Advanced processing of the TREK Project geochemical data

Identifying and Enhancing geochemical anomalies in the TREK project area using sediment transport modelling combined with multimedia and multivariate data analysis

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Executive Summary

Geoscience BC's Targeting Resources for Exploration and Knowledge (TREK) project produced a comprehensive collection of geoscience information for an area with high potential for economic mineralization in central British Columbia. This includes one of the largest, high-quality, and directly comparable surficial geochemistry data sets in North America. This study applies a multivariate and multimedia evaluation, and till sediment-transport modelling and data levelling based on bedrock composition to enhance geochemical anomalies in the TREK project area. The geochemical data set was standardized through regression-based substitutions for censored data and levelled to mitigate geochemical variation related to analytical methods. Areas of influence (AOI) link till samples to dominant bedrock sources, which are used to create subpopulations and level the data. Levelling the data to bedrock source units aims to remove the variation in the regional geochemical data set related to changes in bedrock composition and improve the discernibility of contrasting geochemical data potentially related to economic mineralization. Deposit signatures of common deposit models were determined from publicly available drill core and trench sampling data, and a weighted sum (WS) analysis identifies these signatures within the surface sediment data. This multivariate analysis is more powerful than a single variate analysis because the mineralization signature can still be identified when the individual element concentrations are relatively low. Furthermore, it can reduce the effect of individual element anomalies (e.g. the nugget effect in Au) on the delineation of exploration targets, which can mislead exploration efforts.

The results of this study indicate that the methodology tested here is effective in enhancing the geochemical signal of mineralization in a regional data set. Several limitations to the methodology have been identified through this study, and suggestions have been made to improve similar efforts in the future. Nonetheless, differing results from the elements related to mineralization and bedrock composition verify that the method does mitigate geochemical differences related to changes in regional bedrock composition. Furthermore, the contrast of over half of the anomaly clusters identified by the WS indices was increased by the levelling, particularly in the southern part of the study area where mineralization may be partially covered by Eocene volcanics. Of the 91 anomaly clusters identified by the study, most do not have known mineralized sources, or are likely to have additional unidentified sources. This suggests that the TREK project area still has significant potential for undiscovered economic mineralization.

Table of Contents

Executive Summary

List of Figures

List of Tables

List of Appendices

Appendix C. Database of standardized till and lake sediment data, standardized till data levelled to bedrock, and weighted sums indices for porphyry, epithermal, and Fenton-type mineralization for till and lake sediment samples.
(provided separately in excel file format).

Appendix D. Spatial files for gridded till geochemistry, anomaly clusters, till and lake sediment areas of influence.
(provided separately in ESRI geodatabase and shapefile formats).

1. Introduction

Geoscience BC's Targeting Resources for Exploration and Knowledge (TREK) project produced a comprehensive collection of geoscience information for an area with high potential for economic mineralization in central British Columbia. The surficial exploration component of the project produced one of the largest, high-quality, and directly comparable raw exploration data sets in North America generated by new till and lake sediment sampling combined with a reanalysis and genetic interpretation of similar archive data (Jackaman and Sacco, 2014; 2016; Jackaman et al., 2014; 2015). The TREK surface sediment data set includes geochemistry generated by inductively-induced neutron activation analysis (INAA), aqua regia-type dissolution - inductively-coupled plasma mass spectrometry analysis (ICP-MS), and regia-type dissolution - inductively-coupled plasma emission spectroscopy analysis (ICP-ES). The data set also includes genetic interpretations for all till samples, and heavy mineral concentrations and pebble lithology data for new till samples. The value-added project herein provides advanced processing of the TREK geochemical data that incorporates a bedrock and surficial context into the evaluation to better understand the complex nature of this information and promote its potential as a mineral exploration tool.

The geochemical signal associated with mineralization can be obscured in a regional data set by many factors, such as differences in sediment genesis or composition, differences in anomaly magnitudes, and parent bedrock lithology. To overcome these challenges, we have applied a multivariate and multi-media evaluation, and tested a method to delineate potential source regions for till and lake sediment samples that better reflects their composition. The multivariate analysis is designed to highlight samples with geochemical signatures similar to specific common mineral deposit types. The multi-media analysis focusses on till and lake sediment samples, which are good candidates for comparison as their geochemical concentrations have been shown to be spatially correlative (Cook et al., 1995).

A potential source region, or area of influence (AOI), provides information regarding the composition and transport history of the material. Lake sediment samples are transported by watercourses, so a catchment basin analysis is used that is similar to those used for stream sediment samples by Bonham-Carter and Goodfellow (1986), Arne and Bluemel (2011), and Heberlein (2013). Lake sediment samples can provide information about the composition of bedrock and potential for base-precious metals mineralization within the watershed in terrain with thin surficial cover. This study area, however, has a thick surficial cover and the watercourses are likely transporting this surficial cover rather than the underlying bedrock. Dilution of the bedrock signal through the surficial cover may be responsible for the relatively low background-anomaly contrast common to lake sediment geochemistry. In this situation where till cover is ubiquitous, the catchment basin likely provides a vector back to the till dispersion, which can then be traced back to the bedrock source.

Till samples were initially transported by glaciers, so their AOIs are based on ice-flow data and reflect concepts related to provenance envelopes (Stea and Finck, 2001; Plouffe et al., 2011). Till AOIs are designed to spatially link till samples to a dominant bedrock source unit. The shape of each till AOI is dependent on variables related to ice-flow dynamics, and the AOI delineates a region of bedrock that has influenced the composition of the till sample. Contrasting rock types forming the bedrock geology within the TREK project area will be reflected in the till geochemistry, and can potentially complicate anomaly identification on the regional scale. The till data are levelled using the dominant bedrock source unit to mitigate the influence of these contrasting rock types on the regional data set, which should improve the ability to more confidently identify exploration targets within the project area.

The primary objective of this project is to further develop methodologies that can help more confidently identify low-risk exploration targets in regional surface sediment data sets. This is accomplished by:

- the standardization of the TREK geochemical data to improve its suitability for evaluation;
- levelling surficial geochemical data to dominant bedrock source unit lithogeochemistry and assessing the effect on anomalies;
- determining the geochemical signature of mineral deposit types common to the project area; and
- enhancing geochemical anomalies related to specific deposit types by applying a multivariate evaluation.

2. Project Area

The project area is in the Interior Plateau (Mathews, 1986), south of Vanderhoof and approximately 60 km west of Quesnel, British Columbia. It occupies parts of NTS 093B, C, F and G and covers more than 28 1:50 000-scale NTS map areas, and approximately 25 000 km^2 (Figure 1). Access is through a network of forest service roads in the Vanderhoof, Quesnel, Chilcotin and Central Cariboo forest districts. The project area includes parts of the Nechako Plateau, Fraser Plateau, and the Fraser Basin physiographic regions (Holland, 1976). Surficial deposits up to 100s of metres in thickness and composed dominantly of till and glacial lake sediments obscure most bedrock exposures. Higher relief features include the Nechako and Fawnie mountain ranges of the Nechako Plateau and the Ilgachuz and Itcha mountain ranges of the Fraser plateau. A summation of the bedrock and surficial geology and references for the project area is provided in Sacco et al. (2014k).

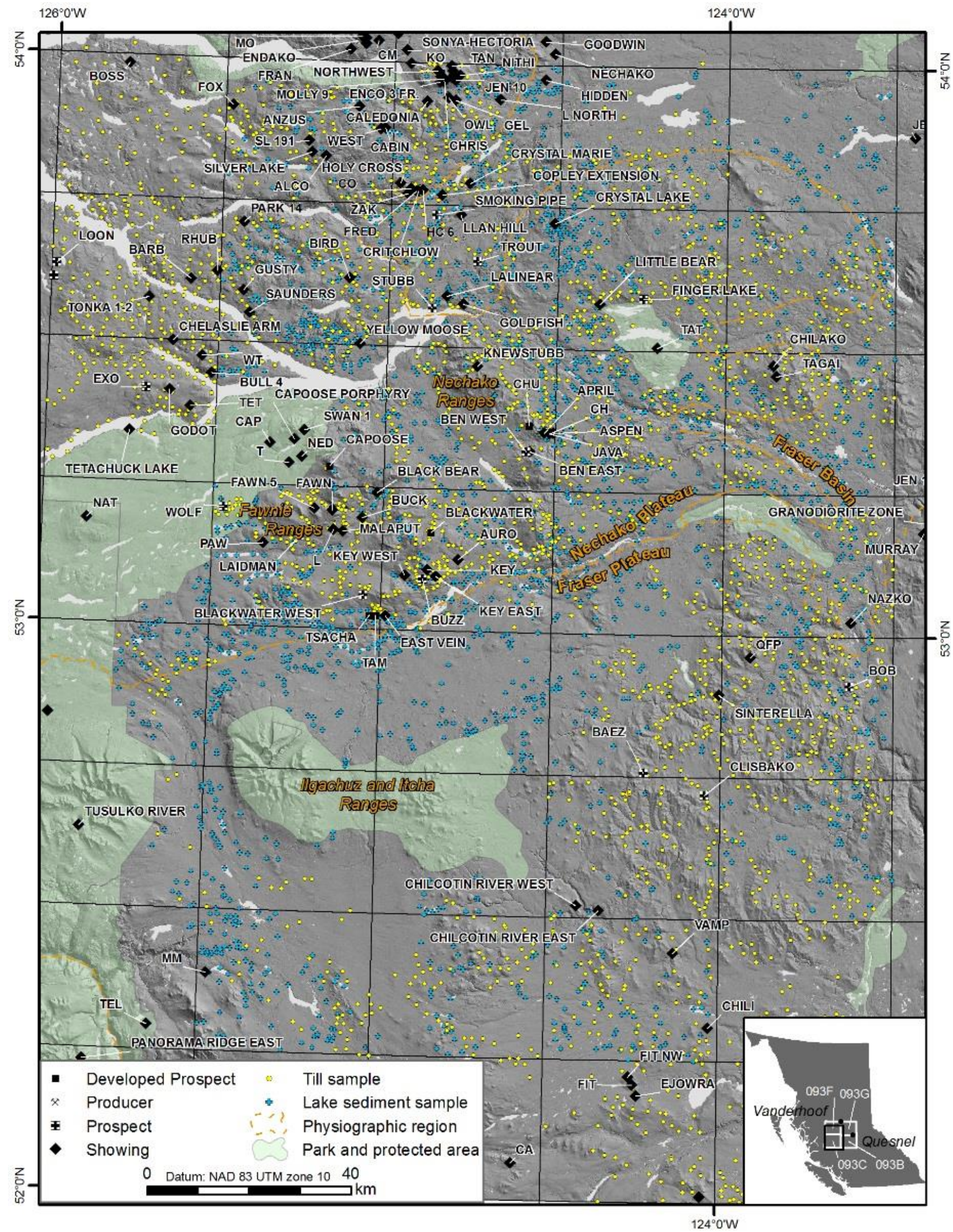


Figure 1. ***Location map showing the study area, till (yellow symbols) and lake sediment (blue symbols) sample locations, and MINFILE (2017) mineral occurrences. Digital elevation model from Canadian digital elevation data (Geobase®, 2007).***

3. Methods

This section outlines the workflow and methods for the study (Figure 2). The study relies on a variety of integrated data sources outlined in Table 1. Due to the complex nature of this collection of information, inherent data discrepancies exist that may affect the results. Significant effort has gone into the assessment, compilation and processing of these data sources to ensure the best possible results.

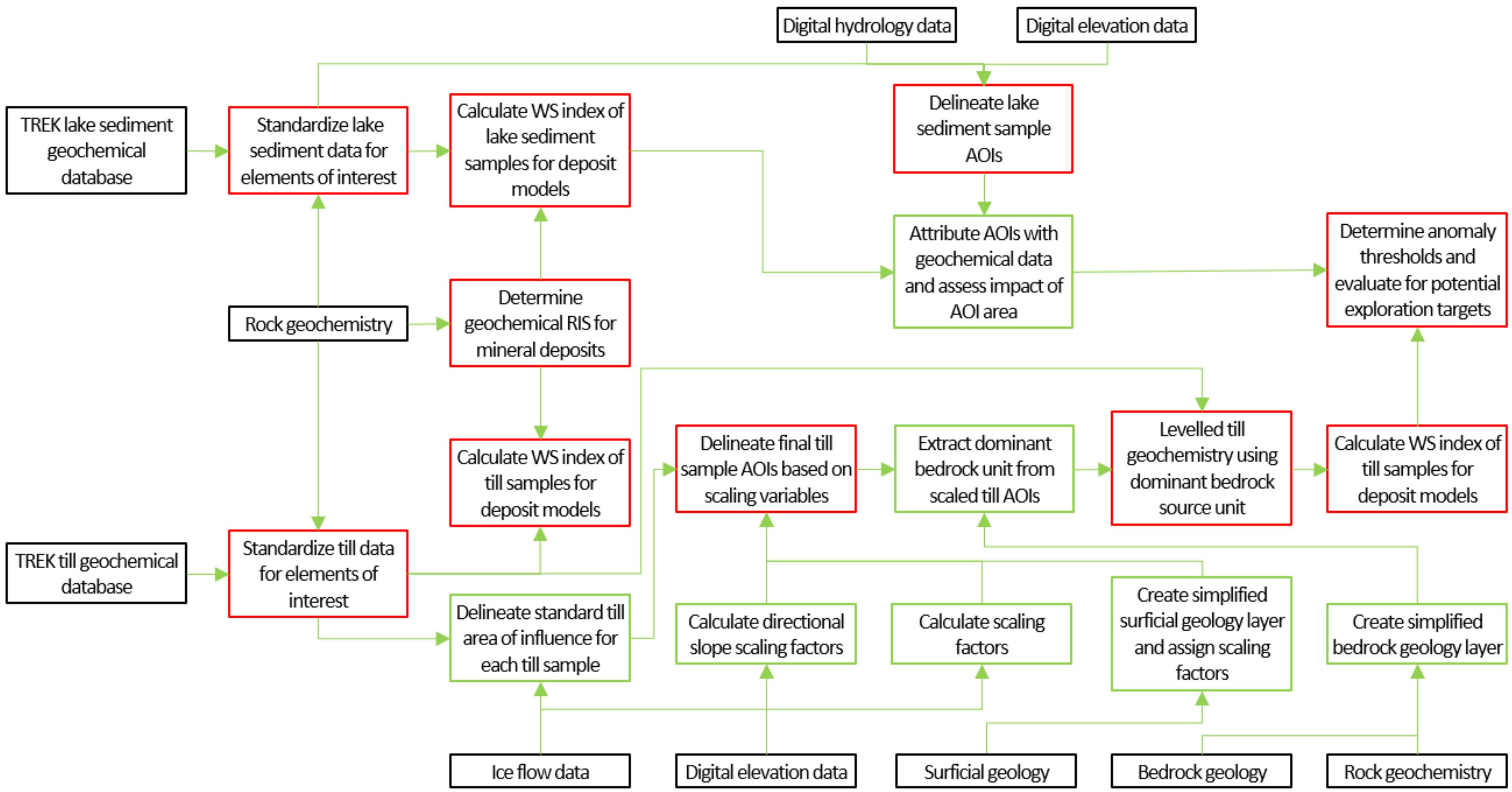


Figure 2. Flow chart illustrating the workflow and data integration for this study. Black boxes identify data sources, green boxes identify processing steps, and red boxes identify final products. WS – weighted sums.

Geochemical data were first standardized to improve their suitability for evaluation. The till geochemical data were then levelled using background lithogeochemistry for the dominant bedrock source lithology. Dominant bedrock source units were determined by delineating sample-specific AOIs. Similarly, lake sediment AOIs were delineated to identify their potential source regions. The till and lake sediment geochemical data were evaluated using a weighted sums (WS) calculation based on a deposit model relative importance signature (RIS) determined from the analysis of existing drill core and trench sample geochemical data. The resulting indices measure the similarity of the sample geochemical signature to that of the deposit model of interest. Suitable anomaly thresholds were determined for these indices, and the data were visually assessed to identify clusters of anomalous samples that represent potential base-precious metals mineralization. The specific procedures used for these tasks are described in the appropriate method subsections below.

Table 1. Data sources and references used in this study.

Data	Reference
TREK till geochemistry	Jackaman and Sacco, 2014; Jackaman et al., 2015a
Reanalyzed archive till geochemistry	Jackaman et al., 2015b
TREK lake sediment geochemistry	Jackaman and Sacco, 2014
Archive lake sediment Geochemistry	Jackaman, 2006; 2008a; 2009a
Reanalyzed archive lake geochemistry	Jackaman, 2009a, b
Rock geochemistry	Mihalynuk, et al., 2008; Angen et al., 2016; BC Geological Survey MINFILE (2017) and ARIS (2017) databases.
Geology	Cui et al., 2015; Mihalynuk et al. (2008a,b)
Surficial geology	Kerr and Giles, 1993; Plouffe *et al.*., 2004; Sacco et al., 2014A-J
Elevation data (SRTM, CDED)	Canadian Digital Elevation Data (CDED) - GeoBase®, 2007; Shuttle Radar Topography Mission (SRTM) - NASA LP DAAC, 2015
Ice flow data	Ferbey et al., 2013; unpublished data from A. Plouffe and D. Sacco
Hydrology	GeoBC, 2016
Deposit model geochemistry	ARIS, 2017

3.1 TREK geochemical data standardization

Data standardization refers to a series of processing steps required to create a genetically comparable, normally-distributed, and statistically equivalent data set. Only sediments with similar geneses should be compared to eliminate geochemical differences associated with different transport and deposition mechanisms. Non-normal and censored data distributions can cause issues when applying mathematical or statistical analytical procedures (*cf.* Grunsky, 2010). Additionally, variation in analytical results from external factors such as different analytical procedures can limit anomaly recognition that is associated with mineralization. A combination of filtering, data transformations and substitutions, and levelling techniques were applied to the raw data to improve its utility.

