subset and examined. In this interpretation, several of the immobile elements evaluated still showed large variation within each spatial subset, so original report was accounted for in the regression step of the interpretation.

Cluster analysis using (Na+K)/Al, Ca, Ti, Zr, Y, Th and Nb was performed on the 2709 till samples, and was done in two parts resulting in seven chemically distinct till types, which were then named based on their signature. Once the till samples were separated into signature groups, a robust regression analysis was performed on appropriate porphyry pathfinder elements and a robust residual was calculated for each pathfinder element within each till type. This removes the effect of varying chemistry based on till source, and also removes the effect of survey area – recall in the first steps of the EDA the comparability issue that was spotted between survey areas and these boundaries roughly matched the boundaries defined by changing BTP. These boundaries are also coincident with the chemically distinct till types (Figure 8).

Finally, the robust residual values for the pathfinder elements (Ag, As, Cu, Mo) were evaluated using an anomaly assessment test, which is the combination of univariate Tukey box-and-whisker plot statistics (Tukey, 1977) and multivariate Mahalanobis distance calculation (Mahalanobis, 1936), which takes correlated sample behaviour into account. The most interesting resultant anomalies are larger symbols on Figure 9 because the size of the symbol is directly proportional to the number of anamolous elements in that sample. Of

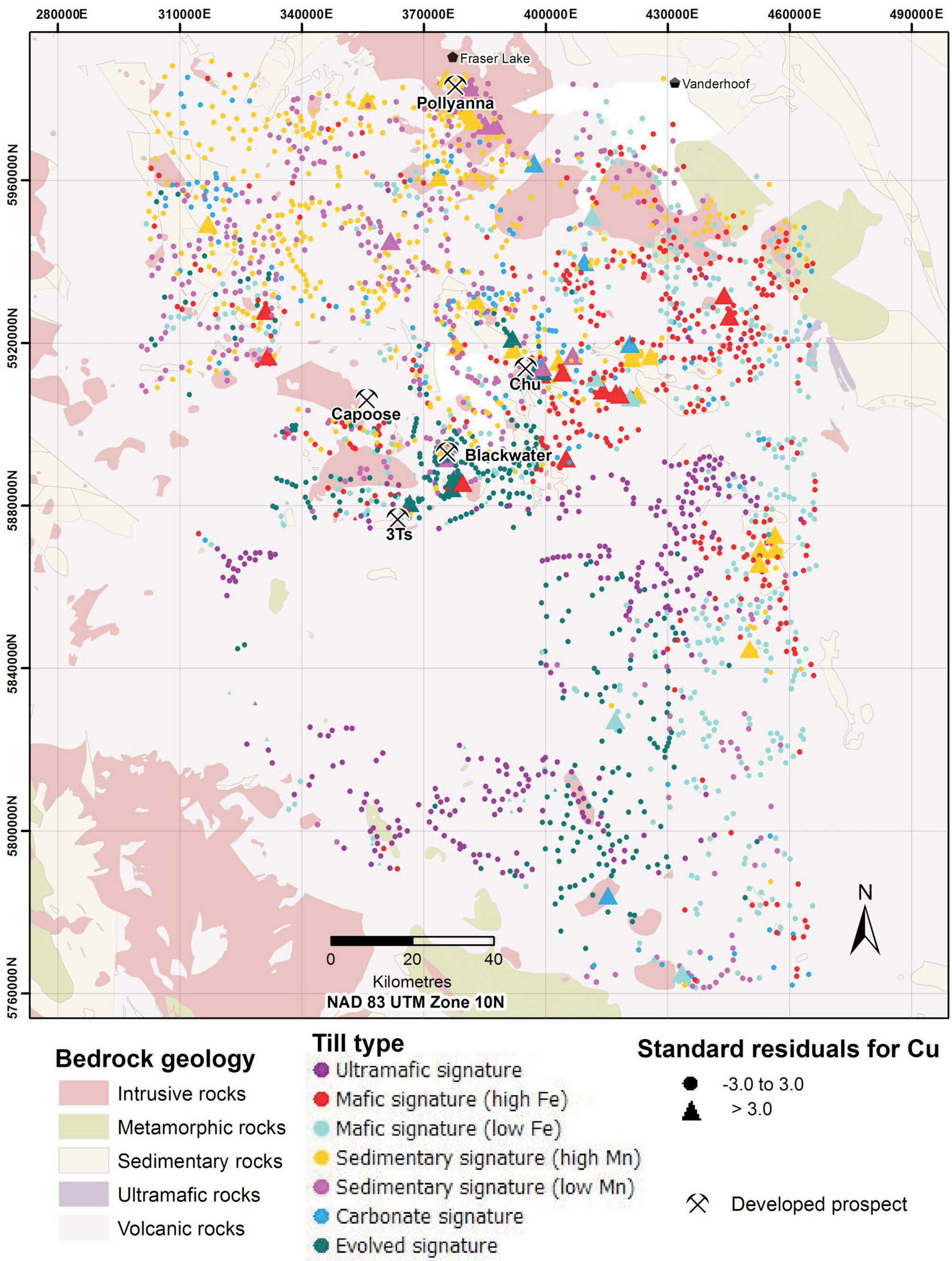

Figure 7. Map of Cu residuals (regression analysis of Cu as a function of Fe), **T**argeting **R**esources through **E**xploration and **K**nowledge (TREK) project area, central British Columbia. New target areas are indicated by the large filled triangles that are not coincident with known prospects. Bedrock geology modified from Massey et al. (2005).