To ensure genetic comparability within the data sets, till and lake sediment data were evaluated separately. Basal till is the optimal till facies to evaluate. Basal till is well suited to assessing mineral potential of an area because it is a first derivative of bedrock (Shilts, 1993) and therefore has a similar geochemical signature. It was eroded, transported and deposited under ice, thus its transport history is relatively simple and can be determined by reconstructing ice-flow histories. Furthermore, it is the dominant surficial material in the study area and produces a geochemical signature that is areally more extensive than the bedrock source, which is easier to detect (Levson, 2001). In contrast, ablation till was transported en- or supraglacially, has a more complex transport history that is difficult to determine, and was affected by meltwater during deposition, which affects its composition. Samples that are not basal till (approximately 25% of archive data), as determined from genetic interpretations conducted earlier in the TREK surface sediment geochemistry program (Jackaman et al. 2015b), were removed from the analysis.

The geochemical data evaluated in this study are a compilation of new till and lake sediment data, and reanalysis results from archive surface sediment samples (see Table 1 for references and Figure 1 for locations). Ag, As, Au, Ba, Bi, Co, Cr, Cu, Fe, Hg, Mn, Mo, Ni, Pb, Sb, V, W, Zn were selected for evaluation because they are commonly associated with local base-precious metals mineralization styles, and available in sufficient samples at concentrations above lower detection limits (L.D.L.) in the data used to determine the RIS (Table 2). Additional elements (e.g. S) were considered but were either not identified in the RIS or do not occur in significant concentrations in the TREK data set to affect the evaluation. Samples from previous surveys without an adequate amount of archived material for reanalysis are missing results. These null results in the reanalysis were substituted with the original analytical results. Data are also missing for some samples in the historical INAA data. The median of the element was substituted for these missing data.

The data distribution of each element for subpopulations based on analytical method was assessed to determine the normality and proportion of censored data. Skewed data were Log(10)-transformed to produce more normal data distributions. Censored data distributions occur when enough data points fall below detection limits, which artificially skews the data distribution. Data points below the detection limit were substituted with half of the lower detection limit for elements with <1% censored data. Data points below the detection limit were substituted with predicted values based on linear regression coefficients for elements with >1% censored data. This is accomplished by fitting a line by linear regression on a normal probability plot, and then replacing the censored data with their expected values (Figure 3).

Table 2. Details for TREK geochemical data used in this study. See Table 1 for data sources.

Element		Method	Unit	L.D.L.	Comment
silver	Ag	ICP-MS	ppb	2	
		ICP-ES	ppb	200	79 samples have values below the L.D.L. where regression-based substitutions may result in numbers higher than the L.D.L. of the ICP-MS results
arsenic	As	INAA Lab1	ppm	0.5	
		INAA Lab2	ppm	0.5	
gold	Au	INAA Lab1	ppb	2	
		INAA Lab2	ppb	2	
barium	Ba	ICP-MS	ppm	0.5	
		ICP-ES	ppm	1; 2; 10	no samples from this data set were below the L.D.L.
bizmuth	Bi	ICP-MS	ppm	0.02	
		ICP-ES	ppm	0.2; 2; 5	82 samples have values below the L.D.L. where regression-based substitutions may result in numbers higher than the L.D.L. of the ICP-MS results
cobalt	Co	INAA Lab1	ppm	1	
		INAA Lab2	ppm	5	no samples from this data set were below the L.D.L.
chromium	Cr	ICP-MS	ppm	0.5	
		ICP-ES	ppm	1	no samples from this data set were below the L.D.L.
copper	Cu	ICP-MS	ppm	0.01	
		ICP-ES	ppm	1	no samples from this data set were below the L.D.L.
iron	Fe	ICP-MS	pct	0.01	
		ICP-ES	pct	0.01	
mercury	Hg	ICP-MS	ppb	5	
		ICP-ES	ppb	20	no samples from this data set were below the L.D.L.
manganese	Mn	ICP-MS	ppm	1	
		ICP-ES	ppm	1; 2	no samples from this data set were below the L.D.L.
molybdenum	Mo	ICP-MS	ppm	1	
		ICP-ES	ppm	0.01	no samples from this data set were below the L.D.L.
nickel	Ni	ICP-MS	ppm	1	
		ICP-ES	ppm	0.1	no samples from this data set were below the L.D.L.
lead	Pb	ICP-MS	ppm	0.01	
		ICP-ES	ppm	2; 3	35 samples have values below the L.D.L. where regression-based substitutions may result in numbers higher than the L.D.L. of the ICP-MS results
antimony	Sb	INAA Lab1	ppm	0.1	
		INAA Lab2	ppm	0.1	
vanadium	V	ICP-MS	ppm	2	
		ICP-ES	ppm	1; 2	
tungsten	W	INAA Lab1	ppm	1	
		INAA Lab2	ppm	1	
zinc	Zn	ICP-MS	ppm	0.1	
		ICP-ES	ppm	1; 2	no samples from this data set were below the L.D.L.

Note: INAA Lab 1 refers to Becquerel Labs and INAA Lab 2 refers to Activation Labs.

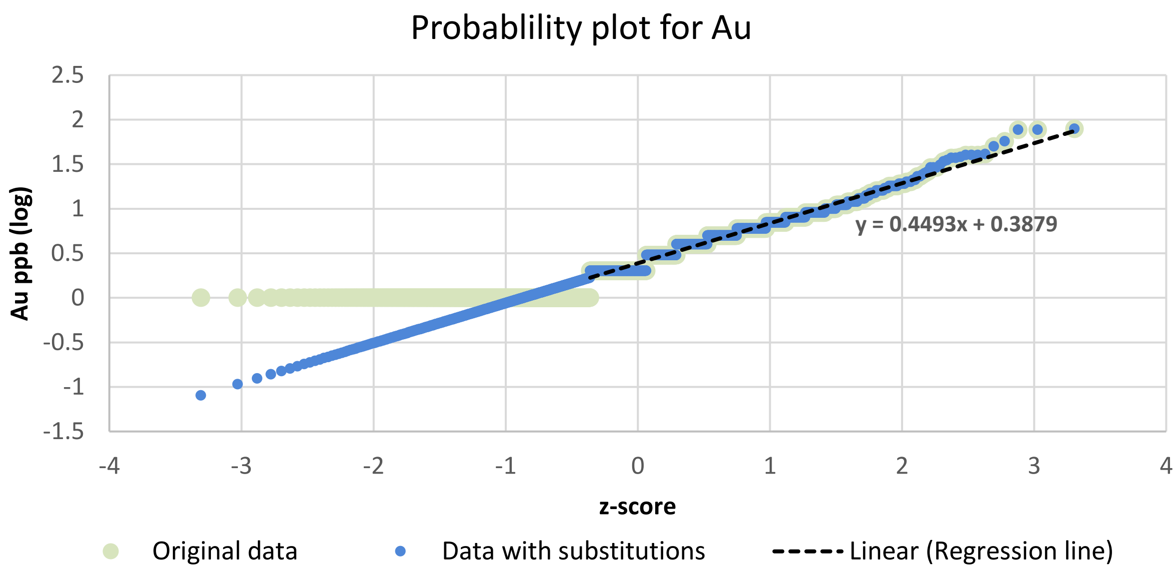


Figure 3. Regression-based substitution for Au. Probability plot shows original data (green symbols), regression line (black dashes), and resulting data set after substitutions (blue symbols).

The INAA was conducted at Activation or Becquerel laboratories, depending on the survey. INAA can be thermal (Activation Labs) or epithermal (Becqueral Labs) and the difference between the two reflects the energy of the incident neutrons that interact with a target element nucleus during sample irradiation in a nuclear reactor (Hoffman, 1992). The two methods differ slightly in sensitivity, the number of elements determined and their detection limits. Archive ICP data, which were substituted where sample material was not available for reanalysis, was finished with atomic emission spectroscopy, whereas the reanalysed and recent data were generated by mass spectroscopy. An assessment of analytical results from the different sources indicates there are minor differences between each laboratory in the INAA data, and element detection method in the ICP data. There is significant spatial overlap of sample locations analysed with different methods, thus it is unlikely the differences are related to geology. To mitigate this variation associated with analytical methods, the data were levelled using a robust z-score method. The z-score levelling method was chosen because it does not change the shape of the data distribution and preserves genuine outliers. This method converts each data point into a group-based z-score, expressing the data in units of standard deviation from the central tendency. The median is used as a robust estimate of the mean and the interquartile range (IQR) multiplied by 0.7413 as a robust estimate of standard deviation. It is defined by the equation:

$$z = \frac{input\ value - median}{IQR \times 0.7413}$$

3.2 Levelling till data using bedrock

Regional changes in bedrock composition are reflected in the geochemistry of till, and can inhibit the recognition of anomalous till samples in the data set. Till geochemical data can be levelled to bedrock lithology to mitigate the variation associated with regional bedrock composition if the bedrock geology is known and a link between a till sample and the geology are established. A simple overlay spatial correlation cannot be used because it does not consider the down-ice transport of till. Instead, till AOIs were delineated to estimate the potential source region for a till sample.

Till AOIs are defined by a sector of a circle that is centred on the sample location. The angle of the sector is a function of the range of ice-flow directions that affected the location, and the length of the radii (arms) is a function of estimated sediment transport distance (Figure 4). Till AOI delineation is an iterative process that begins with a standard till AOI that has a standard length, and an arc length that is specific to the ice-flow history at each sample location (Figure 4a). The standard AOI is used to extract scaling factors that reflect increased or decreased sediment transport distances (Figure 4b). These scaling factors are then applied to the standard AOIs to create the final till AOIs that are used to determine dominant bedrock influence (Figure 4c).

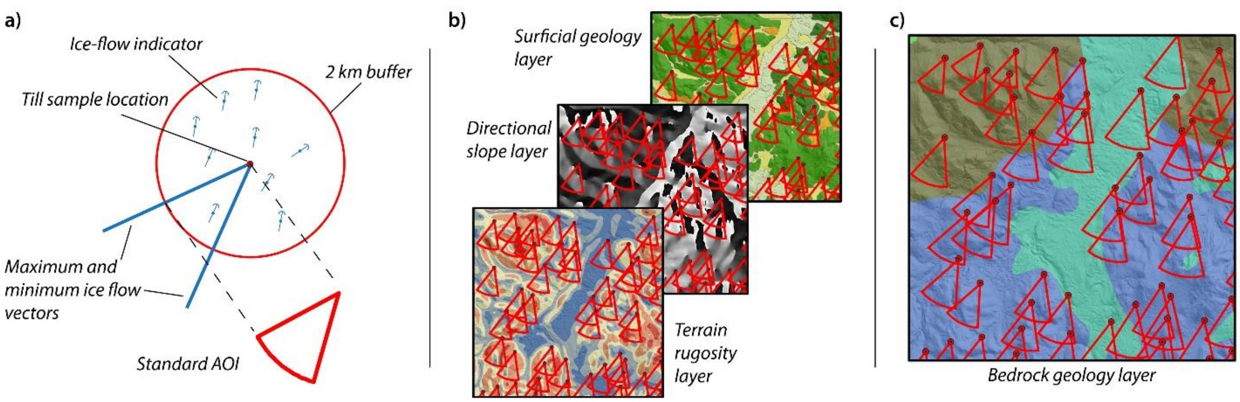


Figure 4. Standard till AOIs are delineated based on sample locations, ice-flow vectors, and a standard length (a). Length-scaling factors are extracted from data layers that affect sediment transport distances using the standard till AOIs (b). The length of standard till AOIs are multiplied by the scaling factors to create sample specific AOIs, and the dominant bedrock units affecting the samples are extracted (c).

3.2.1 Bedrock compilation

Bedrock geology data were used to identify dominant bedrock source units that have contributed to the composition of till samples, and determine the subpopulations used to level the till geochemical data. The efficacy of this levelling is largely determined by the congruency and quality of the bedrock mapping sources, and thus, it is essential to have the most accurate and consistent mapping data available.

The most continuous bedrock geology in the project area is compiled by Cui et al. (2015), in which significant efforts have been made to maintain consistency. However, higher resolution bedrock mapping exists for parts of the project area (Mihalynuk et al., 2008a, b; Angen et al., 2015; Bordet, 2016) that is not included in Cui et al. (2015). To produce an updated geology layer for this study, the data sources were overlaid to assess the spatial comparability, and unit designations and descriptions. The new mapping was converted to a common legend based on Cui et al. 2015, and spliced into the compilation. No attempts at edge-matching were made between the units as it is a complicated process that requires resources beyond the scope of this study. The new compiled layer was simplified so that the geology could be represented by major bedrock units that are most likely to influence the till geochemistry. Simplifications were based largely on unit descriptions and supplemented with available rock geochemistry where possible.

3.2.2 Delineation of standard till area of influence

The length of the standard AOIs was determined using average anomaly dispersion distances in till from known mineral deposits within the region. The dispersal distance was measured from the deposit to the location where associated element concentrations are below the 75th percentile. Based on the references listed in Table 3, the average dispersal length is roughly 2.5 km.

Table 3. Geochemical dispersal distances in till to the 75th percentile from known mineral occurrences in central British Columbia.

Dispersal distance (km)	NTS 1:250k map sheet	Reference
2	093M/L	Ferbey et al., 2009
5	093M/L	Ferbey et al., 2009
1-3	93L	Stumpf, 2012
2.5-5	093F	Levson et al., 1994
1-2	093F	Levson et al., 1994
2	093F	Levson et al., 1994
3-7	093F	O'Brien et al., 1997
2-4	093F	O'Brien et al., 1997
2	093F	O'Brien et al., 1997
>1	093O	Plouffe, 1997
>1	082E	Lett et al., 2001
2-4	093F	Sibbick et al., 1996
1.6	093E	Ferbey et al., 2012
1-2	O92P	Paulen et al., 2000
3	082M	Paulen et al., 2000
2-5	various	Weary et al., 1997

The angle of a standard AOI is based on the range of ice-flow directions that affected a sample location (Figure 4a). Ice-flow directions were determined from the azimuth of small- and large-scale ice flow indicators (see Table 1 for references). Ice-flow histories were determined where relative chronologies could be assigned to the indicators, and from regional ice-flow patterns. A 2 km buffer was created for each till sample location, and the maximum and minimum azimuth values from all ice flow indicators were attributed to the sample point. The range for each sample location was assessed for the influence of spurious values and adjusted accordingly. During this assessment, modifications were also made to the ranges based on known ice-flow histories and topographic influences.

3.2.3 Till area of influence length scaling factors

Length-scaling factors were used to modify the length of a till AOI based on the specific surface conditions to improve the accuracy of the estimated transport distance of each sample. It has been shown that transport distances increase with velocity of ice flow (Clark, 1987; Bouchard and Solonen, 1990; Aario and

Peuraniemi, 1992). The ice velocity cannot be directly determined; thus, the scaling factors were based on three surface characteristics (i.e. scaling variables) that can affect ice velocity: 1) slope; 2) surface rugosity; and 3) surficial material. Transport distances can also be affected by the physical properties of the source (e.g. areal extent, erodibility, topographic position), and re-entrainment potential (Parent et al., 1996). The physical properties of the base-precious metals exploration targets are yet to be identified, and determining re-entrainment potential is not feasible across the study area so these factors are not addressed here.

Glaciers generally accelerate downslope and decelerate upslope. Directional slope was measured using the SRTM (Shuttle Radar Topography Mission) elevation data and the generalized ice-flow directions from the ice-flow indicator compilation (Ferbey et al., 2013). Theissan polygons were created for the generalized ice-flow indicators that define the area closest to each indicator relative to all other indicators. Each polygon was assigned the value of the associated ice-flow indicator. Spurious directions were adjusted where necessary ensuring coordination with surrounding values. The polygon file was converted to an ice-flow direction raster with an equivalent cell size to the SRTM data. The ice-flow direction raster was smoothed using a roaming average of 10 cells to reduce sudden directional changes along polygon borders. The SRTM data set was smoothed using a 25-cell roaming average to remove the influence of minor topographic features that are either too small to affect ice flow, or did not exist during glaciation (e.g. meltwater channels and post-glacial landforms). Slope and aspect rasters were calculated from the SRTM data, and the directional slope was calculated using the formula:

$$S_{D=\left(Scos((D-A)\frac{\pi}{180}\right)}$$

where S_D = directional slope, S= slope raster, D = direction of ice flow raster, and A = aspect raster.

Increased surface rugosity increases basal drag and decreases ice velocity. Surface rugosity was calculated using a modified version of the terrain ruggedness index (TRI) by Riley et al. (1999). Several other methods of measuring rugosity were tested and deemed unsuitable due to issues with scale and the resolution of the elevation data. For example, the true rugosity of a surface is probably best indicated by the 2D : 3D area ratio. This method, however, could not produce accurate results at a scale that would affect a glacier and is better suited to higher-resolution data applications.

The Riley et al. (1999) TRI is the difference between the value of a cell and the mean of a neighborhood of surrounding cells. This calculation was performed on the SRTM data set that was smoothed using a 10-cell roaming average to remove minor topographic irregularities from the calculation. Minimum and maximum 25x25-cell neighborhood rasters were derived from the smoothed DEM, and then the TRI was calculated using the formula:

$$TRI = \sqrt{\left(abs(max^2 - min^2)\right)}.$$

where *max* = maximum 25x25-cell neighborhood raster and *min* = minimum 25x25-cell neighborhood raster.

The surface expression and thickness of the surficial materials were used as qualitative proxies for ice-flow velocity and transport distance, respectively. Thicker till units are generally transported farther (e.g. Levson and Giles, 1995; Paulen, 2001), and streamlined landforms (notably with length-to-width ratios of ≥10:1) suggest higher ice-flow velocities (Stokes and Clark, 2002; Briner, 2007; King et al., 2009). Sediment thickness and surface expressions were extracted from surficial mapping compiled from various sources (see Table 1). The mapping was combined using a common legend, with higher-resolution mapping favoured where overlap occurred.

Quantifying the effects of the scaling variables on ice-flow velocity, and ultimately on sediment transport distance, is beyond the scope of this preliminary study. The scaling factors for this preliminary study are, therefore, relative rather than absolute. Each scaling variable is divided into five factor categories, and each category represents a scaling factor of 0.1 (Table 4). The relative scaling factors are based on the average condition. For example, the average condition is scaled by a factor of 1; one below the average condition is scaled by a factor of 0.9; and one above the average condition is scaled by a factor of 1.1. Directional slope and rugosity variables are numerical indices. The average condition for these indices was determined by the mean, and the scaling-factor divisions measured in units of standard deviation (Table 4). Surficial material characteristics are qualitative and require a different approach. Based on areal distribution, thick material is the average condition in the TREK project area and is assigned a scaling factor of 1. The scaling factors increase as the amount of streamlining increases, and decrease as the material becomes thinner.

Table 4. Length-scaling variables and factors used to adjust till AOIs based on surface characteristics that affect till transport distances.

Scaling factor	Category breaks	Slope value (°)	TRI index value	Surficial geology map unit description
0.8	> -1.5 standard deviation from mean	>5	<71	No surficial material (e.g. dominantly rock with lesser amounts of thin material; R.Tv)
0.9	-1.5 to -0.5 standard deviation from mean	5 – 2.1	72 – 263	Thin surficial material (e.g. Veneers; Tv)
1	-0.5 to 0.5 standard deviation from mean	-2 – 2	264 – 454	Thick surficial material (e.g. Blankets; Tb)
1.1	0.5 to 1.5 standard deviation from mean	-2.1 – -5	455 – 646	Thick material with some streamlining (e.g. Till blanket with some streamlining; Tb.Ts)
1.2	>1.5 standard deviation from mean	<-5	>646	All material is streamlined (Ts)

Note: Thin and thick material categories are based on material thickness and not genesis, thus can include all material types.

The percent coverage of the scaling factors for each scaling variable are measured from within the standard AOIs. A final scaling factor for each variable is determined by weighting each category based on the percent coverage. The standard AOI length is then multiplied by each variable's weighted scaling factor and the final till AOIs are delineated using those lengths.

3.2.4 Levelling till data based on bedrock

The final till AOIs spatially link each till sample to a probable source region. The dominant bedrock source unit was determined by extracting the proportion of different bedrock units within the AOI. The levelling procedure uses the same z-score levelling procedure outlined in the data standardization section because it does not change the shape of the data distribution and preserves genuine outliers.

3.3 Lake sediment sample area of influence

Lake sediment sample AOIs represent the potential area from which lake sediment was derived, and are delineated in the same manner as a catchment basin. For the purposes of this study, a lake catchment is defined as the drainage area from the outlet of the sampled lake to the outlet of the next upstream sampled lake. Lake sediment AOIs are delineated by computing the catchments of sampled lakes using the Canadian Digital Elevation Data (CDED; GeoBase®, 2007). The CDED is preferred to the Shuttle Radar Topography Mission (SRTM; NASA LP DAAC, 2015) data for this exercise because it was created using hydrographic elements, and more accurately represents the hydrological system.

The CDED was processed to remove linear artifacts that affect the drainage modelling. The data were resampled to a resolution of 10 m, and smoothed using the minimum value of the surrounding eight cells. The minimum value was used to ensure lower elevation areas representing drainage networks were not artificially raised, resulting in disconnected upstream areas.

Preliminary catchments were delineated for all sampled lakes using the Arc Hydro tool set, and generally following the methodology for modelling deranged drainage systems (Djokie, 2008). The elevation values under the sampled lakes were reduced to below the minimum value of the elevation data set to ensure the modelling does not allow for water flow through the lake. A flow direction raster was created specifying the sampled lakes as sinks. During this process, each cell that would eventually drain into an identified sink was defined, which delineated the possible sediment source area for each sampled lake.

Errors can occur in the catchment delineation for lakes with upstream, adjacent wetlands. If the upstream wetland is flat in the elevation model, no flow direction can be computed, and the upstream area is cut off from the lake catchment. All wetlands that were adjacent to lakes were identified and screened for potential impact on catchment delineation. Upstream wetlands that impacted the preliminary catchment delineation were merged into the lake, and the process was re-run using the modified lakes.

Lake sediment sample AOIs represent the potential source region for a sample and therefore the source for geochemical anomalies within that sample. The geochemistry of the lake sediment samples is attributed to the AOIs to indicate the ground coverage of the sampling, and an area to focus exploration efforts.

In several large lakes, multiple sediment samples were collected from what were interpreted as different basins (Jackaman, 2006; 2008a; Jackaman and Sacco, 2014). The geochemical concentrations of lake sediment samples collected from the same lake were compared for variation prior to attribution to the AOI. If the variation between key mineralization pathfinder elements (e.g. Cu. Zn) was within 25%, estimated as percent relative standard deviation, the values were averaged and applied to the AOI. Due to this averaging, some catchments may be symbolized differently from the sample points. If significant variation was observed, the catchment was manually modified based on topographic and hydrologic considerations to best represent sediment input into the sampled basins within the lake (Figure 5).

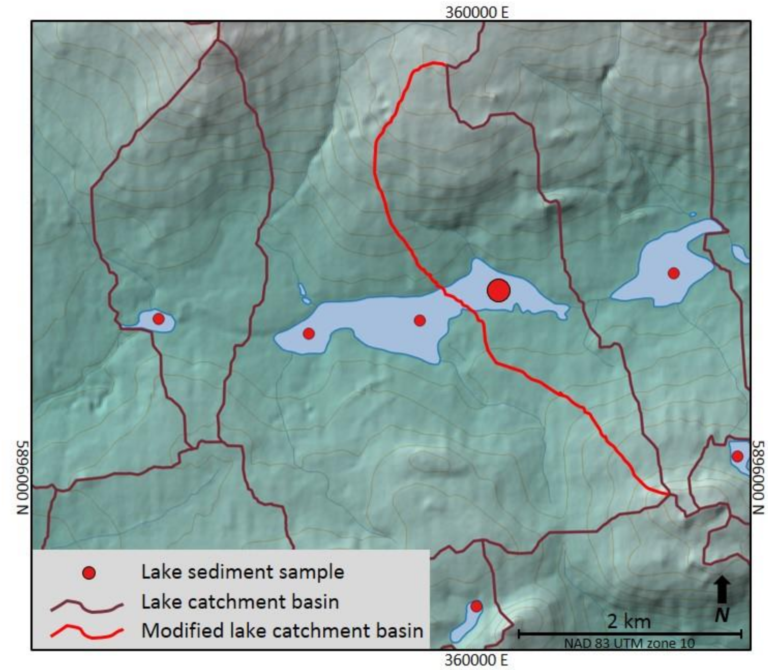


Figure 5. Example of catchment basin delineations for lake sediment samples (burgundy lines). Catchments were manually modified based on topographic and hydrological considerations where samples within the same lake had percent relative standard deviations that are greater than 25% (red lines). Digital elevation model from Canadian digital elevation data (Geobase®, 2007).

3.4 Data evaluation

The focus of the data evaluation was to determine multivariate geochemical signatures for mineral deposit types that are common to the region, and identify till and lake sediment samples that have a similar geochemical signature. The identified sediment samples provide targets for follow-up exploration and insight into the potential mineral deposit style that can facilitate exploration planning.

3.4.1 Deposit models and relative importance signatures

Relative importance signatures were determined for several common mineral deposits as defined by the British Columbia deposit profiles (EMPR, 2017). Geochemical data for eight common deposits were collected from the British Columbia assessment report index system (ARIS, 2017). Data from 22 assessment reports were reviewed and filtered to include only drill core and trench samples with a sufficient number of analytes and similar detection limits. The geochemical signature for each deposit type was determined using a series of principle component analyses after a log(10)-transformation. The resulting components related to mineralization for each deposit type were then compared for congruency and averaged to determine the geochemical signature. Outlier values were removed from the averaging. The individual element loadings of the component related to mineralization were converted to the RIS (Table 5). Positive values in the RIS indicate elevated concentrations of pathfinder elements are significant, and negative values indicate depleted concentrations are significant.

Table 5. Conversion from the element loadings calculated during principle component analyses to relative importance used for the weighted sums analysis.

Element loading (+ or -)	Relative importance (- or +)
0 – 0.3	0
0.31 – 0.45	1
0.46 – 0.6	2
0.61 – 0.75	3
0.76 – 0.9	4
> 0.9	5

3.4.2 Weighted sums indices

The weighted sums (WS) analysis creates a single index that considers multiple elements, and is specific to the geochemical signature of the exploration targets. WS analysis uses *a priori* knowledge of mineralization to reduce its multi-element signature to a single linear function (see Garrett and Grunsky (2001) for a description of the calculation). The specific RISs were used to calculate the WS index for each deposit type of interest. The relative importance values are converted to weights by dividing each importance by the square root of the sum of the squares of all the importance values, resulting in the sum of squares of the weights equating to 1. The WS analysis was carried out on the standardized geochemical data sets for the till and lake sediment, and on the standardized till data set that was levelled using dominant bedrock source.

3.4.3 Symbology, anomaly evaluation and target delineation

Data distributions were assessed on probability graphs to determine appropriate anomaly thresholds for each WS index (*cf.* Sinclair, 1981; Grunsky 2010). Where data distributions are normally distributed, standard unequal bins (i.e. 30th, 60th, 80th, 90th, 95th, 98th, 99th percentiles) accurately describe the data and can used for visualization. If data distributions are not normally distributed, anomaly thresholds are determined based on the shape of the distribution shape. Specifically, where the data distribution diverges from the normal distribution (i.e. slope breaks). Till and lake sediment sample points are symbolized using progressively-coloured proportional-dots. The catchment for each lake sediment sample is coloured to the appropriate anomaly level. Catchments greater than 10 000 ha are not included because a sample in a catchment this large is not representative of the entire area. Till data was gridded for visualization using a 1000 m cell size that was averaged over a search radius of 4 cells, with a maximum smoothing radius of 2 cells.

The symbolized point and catchment data were visually evaluated in a GIS to identify multi-element geochemical trends that may be related to base-precious metals mineralization. Both the standardized data and the standardized data levelled to bedrock were evaluated. Clustered anomalous samples are identified as indicating exploration targets worthy of additional investigation. The delineated exploration targets are generalized, and due to the low-density of samples in regional surveys, these targets rarely delineate a sediment dispersal pattern. In most cases, however, the source mineralization is likely up-ice of the delineated anomaly cluster. Anomalies were delineated at a view scale of 1:50 000 to 1:100 000. Anomaly clusters apparent at smaller scales may not have been identified. Single anomalous samples were not delineated as targets; however, they could also represent mineralization.

Characteristics used to describe the exploration targets are defined in Table 6. The media refers to whether the anomaly occurs in the till or lake sediment data, and is used to determine the relationship between till and lake sediment geochemistry. The deposit signature of the target is assigned based on the WS indices with the strongest anomalies. Targets with previously identified associated base-precious metals mineralization (i.e. MINFILE) are used to measure the ability of the WS analysis to reliably identify the mineralization style. The strength and continuity indicate the discernibility of the anomaly. The thresholds for anomaly strength differ from typical geochemical thresholds because an index representing similarity to a desired signature is used as opposed to an absolute value. Comparing the discernibility in the levelled and unlevelled data provides a measure of the efficacy of the levelling to enhance the anomaly. The potential for additional sources for the anomaly, other than what may already be identified, provides an assessment of the mineral potential in the region.

Table 6. Definitions for characteristics used to describe anomaly clusters.

Field	Description
Target ID	Unique target ID.
Media	Media in which anomaly occurs.
Deposit Signature	WS indices with the strongest anomalies.
Strength	Description of strength for majority of samples in anomaly cluster: weak (< 80th percentile); moderate (90th to 98th percentile); strong (>98th percentile).
Continuity	Measure of similarity between anomalies in sample cluster: low (< 1/3 samples are similar); medium (1/3 to 2/3 of samples are similar); high (> 2/3 of samples are similar).
Effect of levelling	The effect of levelling till data to bedrock on the strength of the anomaly: increase; decrease; none; n/a (no till anomalies).
Associated MINFILE (2017)	Name of associated MINFILE occurrence that could be contributing to the anomaly.
Associated mineralization style	Mineralization type of associated occurrence as described in MINFILE database (2017).
Additional source	Possibility of an undiscovered source for anomaly.
Comment	Additional information.

4. Results and discussion

4.1 Data standardization

All elements required standardization to improve their suitability for evaluation (Table 7). In the till data, 222 samples did not have sufficient material archived for ICP-MS reanalysis, so the original ICP-ES analytical results were used. Data were not available in the original analysis for Ag in 18 samples, Hg in 106 samples, and As, Au, Sb and W in 5 samples; the group median was substituted for these missing data.

Table 7: Data standardization procedures performed for each element of interest from the till and lake sediment samples. After the standardization, all elements were near normally distributed and their suitable for evaluation was improved.

Media	Method	Ag ICP	As INAA	Au INAA	Ba ICP	Bi ICP	Co INAA	Cr ICP	Cu ICP	Fe ICP	Hg ICP	Mn ICP	Mo ICP	Ni ICP	Pb ICP	Sb INAA	V ICP	W INAA	Zn ICP
Till	*Substitute archive results for missing reanalysis data*	x (n=222)			x (n=222)	x (n=222)		x (n=222)	x (n=222)	x (n=222)	x (n=222)	x (n=222)	x (n=222)	x (n=222)	x (n=222)				x (n=222)
	Substitute group median for samples missing data points	x (n=18)	x (n=5)	x (n=5)							x (n=106)					x (n=5)		x (n=5)	
	Log(10)-transform	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
	Substitute for censored data	x (AES n=79)	x (Lab1 n=34)	x (Lab1 n=474; Lab2 n=937)		x (AES n=82; MS n=51)					x (MS n=79)				x (AES n=35)			x (Lab1 n=412; Lab2 n=888)	
	Level by lab		x	x			x									x		x	
	Level by analytical method	x			x	x		x	x	x	x	x	x	x	x	x			x
Lake sediment	*Substitute group median for samples missing data points*	x (n=1)			x (n=1)	x (n=1)	x (n=1)	x (n=1)	x (n=1)	x (n=1)	x (n=1)	x (n=1)	x (n=1)	x (n=1)	x (n=1)		x (n=1)		x (n=1)
	Log(10)-transform	x	x	x	x	x	x	x		x	x	x	x	x	x	x	x	x	x
	Substitute for censored data		x (n=129)	x (n=1679)		x (n=316)										x (n=24)	*	x (n=1528)	

Note: Lab 1 refers to Becquerel Labs and Lab 2 refers to Activation Labs

Regression-based substitutions for censored data were made for Ag, As, Au, Bi, Hg, Pb, and W. In the lake sediment data, median substitutions were made for one sample, albeit not the same sample, in most elements. Regression-based substitutions for censored data were made for As, Au, Bi, Sb, and W. The purpose of the substitutions is to ensure the data set is complete. Missing data were substituted with the group medians to limit the impact on evaluation. The regression-based substitutions provide a solution to data censoring due to lower detection limits, while also completing the low end of the data distribution in a normal pattern. These substitutions have little effect on the evaluations because the values are smaller than the lower detection limits. After the median- and regression-based substitutions, the data distributions of all elements were positively skewed and required the log(10)-transformation resulting in generally normal data distributions (Figure 6).

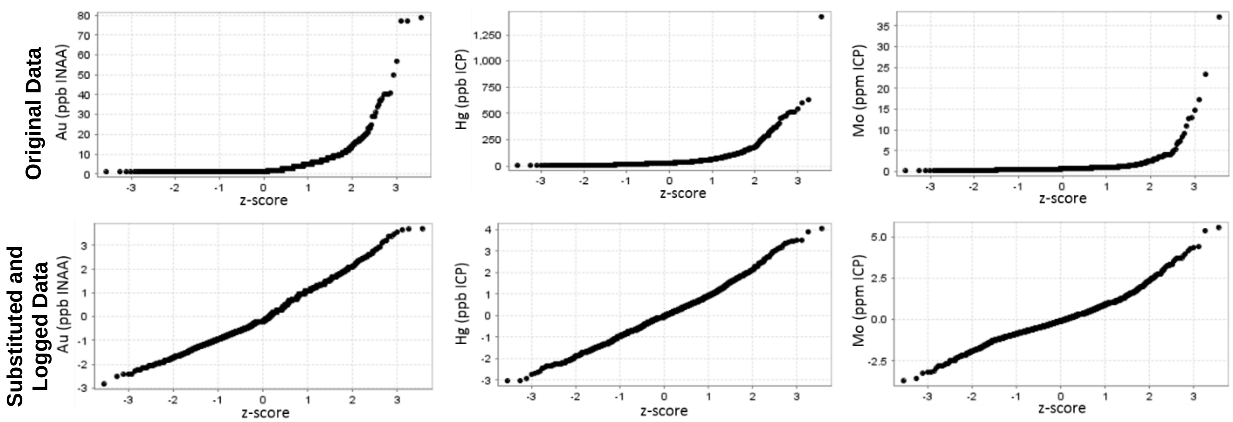


Figure 6. Probability plots illustrating the data distributions of select elements before (upper plots) and after (lower plots) data standardization. Normal distributions plot as straight lines, indicating that the data standardization procedure successfully improved the normality of the data distributions.