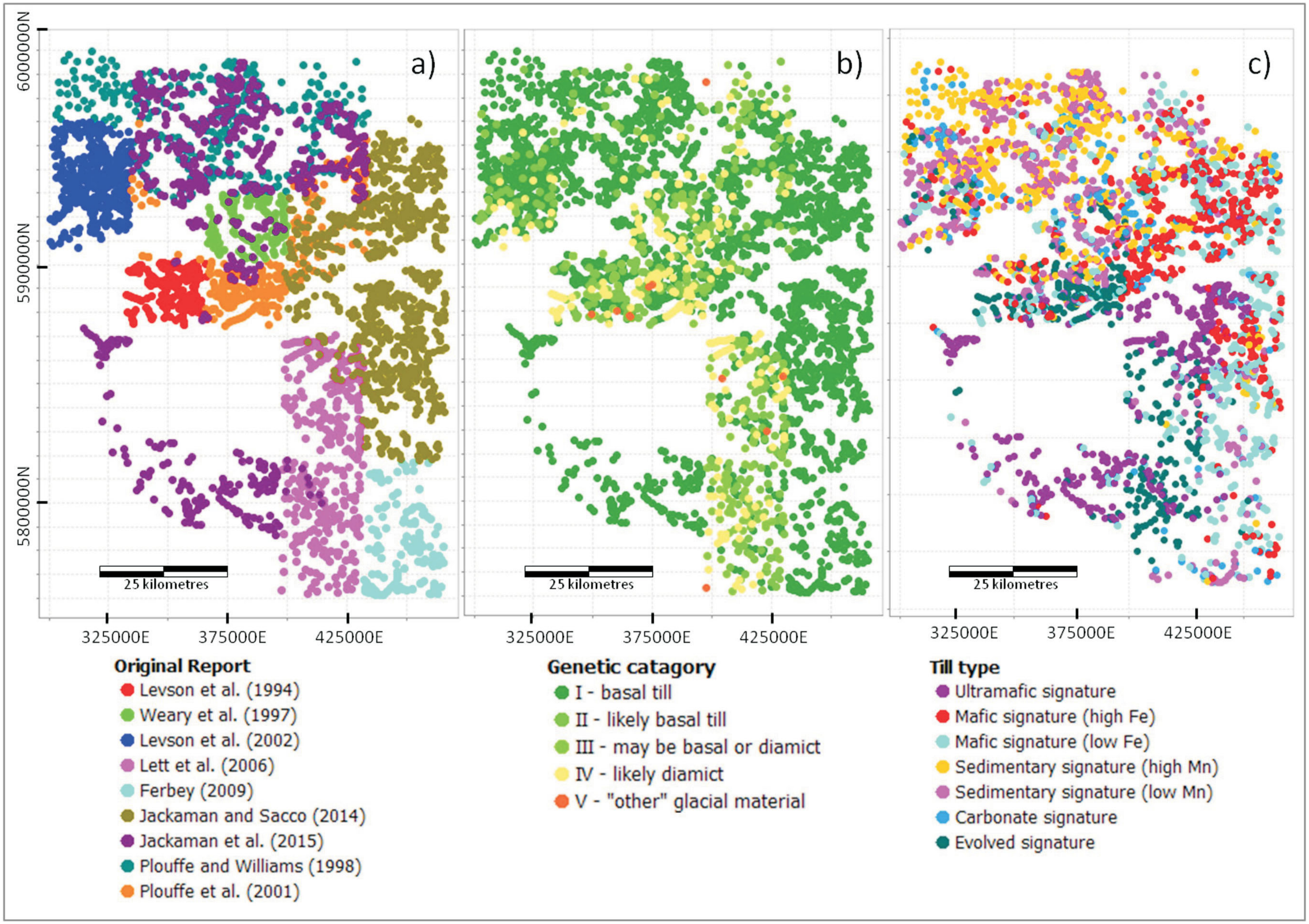

Figure 8. Comparison maps of **a)** original report, **b)** basal till potential (BTP) and **c)** till type, **T**argeting **R**esources through **E**xploration and **K**nowledge (TREK) project area, central British Columbia (NAD 83, UTM Zone 10N). Boundaries from original report are also visible in the BTP and till type maps, which means accounting for till provenance in the interpretation will automatically explain the variation in BTP and original report.