Till data were levelled to mitigate differences in analytical results due to analytical method and the lab in which the analysis was performed. Elements measured by aqua regia type dissolution - inductively coupled plasma were levelled using element detection method (i.e. ES vs MS) (Figure 7). Most elements show notable differences in results from the two detection methods, although the differences in Cu, Hg, Pb, and Zn were minimal. All elements show improved comparability after levelling by analytical method. All elements analysed by INAA showed differences related to the processing lab (Figure 8). The analytical results for Au, As, Sb, and W are higher from Activation Labs, whereas the Co results are lower. Comparability between the results from the different labs is improved after processing.

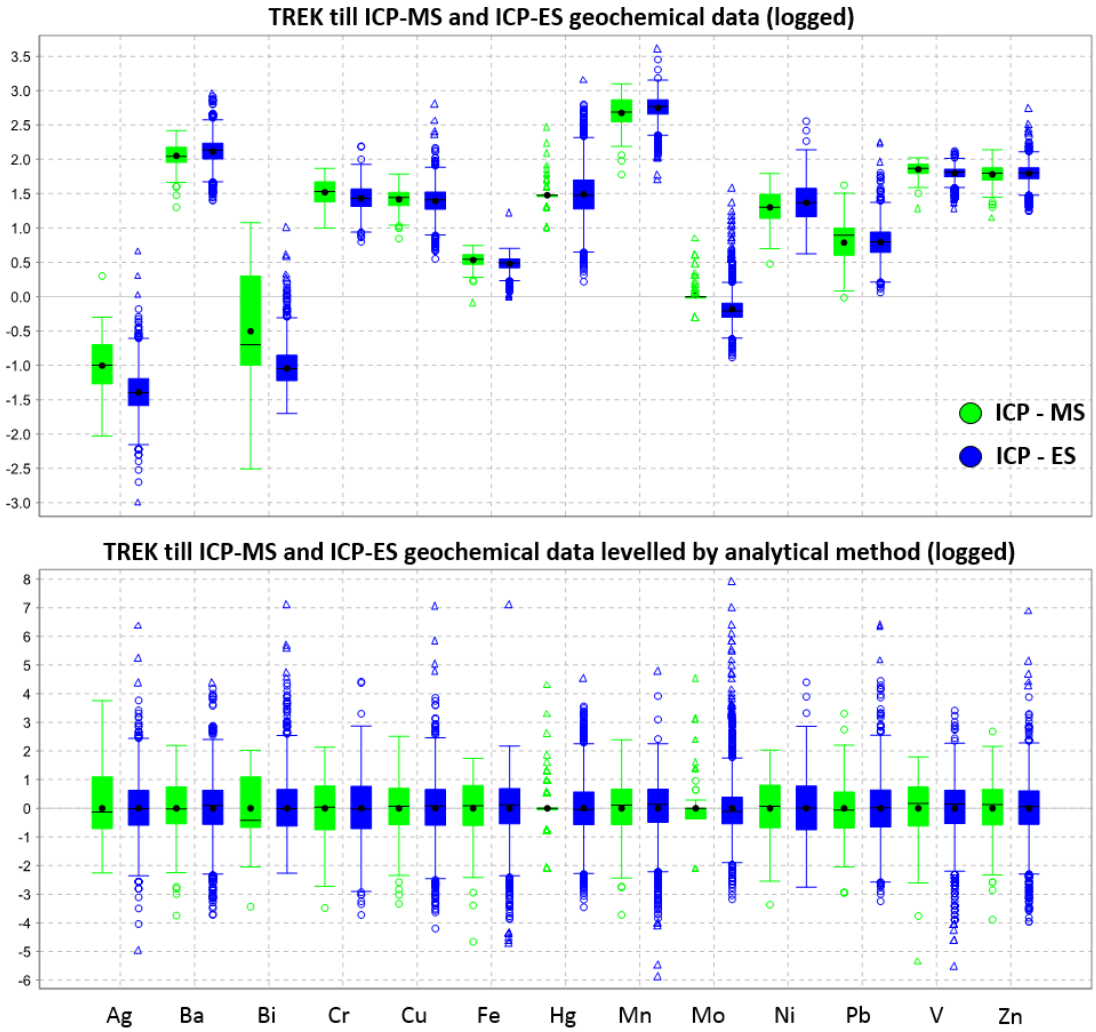


Figure 7. ***Box plots comparing analytical results from ICP-MS and ICP-ES before (top) and after (bottom) z-score levelling. The levelling procedure converts each value to a group-based z-score. After levelling, all groups have a mean of 0 (black dot on box plots) and a standard deviation of 1. The z-score levelling method does not change the shape of the distribution and genuine outliers are preserved.***

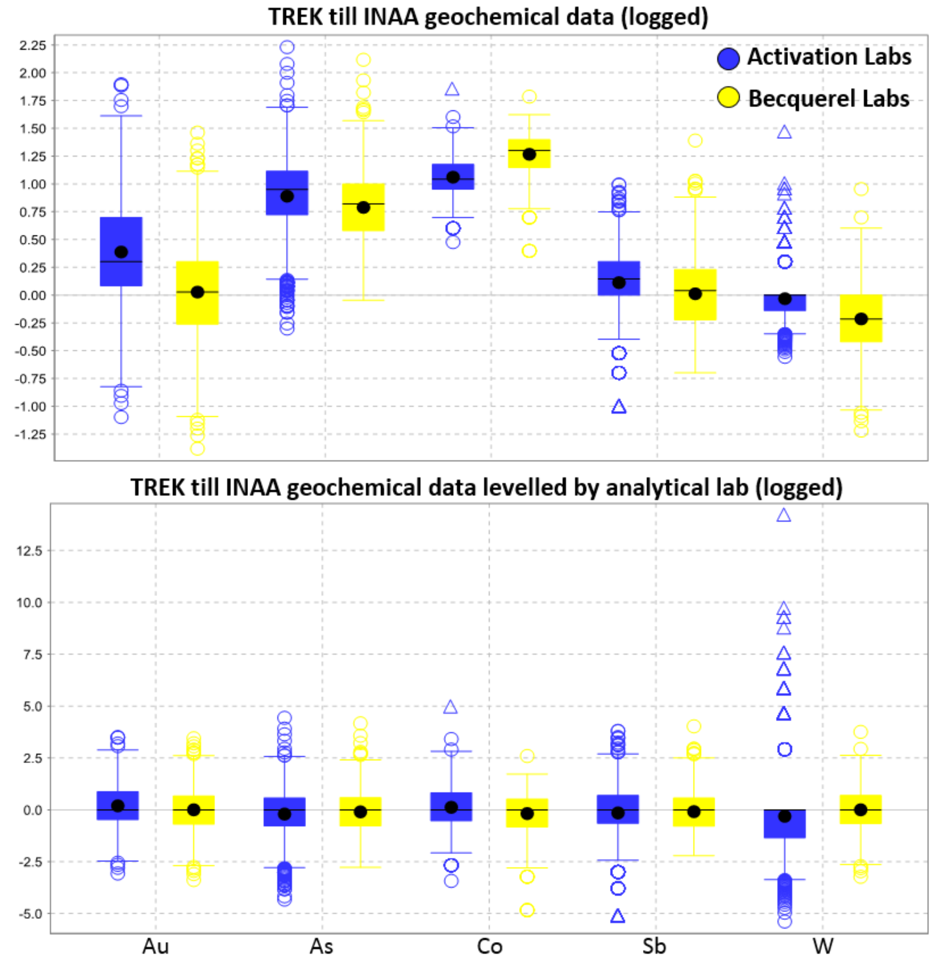


Figure 8. ***Box plots comparing analytical results from INAA for each lab before (top) and after (bottom) z-score levelling. The levelling procedure converts each value to a group-based z-score. After levelling, all groups have a mean of 0 (black dot on box plots) and a standard deviation of 1. The z-score levelling method does not change the shape of the distribution and genuine outliers are preserved.***

4.2 Levelling till data based on bedrock source unit

The till data were levelled using the dominant bedrock unit that most likely contributed to the composition of the till. The purpose of this levelling is to reduce the influence of regional changes in the geochemical composition of bedrock on the evaluation of the till geochemical data. For this procedure, till sample AOIs are delineated to identify the probably source region, and a compiled and simplified bedrock data layer defines the subpopulations used for the z-score levelling.

4.2.1 Bedrock compilation

Bedrock data from several sources were evaluated for compatibility to create one continuous bedrock data set. The interpretations from Angen et al. (2015) and Bordet (2016) were not complete at the time of the study, and would require resources beyond the scope of this study to incorporate into the existing compilation (Cui, et al., 2015). These data were excluded from the compilation. A uniform, continuous geology layer was produced for this study that incorporates Mihalynuk et al. (2008a, b) with the existing bedrock compilation for British Columbia (Cui et al., 2015). These data were more congruent with the existing compilation legend. The original 117 stratigraphic units that occurred in the study area were simplified to 38 (Table 8; Figure 9).

Table 8. Bedrock geology descriptions for simplified bedrock units.

Unit Reference	Simplified unit code	Dominant rock type	General description	Composition*
1	Eeva	volcanic	Andesitic volcanic rocks	I
2	EFLgd	intrusive	granodioritic intrusive rocks	F
3	Egd	intrusive	Dioritic intrusive rocks with some gabbroic rocks	I to M
4	Ego	intrusive	monzodioritic to gabbroic intrusive rocks	I to M
5	Egr	volcanic	undivided volcanics; basalt to rhyolite	F to M
6	EKqd	intrusive	quartz monzonite	I
7	EMiE	volcanic	basalt to andesite volcanics	M to I
8	EMJdr	intrusive	diorite	I
9	Eo	volcanic	rhyolitic volcanics; minor andesite	F
10	EOva	volcanic	andesitic volcanics	I
11	EOvf	Intrusive / volcanic	Dacite, rhyolite, andesite and undivided felsic intrusives	F to I
12	EQ	intrusive	granite, granodiorite	F
13	JB	Sedimentary / volcanic	undivided sedimentary and volcanic rocks	n/a
14	JFC	intrusive	quartz dioritic and monzonitic to monzogranitic rocks	I
15	JKcl	intrusive	quartz monzonitic to monsogranitic rocks	I to F
16	JKg	Intrusive / metamorphic	Quartz diorite, granodiorite, gneissic granodiorite	I
17	JKTo	no data	no data	no data
18	Kca	volcanic	hyaloclastite	M
19	KK	volcanic / sedimentary	andesitic volcanic rocks; minor coarse clastic rocks	I
20	LJLaqd	intrusive	quartz diorite	I
21	LJLaqm	intrusive	quartz monzonitic to monzogranitic	I to F
22	LJqd	intrusive	quartz monzonite	I
23	LKCL	intrusive	quartz monzonitic to monzogranitic	I to F
24	Lki	intrusive	undivided intrusive, granodiorite, mafic sills and dykes	F to M
25	IKS	sedimentary	undivided sedimentary rocks; minor andesite	n/a
26	LKTDfp	intrusive	felspar porphyritic intrusive rocks	I
27	ImJH	volcanics / sedimentary	Felsic-basaltic volcanics; coarse clastic sedimentary rocks	F to M
28	MiCCl	volcanic	basalt plugs and flows	M
29	MiCvb	volcanic	basalt; basalt breccia; hyaloclastite	M
30	MiPlCb	volcanic	basaltic volcanics; minor andesite and sedimentary rocks	I to M
31	MJfp	intrusive	feldspar porpheritic (augite) intrusive rocks	I to M
32	muJHo	volcanic	Andesitic, dacitic and rhyolite tuffs	I to F
33	PJV	metamorphic	Granites and biotite quartzo-feldspathitic schist, granodiorite orthogneiss	I
34	PTrC	volcanic / metamorphic	Mafic volcanics; peridotite, serpentinite	M
35	TrJB	intrusive	Diorite, monzodiorite, monzonite	I to F
36	unknown	no data	no data	no data
37	uTrim	sedimentary	limestone; marble	n/a
38	uTRv	Sedimentary / volcanic	undivided sedimentary and mafic-intermediate volcanics	I to M

*Note: * F – felsic; I – intermediate; M – mafic; dominant composition listed first.*

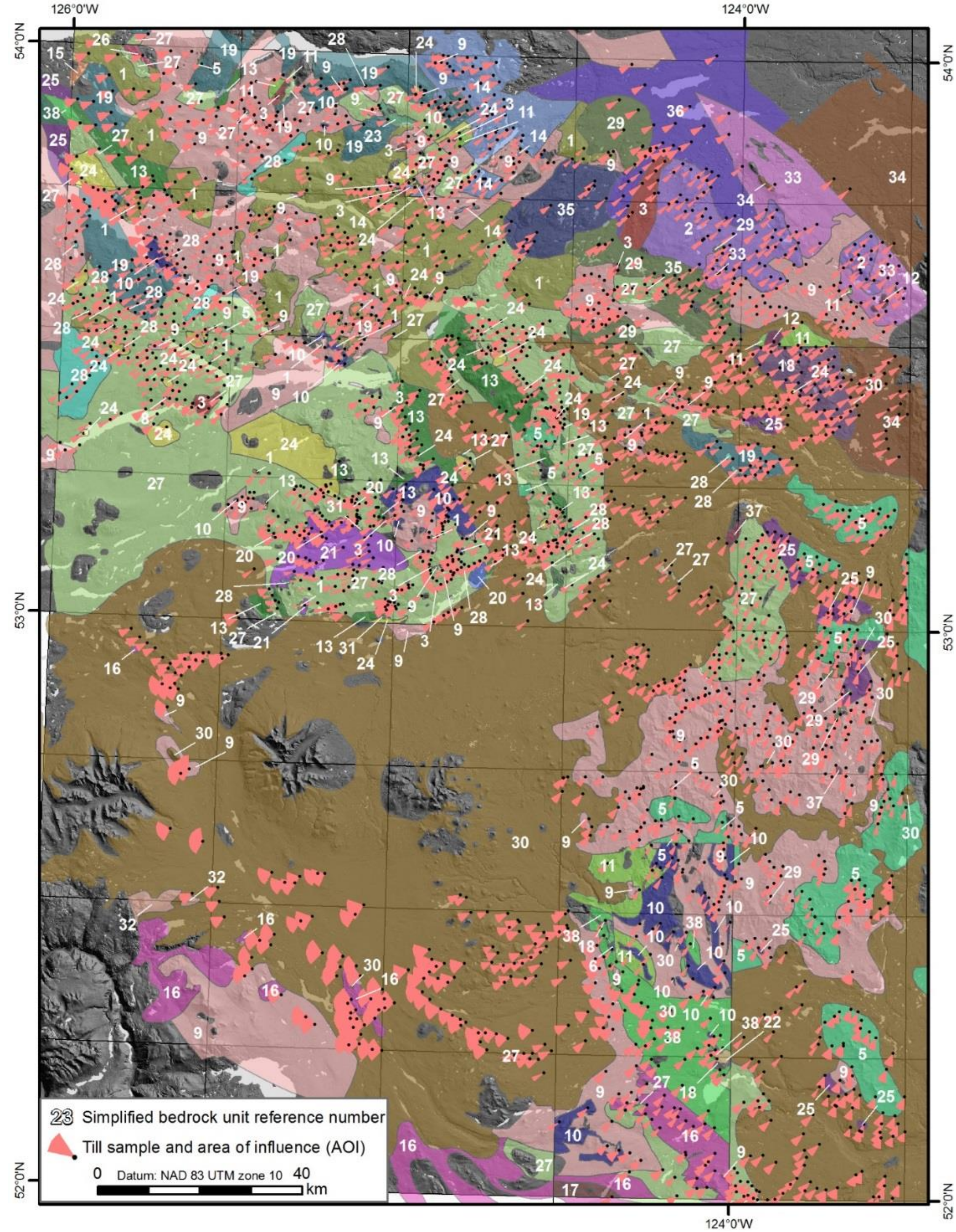


Figure 9. Simplified bedrock geology and till areas of influence (AOI) that identify the dominant bedrock source unit for each till sample. Refer to Table 8 for bedrock unit definitions. Digital elevation model from Canadian digital elevation data (Geobase®, 2007).

The accuracy of the bedrock data and resulting simplifications are critical to the correct determination of bedrock source units for till samples. Inaccuracies will result in the incorrect attribution of bedrock source units and cause spurious data levelling results. Significant efforts were made to incorporate the highest resolution, comparable bedrock mapping into one layer, and to create accurate simplifications. Even with these efforts, the bedrock data likely contributed the largest error to the data levelling. Optimally, bedrock units with similar geochemical signatures are combined; however, there is a lack of geochemical information for these units. Combinations relied heavily on unit descriptions by the various bedrock mappers, which were not always consistent. Future work should concentrate on the assimilation of different bedrock data sources, and the acquisition of geochemical data for the different lithologies that will better inform the simplification process.

4.2.2 Till AOIs and bedrock associations

Till AOIs were produced to spatially link each sample to a dominant bedrock source (Figure 9; Appendix D). The method for determining the direction and width of the till AOIs is based on the ice-flow history at the sample location. This method assumes that each identified ice-flow vector has the same potential to contribute to the composition of the till sample. Dominant, and possibly the most recent, ice-flow directions, however, likely have a greater influence. Future attempts at delineating till AOIs could consider weighting dominant transport vectors more heavily when determining the AOI width and direction.

The determination of till transport distances (i.e. length of till AOIs) is relative and based on factors that influence glacier velocity. As a pilot, this study used an average transport distance of 2.5 km for the average sediment transport distance, which is then scaled up or down by factors of standard deviations. This method provides relative consistency; however, attempts to apply more absolute scaling values based on sediment transport studies (e.g. Clark 1987; Parent et al., 1996) could improve the accuracy of the AOIs.

The discussion of AOI delineation is focussed on improving their accuracy. It must be considered, however, that these minor improvements could be within the error of the bedrock mapping. Where high resolution bedrock mapping is available, these refinements could make a significant difference. In an area where the bedrock mapping is of lower resolution, efforts in improving the bedrock data source would likely provide greater improvements than modifying the AOIs.

Twenty-four of the 38 simplified bedrock units were determined to be dominant source units by the till AOIs. If the till AOIs correctly identified the source units, the associated till geochemical results should reflect expected values for the rock types. Analytical results for the till geochemical data from the simplified volcanic bedrock units correspond well with published background values for contrasting elements in rhyolitic and basaltic volcanic rocks (Table 9; Figure 10). In general, the till geochemistry associated with felsic and intermediate rocks in the TREK area indicate low concentrations of Co, Cr, Fe, Ni, and V, whereas the data associated with mafic units consistently indicate higher concentrations of these elements. Geochemical data associated with undifferentiated volcanic units composed of both felsic and mafic rocks have expectedly larger ranges that span the data set. These comparisons support that the till AOIs were generally accurate in identifying a source bedrock unit.

Table 9. Ratios for select elements calculated from geochemical background concentrations in rhyolite (Gabour and Pearson, 2008) and basalt (Levinson, 1974).

	Co	Cr	Fe	Ni	V
Rhyolite	1	1	1	1	1
Basalt	5	5	2	7	5

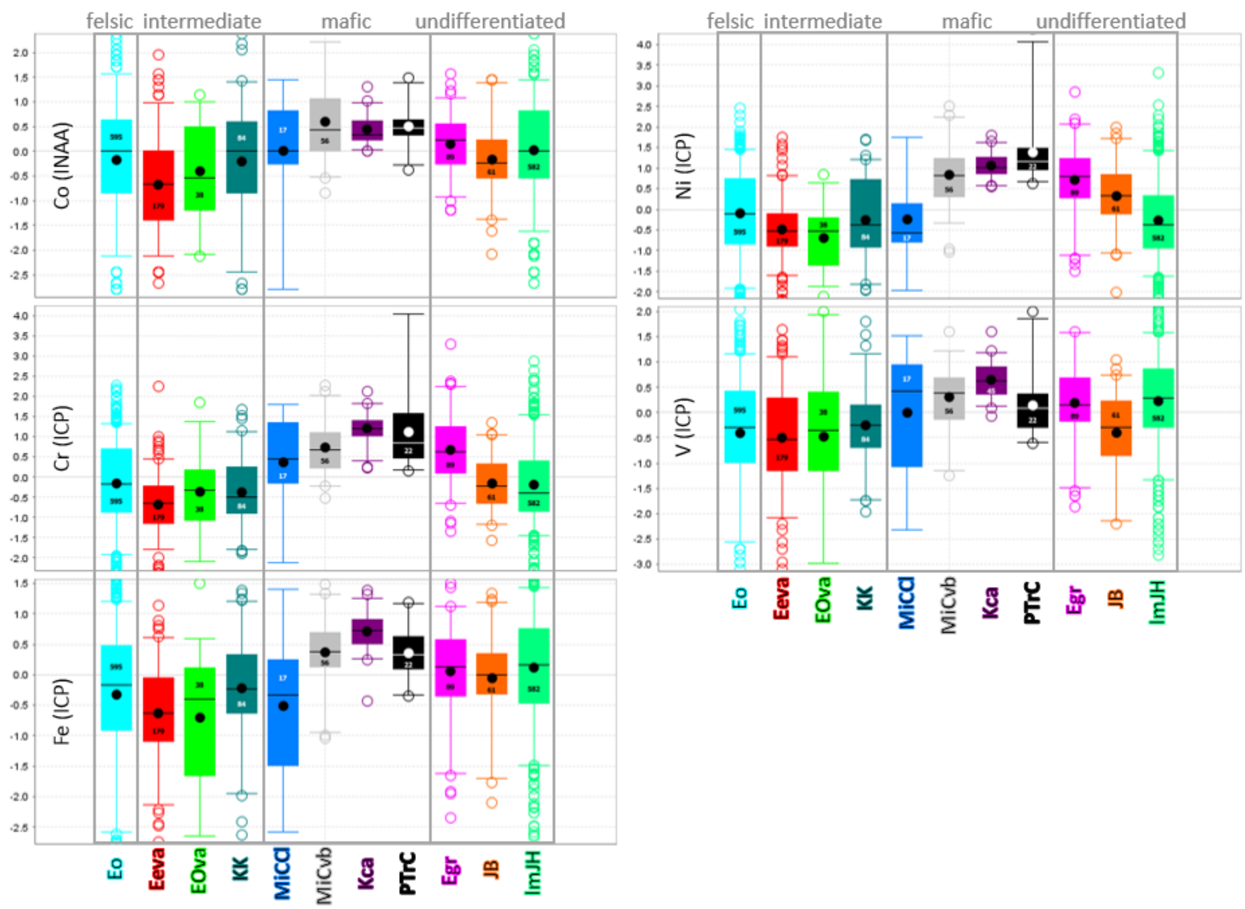


Figure 10. Till geochemical data distributions for simplified source bedrock unit subpopulations (See Table 8 for unit descriptions). Till derived from mafic units has higher concentrations in Co, Cr, Fe, Ni, and V than till derived from felsic and intermediate units. These results suggest the AOIs were generally accurate in delineating source bedrock units. Spurious result could be a result of a high range in geochemical concentrations within the bedrock unit, different rock types within this group not being reflected in the bedrock mapping, the till AOIs not being accurate, or mineralization.

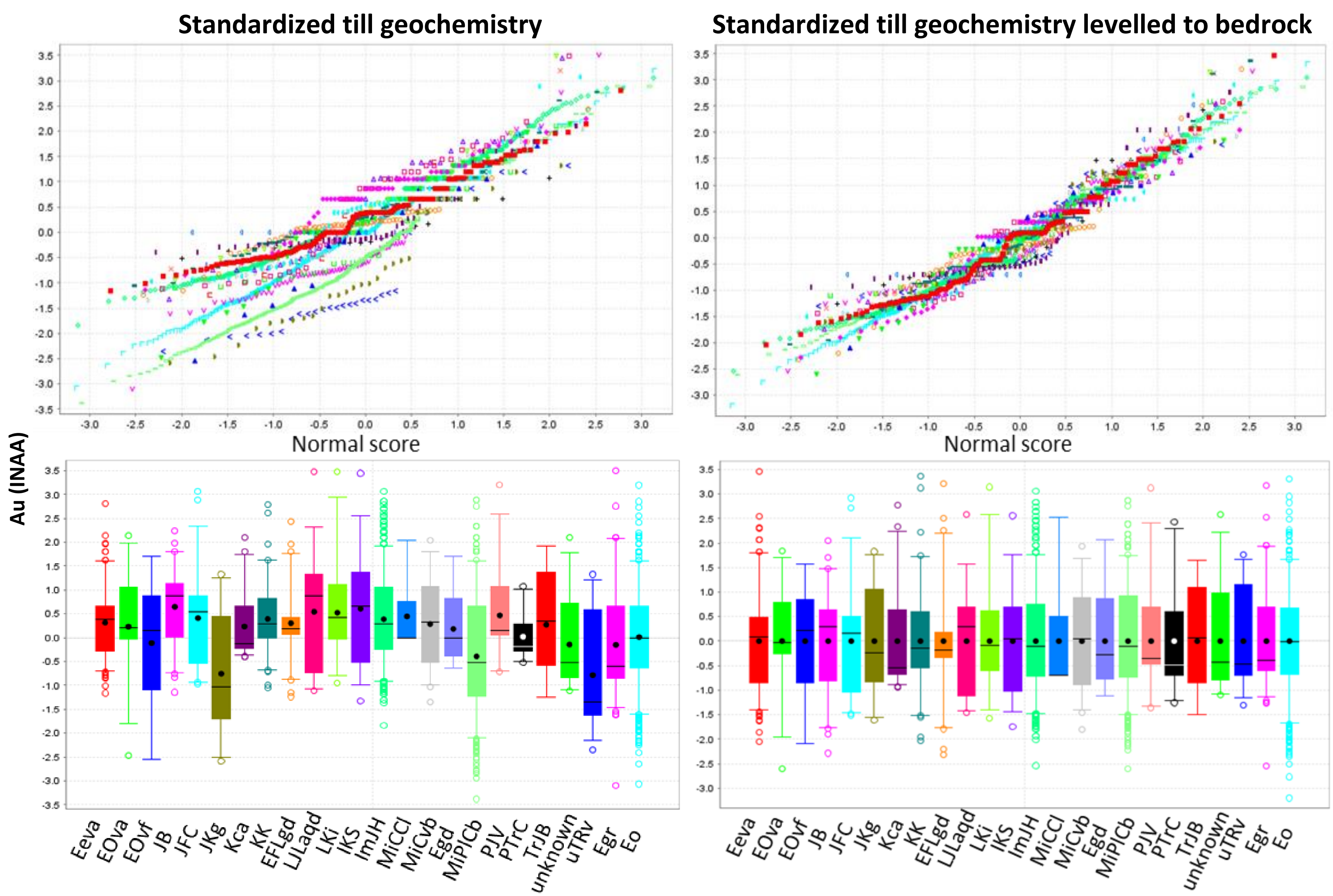
The trends of till geochemical data associated with felsic and mafic volcanic units showed some differences from the published geochemical relationships. The till data associated with felsic rocks, which are dominantly composed of rhyolite flows of the Ootsa Lake Formation, have a larger range than expected, and are generally of similar or higher concentrations to those of the intermediate rocks. The central tendencies of the data plot within the expected range; however, the maximum (anomalous) values are similar to those of the mafic rocks. The large range and higher than expected element concentrations could indicate that the Ootsa Lake Formation has a high range in geochemical composition, different rock types occur within this group are not reflected in the bedrock mapping, or the till AOIs are not accurate. It is also possible that these variations are due to mineralization, as the elements chosen for this study are pathfinders for certain types of base-precious metals mineralization. Anomalies will be preserved after levelling, and thus these potential indications of base-precious metals mineralization will be maintained. Unit MiCCl is composed vesicular basalts and should reflect mafic composition. The associated till data, however, generally shows lower mafic-related composition than that the other mafic units. This could be due to the previously discussed factors, or the result of the group being composed of too few samples to adequately describe the unit.

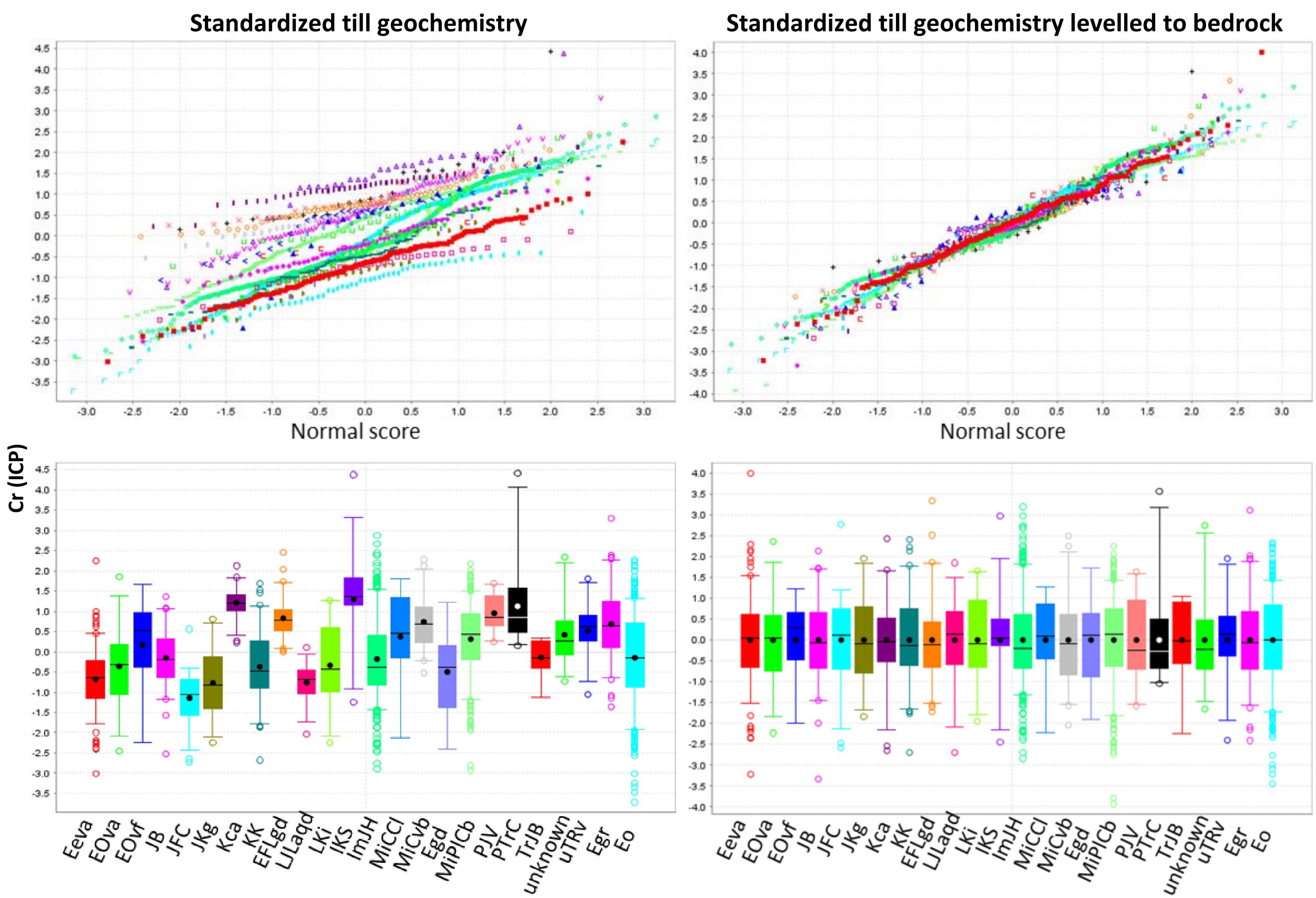
These results suggest that the till AOIs were generally successful in identifying a source bedrock unit, and the resulting subpopulations can be used to level the geochemical data. In theory, geochemical anomalies in pathfinder elements that remain after the levelling can more confidently be attributed to base-precious metals mineralization. Additional geochemical data specific to the bedrock units would provide the best validation for the subpopulations; however, this information does not presently exist. Similar evaluations using till major oxide and minor element geochemistry (Jackaman and Sacco, 2014; 2016; Jackaman et al., 2014; 2015) may provide another measure for the efficacy of this method, as these data are more indicative of rock composition. Higher resolution bedrock data and more absolute scaling factors for till AOIs could help improve identification of dominant source bedrock units for till.