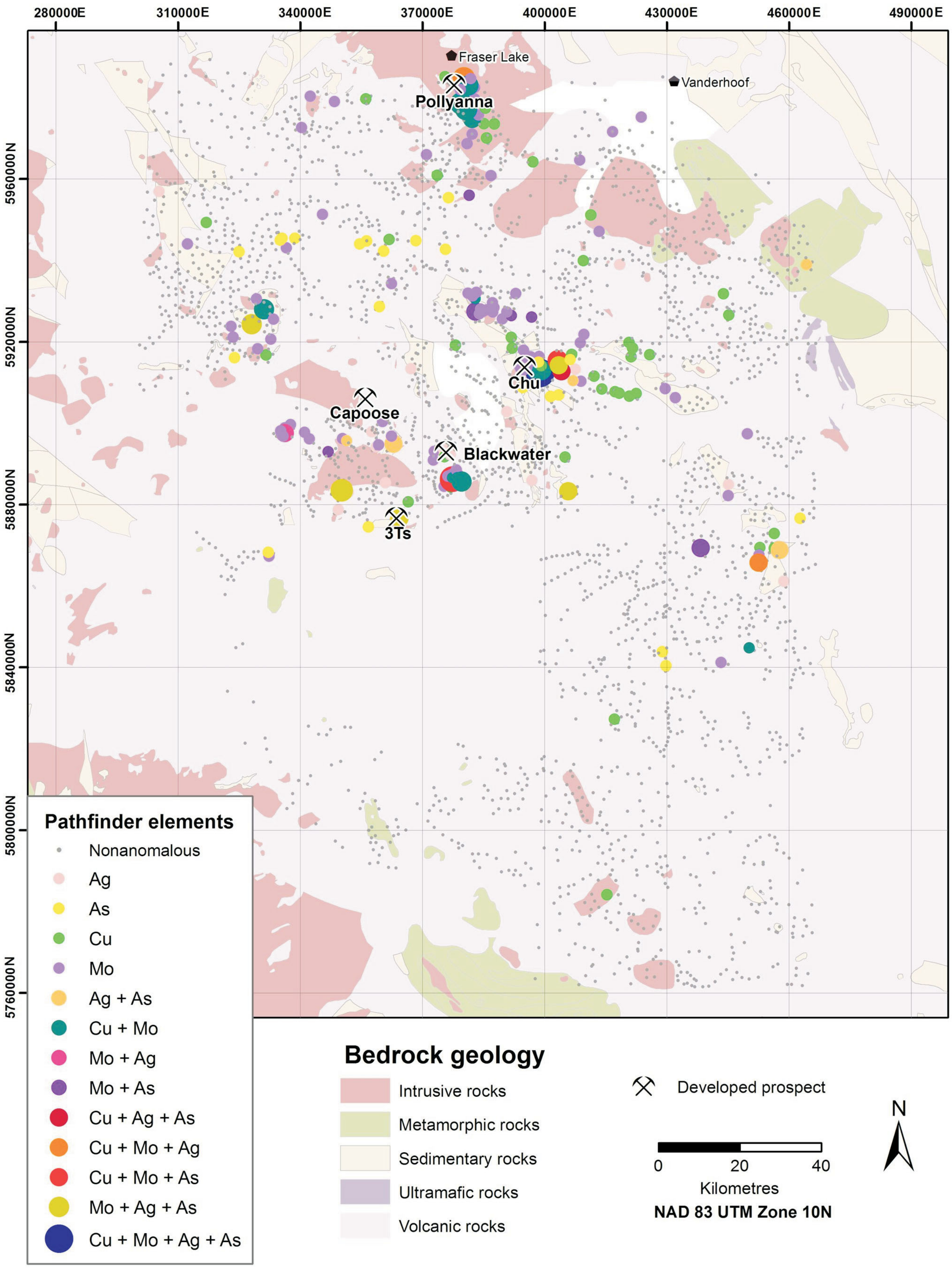

Figure 9. Map of multivariate anomaly assessment results from till samples, **T**argeting **R**esources through **E**xploration and **K**nowledge (TREK) project area, central British Columbia. The colour and sizing scheme is based on the input variables (Cu, Mo, Ag, As). Larger symbols are samples with anomalous values (>3 standard deviations [sd]) in one or more pathfinder elements. Bedrock geology modified after Massey et al. (2005).

note is the Cu+Mo+Ag target 77 km east-southeast of Blackwater, the Cu+Mo+As, Cu+Mo and Mo+As target 7 km southeast of Blackwater and also the Cu+Mo and Mo+Ag+As target 32 km northwest of Capoose.

Conclusions

Basic geochemical interpretation methods, such as clustering and regression analyses, allowed greater insight into the architecture of the till geochemical data in the TREK project area. Data effects, such as changes in survey area, were overcome and the till samples were classified into till types based on immobile and trace element chemistry (signature). Anomalous samples were then identified in each till type based on a selection of chalcophile elements, and these anomalies were quantified using a robust regression analysis and combined using an anomaly assessment test. The residual results show spatial coincidence with known developed prospects, and several targets were generated in areas without known mineralization.

Future Work

Multivariate anomaly assessment analysis highlights several areas of interest, which have been ranked based on multivariate element combinations as well as their coincidence with developed prospects (anomalies not associated with known mineralization have a higher ranking). These ranked areas can be followed up with more detailed fieldwork to validate potential targets and advance prospectivity.

Acknowledgments

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