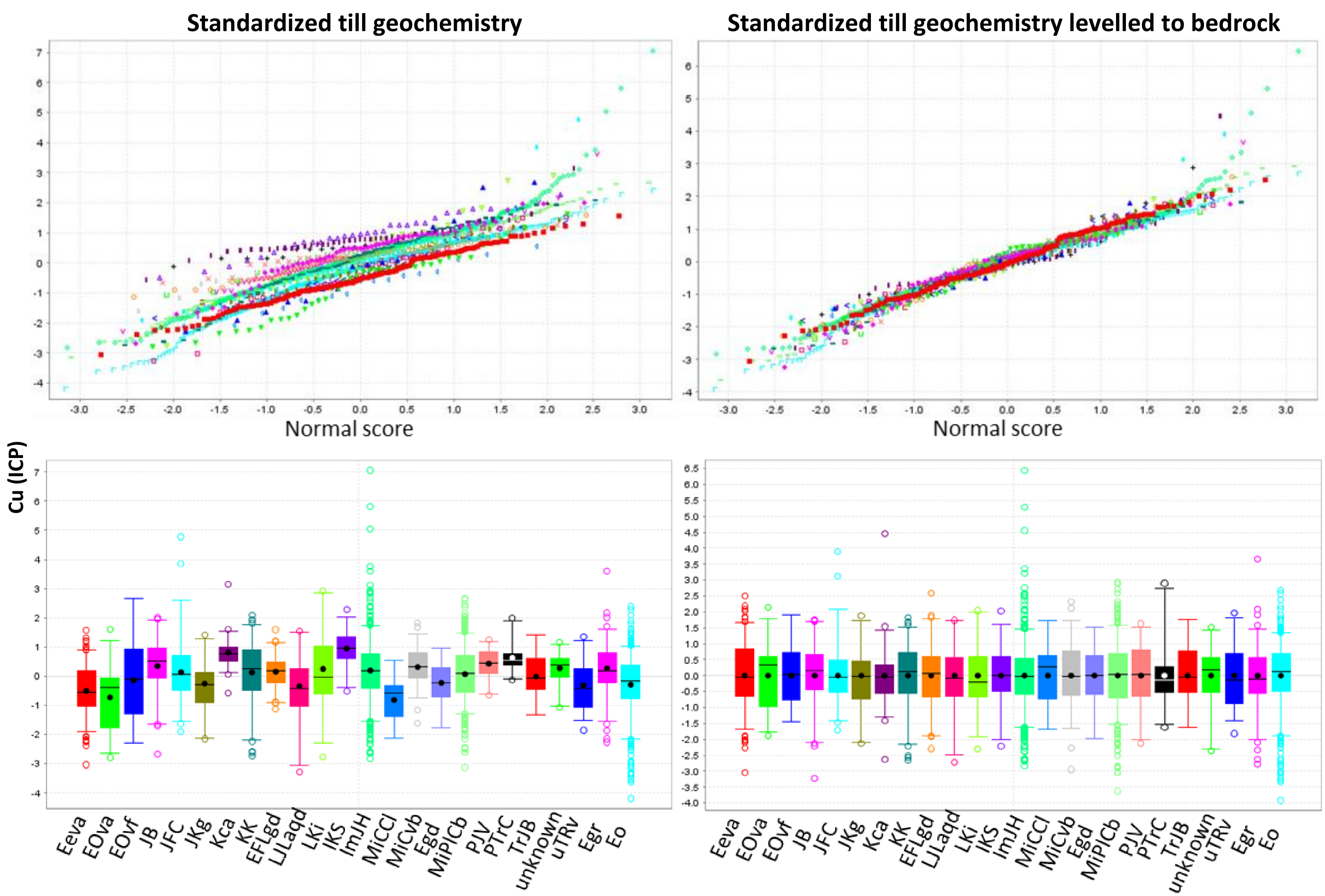
4.2.3 Levelling results

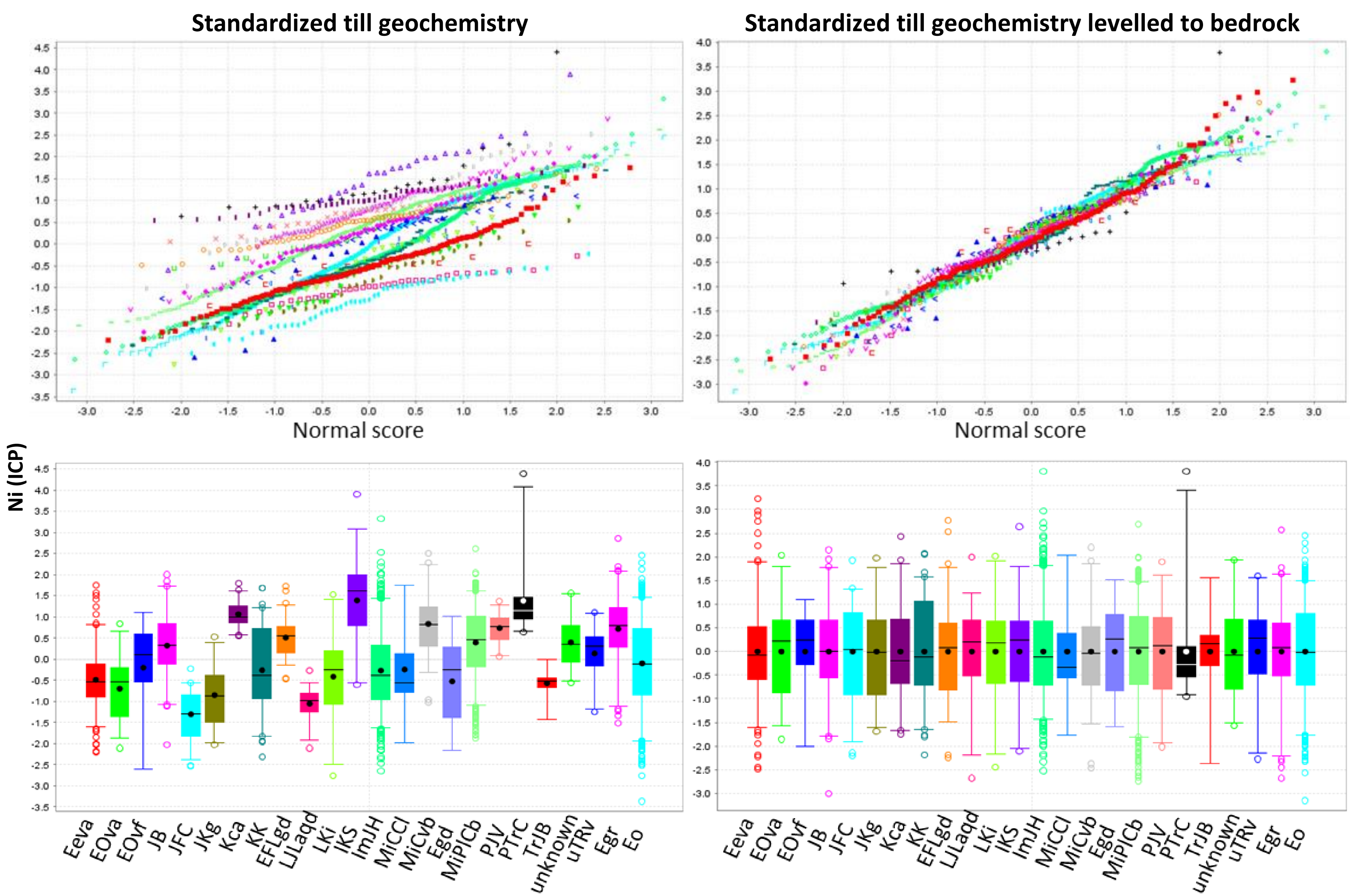
Most elements in the till geochemical data for the 24 bedrock subpopulations have near-normal data distributions and differences in their geochemical concentrations. Comparisons of the standardized levelled and unlevelled data show that the z-score levelling successfully mitigated the differences in geochemical concentrations while maintaining similar data distributions and outliers (e.g. Figure 11; Appendix B).

Figure 11. Data distributions of bedrock subpopulations for select elements in till before and after levelling to bedrock. Legend below; see following pages for probability and box plots.


Standardized till geochemistry
Standardized till geochemistry levelled to bedrock
Normal score
Normal score
Au (INAA)
Eeva
EOva
EOvf
JB
JFC
JKg
Kca
KK
EFLgd
LJLaqd
LKi
lKS
lmJH
MiCCl
MiCvb
Egd
MiPlCb
PJV
PTrC
TrJB
unknown
uTRv
Egr
Eo


Standardized till geochemistry
Standardized till geochemistry levelled to bedrock
Normal score
Normal score
Cr (ICP)
Eeva
EOva
EOvf
JB
JFC
JKg
Kca
KK
EFLgd
LJLaqd
LKi
lKS
lmJH
MiCCl
MiCvb
Egd
MiPlCb
PJV
PTrC
TrJB
unknown
uTRV
Egr
Eo


Standardized till geochemistry
Standardized till geochemistry levelled to bedrock
Normal score
Normal score
Cu (ICP)
Eeva EOva EOvf JB JFC JKg Kca KK EFLgd LJLaqd LKi lKS lmJH MiCCl MiCvb Egd MiPlCb PJV PTrC TrJB unknown uTRv Egr Eo



Standardized till geochemistry
Standardized till geochemistry levelled to bedrock
Normal score
Normal score
Ni (ICP)
Eeva
EOva
EOvf
JB
JFC
JKg
Kca
KK
EFLgd
LJLaqd
LKi
lKS
lmJH
MiCCl
MiCvb
Egd
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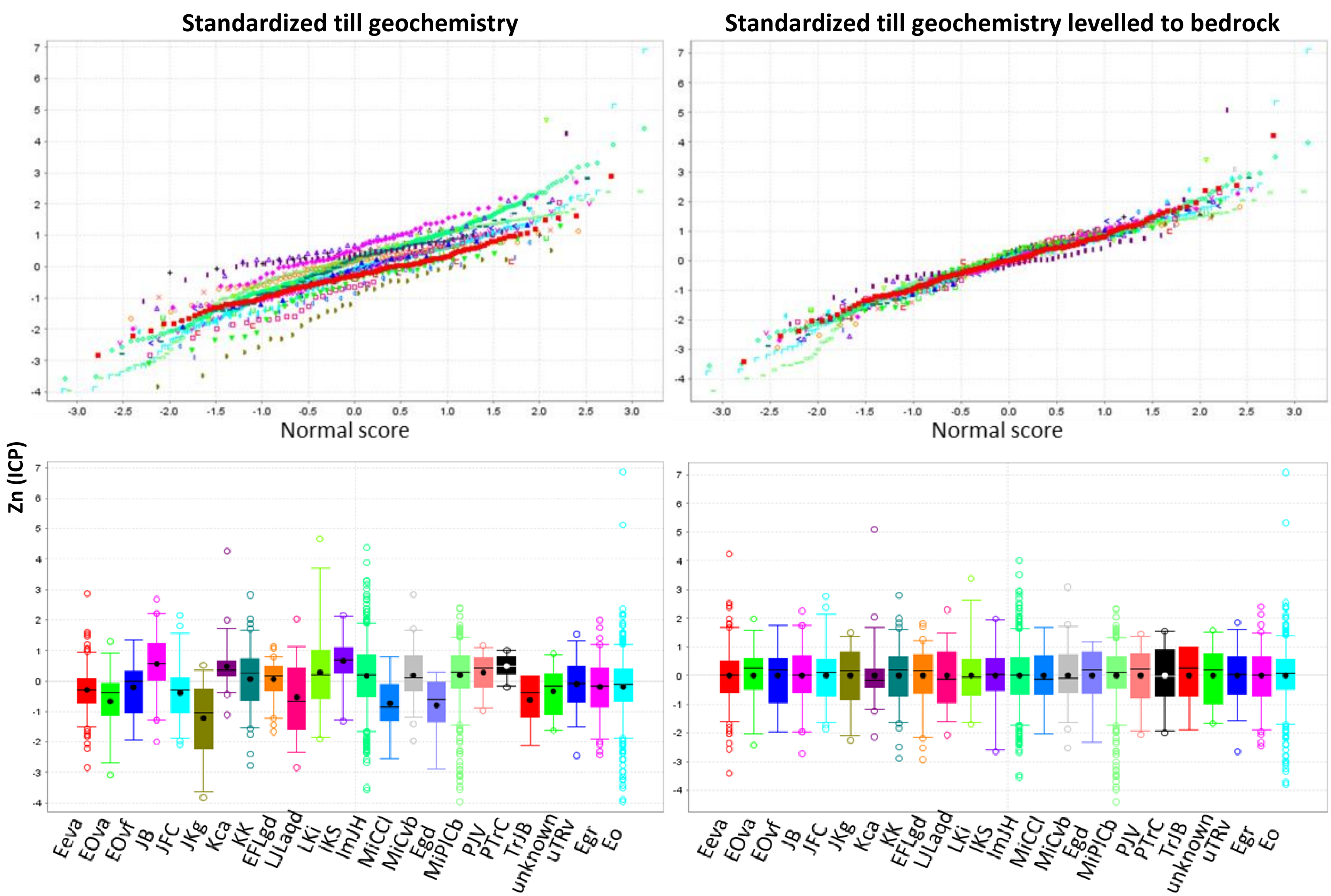
unknown
uTRV
Egr
Eo


Standardized till geochemistry
Standardized till geochemistry levelled to bedrock
Normal score
Normal score
Zn (ICP)
Eeva
EOva
EOvf
JB
JFC
JKg
Kca
KK
EFLgd
LJLaqd
LKi
lKS
lmJH
MiCCl
MiCvb
Egd
MiPlCb
PJV
PTrC
TrJB
unknown
uTRv
Egr
Eo

Many pathfinder elements for base-precious metals mineralization (e.g. As) occur at low background concentrations in unmineralized bedrock and do not differ significantly in different bedrock units. As a result, levelling elements that are specific to base-precious metals mineralization generally changed the size and shape of anomalies, whereas the location of anomalies changed for elements more common to bedrock composition. For example, elements such as Au show less spatial change after levelling than Ni, because Ni occurs in variable concentrations in different bedrock units and Au is generally not related to specific units (Figure 12). All elements showed increased anomaly contrast in the southern part of the study area where younger volcanic bedrock units are extensive (Appendix B). This indicates that the levelling improved the discernibility of till geochemical anomalies where younger volcanic bedrock units occur at surface. These units can otherwise hinder exploration efforts because they mask the older rocks potentially mineralized with base-precious metals.

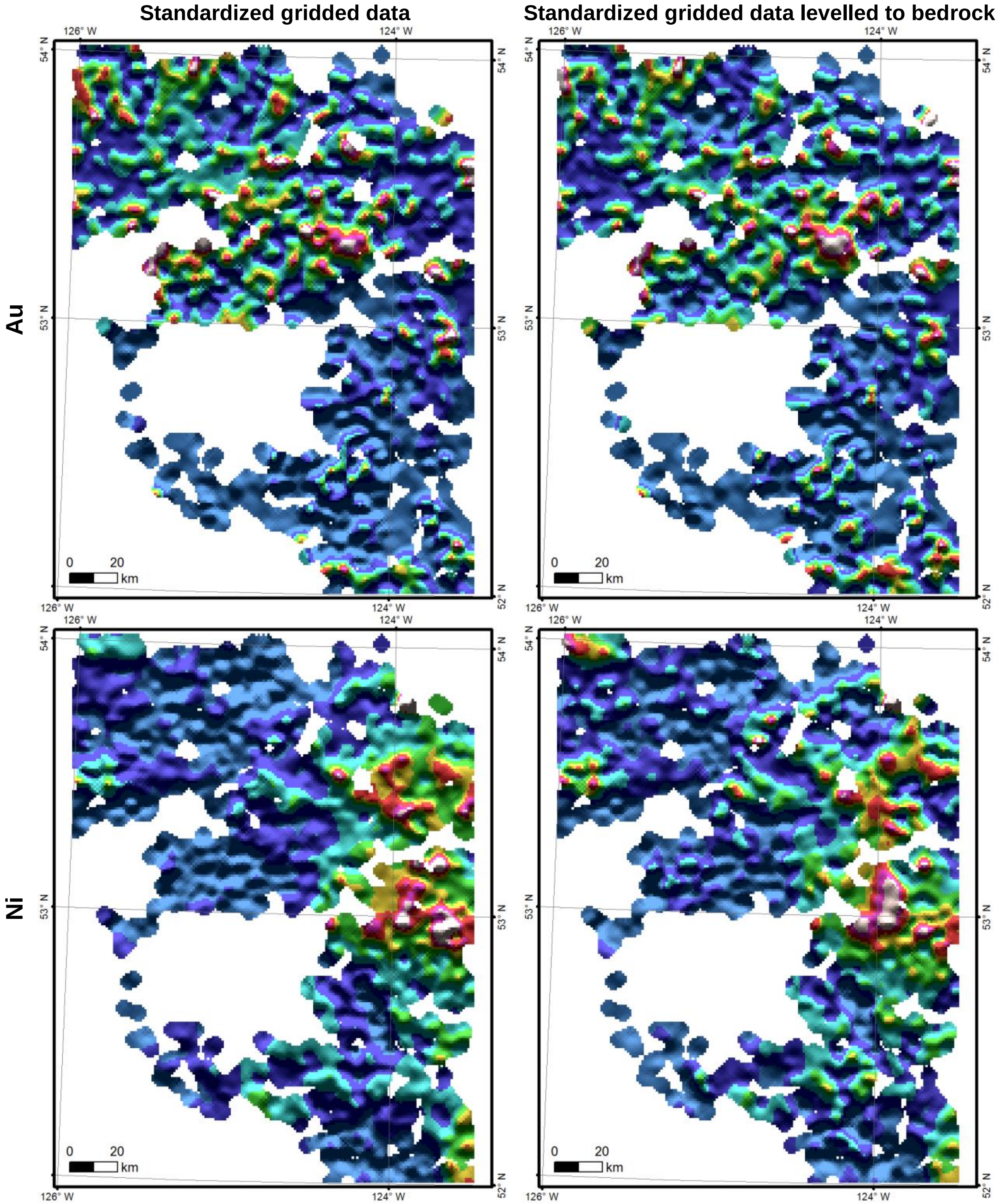


***Figure 12.** Gridded Au and Ni results for standardized till data and standardized till data levelled to bedrock. Gridding uses a 1000 m cell size averaged over a search radius of 4 cells, with a maximum smoothing radius of 2 cells.*

4.3 Lake sediment sample AOI

Lake sediment AOIs were produced by delineating catchments for each sampled lake (Figure 13). As previously mentioned, the size of the catchment is important when evaluating the data. Dilution of a geochemical signal will occur in large catchments. Furthermore, an excessively large catchment does not provide adequate guidance to follow-up anomalous samples. For this study, catchments were not used for evaluation when the area was greater than 10 000 ha, which was 70 catchments or 1.97% of the data (Figure 14). The associated sample data for the removed catchments is symbolized by proportional-dots for evaluation.

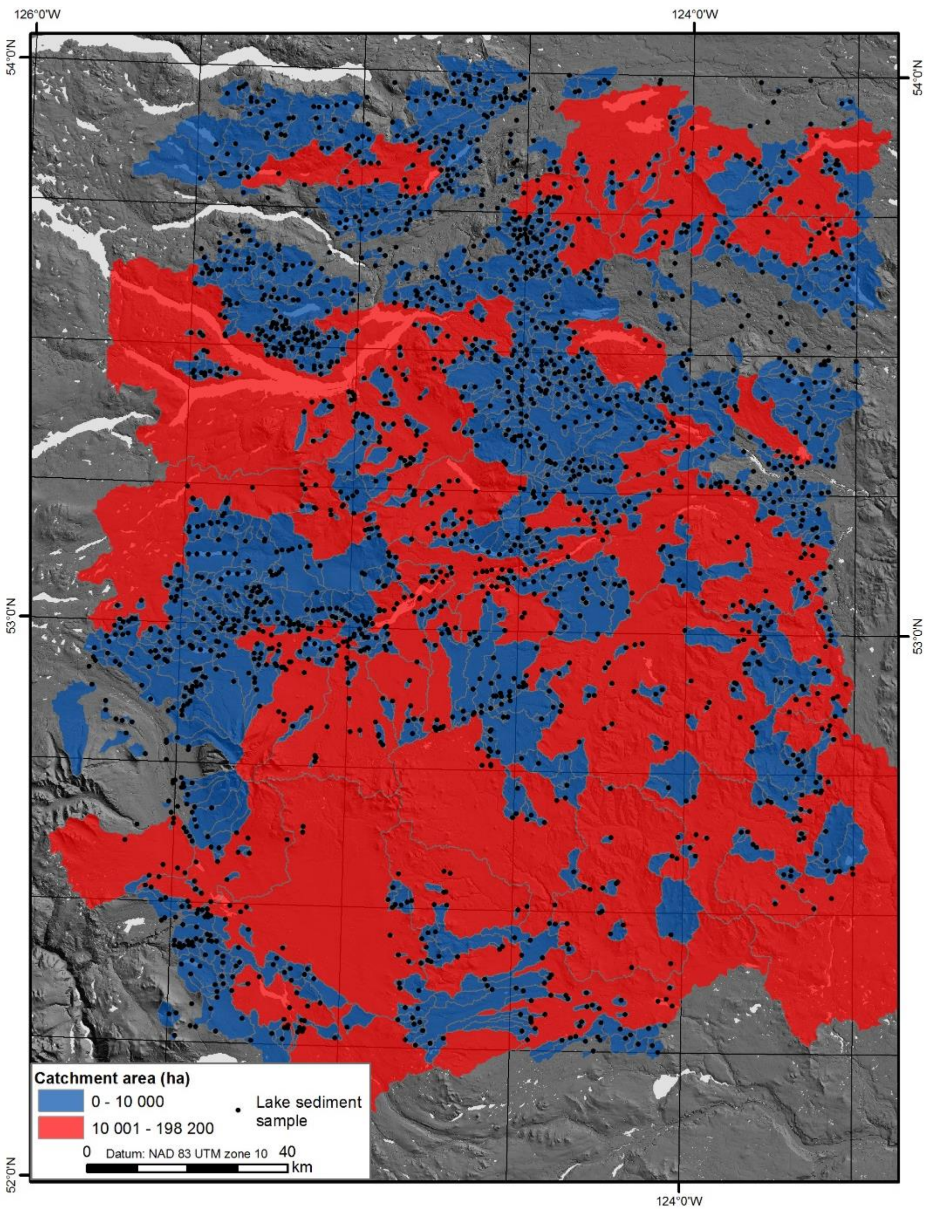


Figure 13. Lake sediment sample locations and their associated catchments symbolized by area.

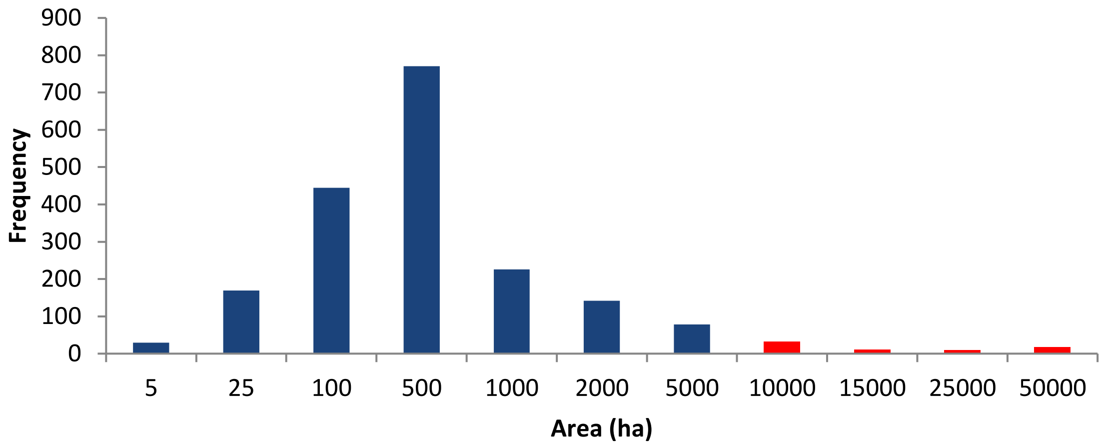


Figure 14. Histogram depicting the distribution of catchment areas. Red bars indicate the catchments that were removed from the evaluation.

Lake sediment sample AOIs are delineated from the outlet of the sampled lake to the outlet of the next upstream sampled lake. This definition assumes that there is minimal sediment transfer through the sampled lakes; however, the catchments of upstream lakes that were not sampled are included in the delineation. The catchments of upstream lakes that were not sampled were included in an effort to avoid excluding potential sources areas. A comparative analysis of geochemical data using nested and non-nested catchments may provide empirical evidence to inform whether upstream catchments should be included in the AOI delineation. Evaluation of the lake sediment geochemistry could also include consideration for AOI size because samples with larger AOIs generally have geochemical values that are closer to background levels due to dilution. The effect of dilution can be assessed empirically using concentration versus AOI area scatterplots to identify samples from large catchments that are above the mean concentrations (e.g. Heberlein, 2013). This would provide additional information to prioritize targets, although it is beyond the scope of this study.

Using catchment basins as lake sediment sample AOIs presumes that any sediment within the catchment is available for erosion and transport to the lake. Soil erosion in most areas is limited by vegetation, and likely only occurs in significant amounts near the stream networks. Incorporating a buffer around active watercourses may provide a more precise delineation of the major contributing sediment sources to the lakes. This would reduce the size of the exploration target and may provide a better estimate of catchment area that can be used to determine dilution during data evaluation.

5. Data evaluation

5.1 Deposit models and relative importance signatures

Initial analyses to determine the geochemical signature of common deposit types included nine different mineral deposits as defined by British Columbia Geological Survey MINFILE (2017) deposit models. These deposits include: porphyry Cu ± Mo ± Au, porphyry Mo, epithermal Au-Ag-Cu (high sulphidation), epithermal Au-Ag (low sulphidation), Skarn and subvolcanic Cu-Ag-Au (As-Sb) mineralization, and a speculated new style of mineralization combining Zn-Pb volcanic massive sulphide and epithermal mineralization (Fenton Creek; MINFILE 93L004; personal communication, Holbek, P. 2017). Preliminary factor analyses of the drill core and chip trench sample geochemistry did not produce consistent signatures for the deposit types. The input data was then filtered to only include drill core data that intercepted significant mineralization, and the deposit types simplified to porphyry, epithermal, and Fenton-type mineralization. The factor analyses on these data produced more significant results, which were converted to RISs for the three deposit types (Table 10).

Table 10. Relative importance signatures for porphyry, epithermal and Fenton-type mineralization determined from principle component analyses of drill core geochemical data.

	Ag ppb	As ppm	Au ppb	Ba ppm	Bi ppm	Co ppm	Cr ppm	Cu ppm	Fe pct	Hg ppb	Mn ppm	Mo ppm	Ni ppm	Pb ppm	Sb ppm	V ppm	W ppm	Zn ppm
Porphyry	4	2.5	3	0.5	3	1.5	0	3	-0.5	1.5	-1	1.5	-1	3	2.5	1	0	2.5
Epithermal	3	3	3	-0.5	1.5	0.5	0	2.5	0	2	-1	1.5	0	1.5	2.5	-1	0	0
Fenton-type	5	5	3.5	0	4	0.5	0	1	2	1	3	3	0.5	5	4	0	2.5	4

The applicability of the available data was a factor contributing to the lack of consistent results in the initial principle analyses for the nine deposit models. Many of these drill holes and trench samples were for exploration purposes, and potentially intersected more than one style of mineralization. If these styles of base-precious metals mineralization have contrasting geochemical signatures, the factor analysis would likely not produce separate factors, especially if there are common commodities within each style of base-precious metals mineralization. Thus, the resulting signature would be a blend of two deposit types. Another potential source of error is that the deposits may have been misclassified in the assessment reports. Many of these classifications are made based on a small window of exposure to base-precious metals mineralization, and mineralization does not always occur within the confines of the defined deposit types. The geochemical signatures were determined herein from the best available local data. Limiting this data to include drill core from more advanced projects (e.g. resource assessment drilling vs. exploration drilling) could provide more consistent data. These data would allow for improved accuracy in the determination of the geochemical signature for a specific deposit type, and possibly for the determination of signatures from more deposit types.

5.2 Weighted sums analysis and target delineation

The WS analysis was performed on the till and lake sediment geochemical data sets using RISs for epithermal, porphyry and Fenton-type mineralization. The results provide a metric of similarity for the sample's geochemical signature to that of a deposit type. All indices were normally distributed and were symbolized by percentile breaks (Table 11; Figure 15).

Table 11. Summary statistics and anomaly thresholds for weighted sums indices from the standardized till data and the standardized till data levelled to bedrock.

	Till geochemical data						Lake sediment geochemical data		
	Porphyry	Porphyry levelled	Epithermal	Epithermal levelled	Fenton-type	Fenton-type levelled	Porphyry	Epithermal	Fenton-type
Count	2632	2632	2632	2632	2632	2632	2117	2117	2117
Minimum	-6.902	-7.390	-6.305	-7.417	-8.942	-9.074	-10.1646	-8.04816	-8.69633
Maximum	11.954	10.682	12.415	11.032	12.945	10.796	7.642573	7.001889	7.497437
Mean	-0.063	0.014	0.002	0.058	-0.152	-0.003	-0.12953	-0.05813	-0.09538
Median	0.027	0.001	0.111	0.066	-0.031	0.026	-0.03429	-0.02889	-5.74E-04
Range	18.856	18.072	18.720	18.450	21.887	19.869	17.807	16.194	15.05
I.Q.R.	2.901	2.802	2.820	2.651	3.293	3.190	3.015099	2.69777	3.167563
S.D.	2.262	2.103	2.179	1.953	2.554	2.372	2.183984	1.915385	2.297978
30th %ile	-1.174	-1.132	-0.948	-0.976	-1.416	-1.29	-1.20521	-1.11635	-1.24611
60th %ile	0.564	0.535	0.611	0.57	0.555	0.616	0.597145	0.523138	0.622273
80th %ile	1.792	1.701	1.751	1.665	1.91	1.922	1.744146	1.584799	1.850062
90th %ile	2.701	2.559	2.629	2.353	2.903	2.828	2.466202	2.352632	2.719876
95th %ile	3.359	3.339	3.345	3.021	3.799	3.757	3.192276	2.973592	3.449899
98th %ile	4.322	4.435	4.156	4.17	4.889	4.807	3.964903	3.715606	4.151437
99th %ile	5.195	5.388	4.902	5.031	5.856	5.888	4.460278	4.331982	4.822055
100th %ile	11.954	10.682	12.415	11.032	12.945	10.796	7.642573	7.001889	7.497437

Note: I.Q.R. – interquartile range; S.D. standard deviation

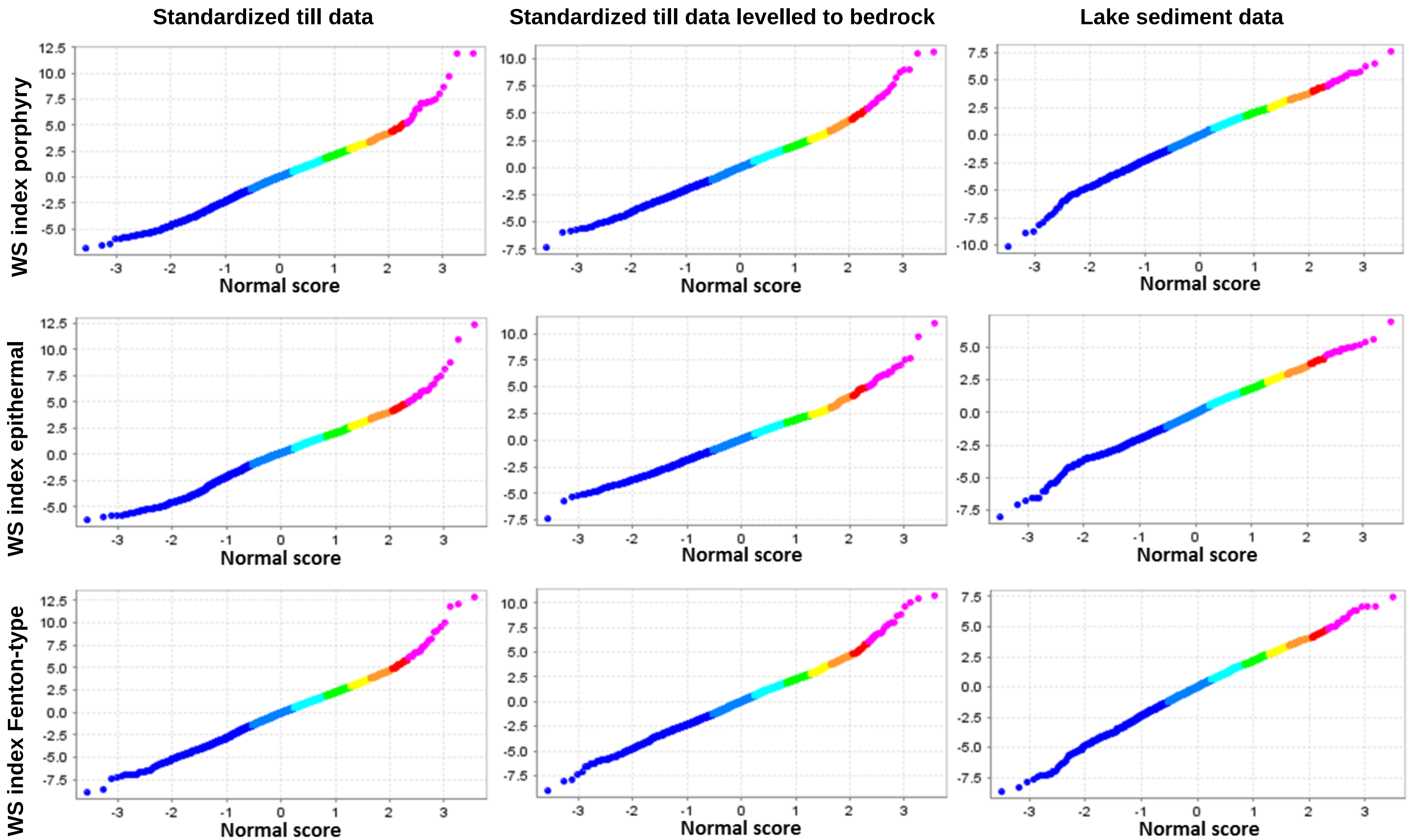


Figure 15. Probability plots depicting data distributions and anomaly thresholds for the standardized till data and the standardized till data levelled to bedrock.

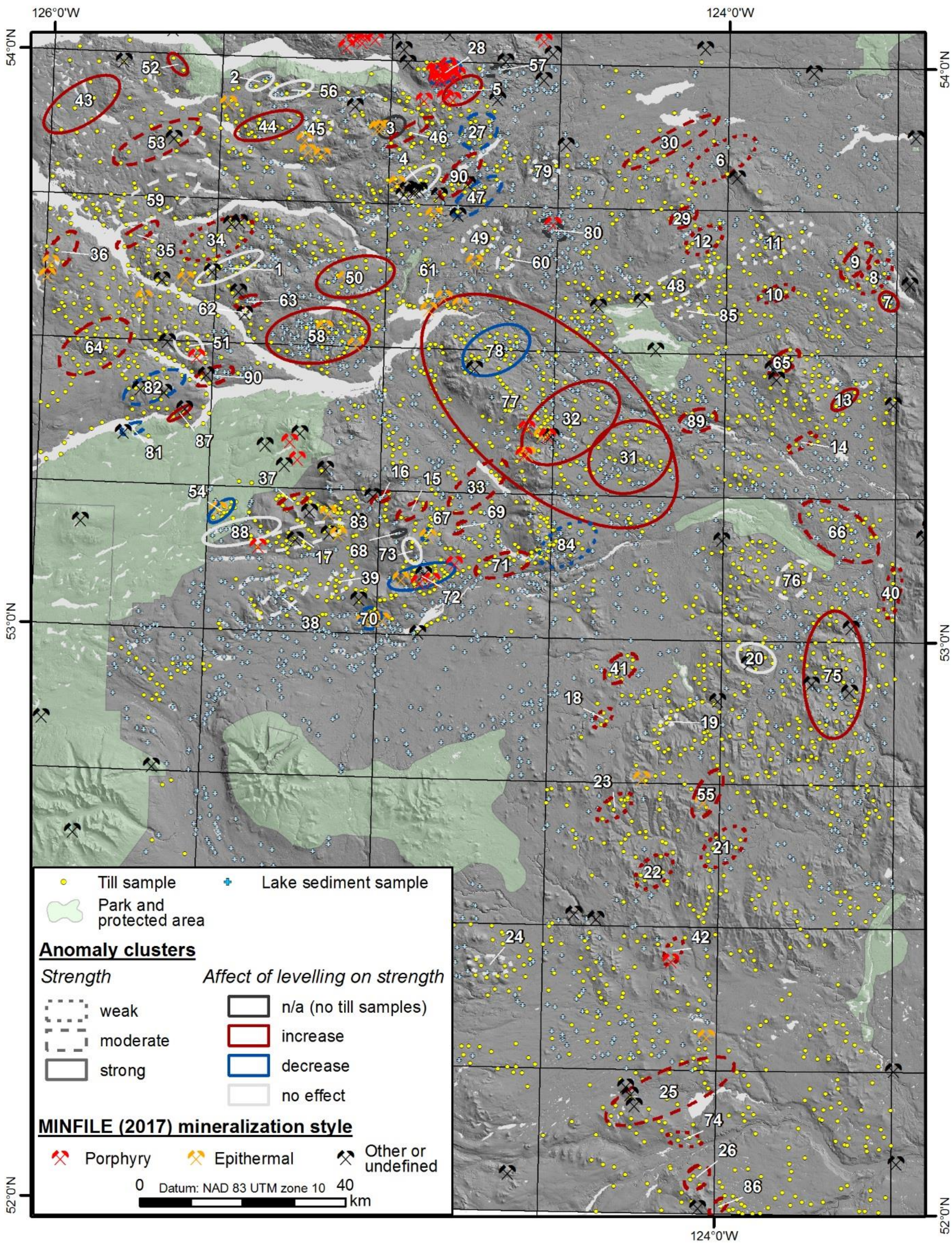


Figure 16. Location, strength, and effect of levelling on anomaly cluster strength. See Table 6 for definitions of anomaly strengths. See Table 12 for descriptions of anomaly clusters.

Ninety-one anomaly clusters that varied in size, strength and continuity are identified in the TREK project area using the WS indices (Figure 16; Table 12; Appendix D). Twenty-two of these are categorized as weak strength, 41 as moderate, and 28 as strong (Figure 17). Fifty-six of the 91 anomaly clusters are not associated with known mineralization. Of the 35 that are associated with known mineralization, 28 either possibly or likely have additional sources that have not been identified. Nearly all MINFILE (2017) occurrences have associated anomalous till or lake sediment samples, where down-ice samples exist. There is a high correlation of anomalies in till and lake sediment samples. Anomalies unique to one media were restricted, in all but a few cases, to areas where samples from only one medium exist.

To assess the effect on levelling the till geochemical data to bedrock, the difference in anomaly strength was determined for each anomaly cluster in the standardized data and the standardized levelled data. After levelling, the discernibility of anomalies increased in 59.1% (n=13) of the weak-strength clusters, 61% (n=25) of the moderate-strength clusters, and 46.4% (n=13) of the strong clusters (Figure 17). The discernibility of anomalies was unchanged for 36.4% (n=8) of the weak-strength anomalies, 19.5% (n=8) of the moderate-strength anomalies, and 32.1% (n=9) of the strong anomalies. The discernibility of anomalies was decreased for 4.5% (n=1) of the weak-strength anomalies, 14.6% (n=6) of the moderate-strength anomalies, and 14.3 (n=4) of the strong anomalies. In total, 56% of anomalies were enhanced by levelling the data using simplified bedrock units, while 28% were unaffected, and 12% were reduced. The remaining 4% were not composed of till data, and thus were not affected by the levelling.

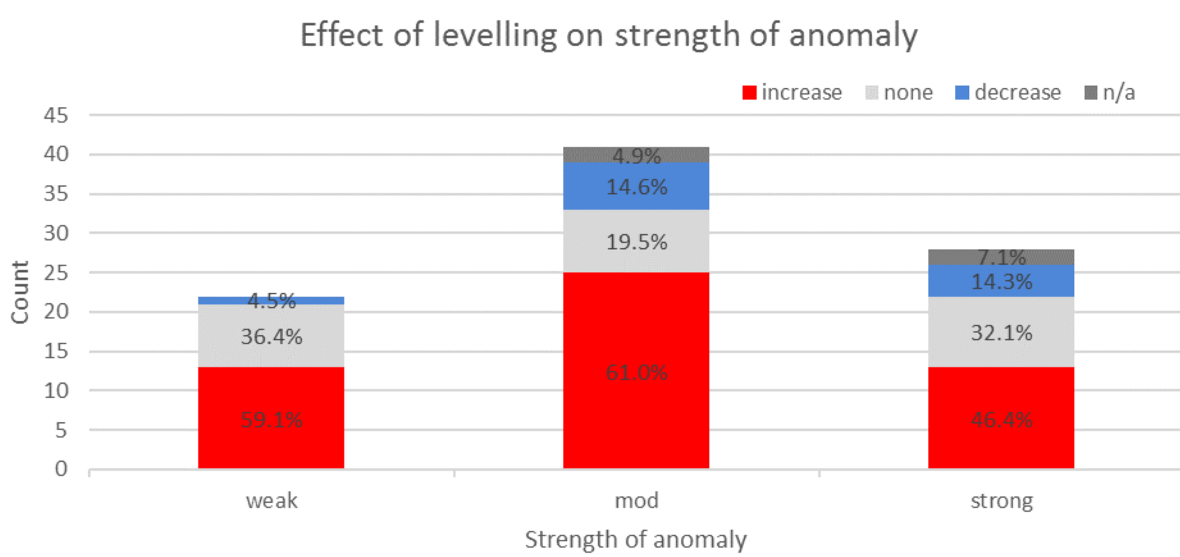


Figure 17. Effect of levelling on anomalies with different strengths.

Most anomaly clusters are apparent in all three WS indices. The WS index with the highest anomalies is used to predict the associated mineralization style. Where these data were similar, the style was categorized as nonspecific. In most cases, there was not a specific style, or two styles had similar anomalousness. This is likely due to the occurrence of more than one mineralization style, or the complexity of the RIS. With 18 possible variables in the RIS, the chances of positive and negative correlations of elements cancelling each other out in the overall index is high. Additional experiments using simpler RISs focussed on variables more unique to the mineralization style could provide more definite mineralization style predictions. Regardless, the differences between the WS indices, albeit subtle, were enough to discern either one or two mineralization styles for 52 anomaly clusters. Only two of these clusters were identified as both porphyry and epithermal (essentially nonspecific), while the rest were either only one style, or one of porphyry or epithermal, and Fenton-type. This suggests that the Fenton-type mineralization is geochemically similar to both porphyry and epithermal. Furthermore, the lack of common anomalies between the epithermal and porphyry indices where specific mineralization types are apparent suggests that the RISs may be accurately distinguishing between the two mineralization types, and supports that the nonspecific signals are a result of multiple mineralization styles occurring in the same area.

Twenty-two anomaly clusters are associated with known porphyry or epithermal mineralization, as described in MINFILE (2017), and could be used to gauge the efficacy of the WS indices to identify the correct type of mineralization. The Fenton-type mineralization could not be used in the assessment because it is a newly defined mineralization style with no occurrences identified in the project area. The WS indices are more anomalous in the correct mineralization type in 10 clusters. The WS indices have nonspecific anomalies for 11 clusters, and are incorrect for only one.

The results of the multimedia and multivariate evaluation verify that there is significant spatial correlation between till and lake sediment anomalies (*cf.* Cook et al., 1995). Only five anomaly clusters are interpreted as unlikely to have additional unidentified mineralized sources, which indicates the region is still under-explored and has good potential for new economic mineralization discoveries. Levelling the till geochemical data to source bedrock units generally improved the discernibility of anomalies related to base-precious metals mineralization. All but one anomaly cluster for which the discernibility decreased are considered moderate or strong; therefore, these anomalies are still easily discernible within the levelled data set. The most consistent improvements in contrast of anomalies are in the southern part of the study area that is covered by young volcanic units (see Appendix C). Some of these anomalies were not apparent in the non-levelled data. In general, the results of this study support that levelling the till geochemical data to bedrock has improved the identification of potential mineralization, especially where it may be partially overlain by younger volcanic units. The effective distinction of epithermal and porphyry mineralization, where specific types were determined, indicates that the use of WS indices can provide insight into the style of mineralization and facilitate the discovery of new occurrences.

Table 12. Targets and their characteristics delineated from the WS indices for porphyry, epithermal and Fenton-type mineralization. T – till; L – Lake sediment; E – epithermal; P – porphyry; F – Fenton-type; V/S – Vein/stockwork; S – Skarn; D – Disseminated; N – nonspecific. See figure 16 for target locations.

Target ID	Media	Deposit signature	Strength	Continuity	Effect of levelling	Associated MINFILE (2017)	Associated mineralization style	Additional Source	Comment
1	T; L	E	strong	high	none	RHUB; BARB	E	unlikely	Anomaly slightly stronger in data levelled to bedrock
2	T; L	N	strong	high	none			likely	Mostly defined by down-ice-decreasing lake sediment anomalies; weaker till anomalies; possibly associated with FOX
3	L	N	strong	low	n/a	WEST, CABIN	E	possible	High lake sediment anomalies likely from WEST and CABIN to northwest
4	T	P; F	strong	high	none	ZAK, CO, FRED, CRITCHLOW, HC 6	D; E	unlikely	Strong till anomalies, weaker lake sediment anomalies
5	T; L	P; F	strong	high	increase	OWL, GEL	P	possible	Strong Lake sediment anomalies; may be from up ice source or drainage sediments from mineral occurrences to NW; additional up-ice source possible
6	T; L	P; F	weak	mod	increase			likely	Weak anomalies and poor till sample density; anomalies slightly stronger in data levelled to bedrock
7	T; L	N	strong	high	increase			likely	Anomalies stronger in data levelled to bedrock
8	T; L	N	weak	mod	increase			likely	Weak anomalies and poor sample density; anomalies more apparent for Fenton-type in levelled data set
9	T; L	N	mod	mod	increase			likely	
10	T; L	N	weak	mod	increase			likely	
11	T; L	P; F	weak	high	none			likely	
12	T; L	F	weak	mod	increase			likely	
13	T; L	E; F	strong	high	increase			likely	Anomalies more apparent in till
14	T; L	N	weak	mod	increase			likely	Weak anomalies; barely above background in non-levelled data
15	T	P; F	mod	high	increase			likely	Lake sediment anomalies to SW may be related to same source; anomaly recognition improved in levelled data set
16	T; L	N	mod	mod	increase	BLACK BEAR	E	possible	
17	T; L	N	mod	high	none	PAW, LAIDMAN, L	P; V/S	unlikely	Many mineral occurrences; anomalies higher in till
18	T	P; F	weak	high	increase			likely	Low sample density in area; anomalies more apparent in levelled data set
19	T	N	weak	high	none			likely	Weak anomaly in area of low background; no lake sediment samples
20	T	N	strong	mod	none	QFP	E; P	likely	

Target ID	Media	Deposit signature	Strength	Continuity	Effect of levelling	Associated MINFILE (2017)	Associated mineralization style	Additional Source	Comment
21	T; L	N	weak	mod	increase			likely	Weak anomaly in area of low background; only apparent in levelled data set
22	T	N	weak	mod	increase			likely	Weak anomaly in area of low background
23	T	E	weak	mod	increase			likely	Weak anomaly in area of low background; more apparent in levelled data set
24	T; L	N	weak	mod	none			likely	Weak anomaly in area of low background
25	T	P; F	mod	low	increase	FIT NW, FIT, EJOWRA	V/S	likely	Anomalies more apparent in levelled data; no lake sediment data; likely additional source up ice
26	T	E; F	mod	mod	increase			likely	Anomalies more apparent in levelled data; no lake sediment data; epithermal mineralization in region
27	T; L	P; F	mod	low	decrease			likely	
28	T	N	strong	high	decrease	NITHI MNT,MOLLY 8/9,ENCO,CHRIS,JEN4/7/10,TAN	P	likely	Many porphyry MINFILE (2017) occurrences; likely additional up-ice source; levelling decreases down ice anomalies, but no change to up-ice anomalies
29	T	E; F	mod	high	increase			likely	Anomalies more apparent in levelled data
30	T; L	E; F	mod	high	increase			likely	Anomalies more apparent in levelled data
31	T; L	N	strong	high	increase			likely	Many strong anomalies with no identified sources
32	T; L	N	strong	high	increase	BEN,CHU,APRIL,JAVA,CH,ASPEN	P; E	possible	Proximal epithermal and porphyry MINFILE (2017) occurrences; levelling increases down-ice anomalies
33	T; L	N	mod	low	increase			likely	Anomalies more apparent in levelled data; strong lake sediment anomaly
34	T	E; F	weak	high	increase			likely	
35	T	N	mod	high	increase			likely	
36	T	N	mod	high	increase	LOON, UDUK LAKE	E	unlikely	Anomalies slightly more apparent data levelled to bedrock
37	T	P; F	mod	high	increase			likely	Anomalies increase for porphyry and decrease for some samples in Fenton-type in data levelled to bedrock; overall increase to anomalies
38	T; L	N	mod	low	none			likely	
39	T	P; F	weak	low	none			likely	
40	T	N	weak	high	increase			likely	
41	T	F	mod	mod	increase			likely	
42	T	N	weak	mod	increase	VAMP	P	possible	Could be another source northwest of VAMP
43	T	E; F	strong	mod	increase			likely	Many anomalous samples in area; may be related to northwest-southeast trending structurally-controlled mineralization
44	T; L	F	strong	mod	increase			likely	
45	T; L	N	weak	high	none	SL191	E	possible	Up-ice epithermal MINFILE (2017) occurrence

Target ID	Media	Deposit signature	Strength	Continuity	Effect of levelling	Associated MINFILE (2017)	Associated mineralization style	Additional Source	Comment
46	T: L	F	mod	high	increase			likely	
47	T	E; F	mod	mod	decrease	LLAN HILL, SMOKING PIPE	E; V/S	possible	
48	T	N	mod	high	none	FINGER LAKE	D	possible	
49	T	N	weak	high	none			likely	
50	T; L	E	strong	mod	increase	BIRD	E	likely	Fenton-type anomalies increased significantly in data levelled to bedrock; proximal epithermal MINFILE (2017) occurrence
51	T	P	strong	high	none	CHELASLIE ARM, WT	P	likely	
52	T	N	strong	low	increase			likely	Many anomalous samples in area; unlikely these are related to the same source
53	T	F	mod	mod	increase			likely	Many anomalous samples in area; difficult to define specific clusters
54	T; L	E; F	strong	mod	decrease	WOLF	E	likely	Adjacent to WOLF (epithermal); additional source likely to southwest
55	T; L	E; F	mod	mod	increase	CLISBAKO	E	possible	Proximal epithermal MINFILE (2017) occurrence
56	T; L	N	strong	high	none			yes	Strong target
57	L	P; F	mod	mod	n/a			likely	No till samples in area
58	T; L	E; F	strong	high	increase	YELLOW MOOSE; OOTSA1	E	likely	Several highly anomalous lake sediment samples; adjacent to epithermal MINFILE (2017) occurrence; additional source likely to west
59	T	N	mod	high	none			likely	
60	T; L	N	mod	high	none			likely	
61	T; L	N	mod	high	none			likely	
62	T; L	E	strong	high	none	SAUNDERS	V/S	unlikely	
63	T; L	N	mod	mod	increase			likely	
64	T	P	mod	mod	increase			likely	No lake sediment data
65	T; L	E; F	mod	high	increase	CHILAKO	D	unlikely	
66	T; L	E; F	mod	low	increase			likely	Anomalous northwest-southeast trending cluster; may be related to structurally-controlled mineralization
67	T	N	mod	mod	decrease	Blackwater	E	possible	Anomalies more apparent in non-levelled data
68	L	N	strong	high	n/a			likely	No till samples in area
69	T; L	N	mod	high	increase			likely	Till anomalies higher than lake sediment for epithermal and porphyry; high lake sediment anomalies than till for Fenton-type
70	T; L	N	mod	mod	decrease	TSACHA, TAM	E	likely	Additional source likely to southwest
71	T; L	E; F	mod	mod	increase			likely	

Target ID	Media	Deposit signature	Strength	Continuity	Effect of levelling	Associated MINFILE (2017)	Associated mineralization style	Additional Source	Comment
72	T; L	N	strong	mod	decrease	KEYWEST, BUZZ, KEY, KEY EAST	E; P	possible	Proximal porphyry and epithermal MINFILE (2017) occurrences
73	T; L	E	strong	low	none			yes	Likely from multiple sources
74	T	E; F	weak	low	increase			likely	
75	T; L	N	strong	high	increase	Bob	V/S	likely	Additional source likely west of BOB; anomaly stronger in till than lake sediment
76	T	P; F	mod	low	none			likely	
77	T; L	N	strong	mod	increase	many	n/a	possible	Regional anomalous in northwest-southeast trending cluster; may be related to structurally-controlled mineralization
78	T; L	E; F	strong	high	decrease	KNEWSTUBB	V/S	likely	Strength slightly lower in data levelled to bedrock; additional source likely north of KNEWSTUBB
79	T; L	N	weak	mod	none			likely	Consists of few samples
80	L	P; F	mod	low	n/a	CRYSTAL LAKE	P	likely	No till samples in area; proximal porphyry MINFILE (2017) occurrence
81	T	P; F	mod	mod	decrease	TELACHUCK LAKE	V/S	unlikely	Down ice from MINFILE (2017) occurrence
82	T	E; F	mod	low	decrease	EXO, GODOT	S; D	possible	Anomalies less apparent in data levelled to bedrock
83	T; L	N	mod	high	none	BUCK		Likely	
84	T; L	E; P	weak	mod	decrease			yes	Anomalies less apparent in data levelled to bedrock
85	T	N	weak	mod	none			likely	
86	T	E; F	mod	low	increase			likely	Epithermal mineralization in region
87	T	E; F	strong	mod	increase	Tet	D	likely	Likely additional source up ice from existing MINFILE (2017) occurrence
88	T; L	E; P	strong	mod	none			likely	Decrease in Fenton-type anomaly in data levelled to bedrock
89	T; L	E; F	mod	high	increase			likely	
90	T: L	N	mod	high	increase	BULL 4	V/S	possible	
91	T; L	N	mod	nod	increase	COPLEY, CRYSTAL MARIE	D; V/S	possible	

Note: T – till; L – Lake sediment; E – epithermal; P – porphyry; F – Fenton-type; V/S – Vein/stockwork; S – Skarn; D – Disseminated; N - nonspecific.

6. Conclusions

The efficacy of this study relies heavily on the quality of the input data. Bedrock mapping that is inaccurate or too small-scale could negatively affect the determination of source bedrock units. Geochemical data derived from the exploration of inaccurately defined or complex base-precious metals mineralization can result in the incorrect determination of deposit model geochemical signatures. Significant efforts were made to ensure that the bedrock and deposit model geochemistry were of the highest quality as they provide the fundamentals for the levelling and multivariate analysis performed herein. Additional advancements into these primary data sources, however, could improve future studies of this nature. This evaluation is conducted on TREK's high-quality surficial geochemical data set, where considerable attention was given to the collection of appropriate material and consistency of analytical methods. Additional improvements have been made through recent reanalysis and genetic interpretations of data from previous surveys. Even with these high-quality data, additional standardization is necessary to ensure they are suitable for the evaluation. A series of data substitutions and levelling generally provided normally-distributed, comparable data.

The z-score levelling method mitigated differences in the till geochemical concentrations associated with bedrock composition. The till requires an accurate association with a bedrock source for this procedure to work correctly. Till geochemical data from source bedrock subpopulations are consistent with expected element concentrations in similar rocks providing evidence that the AOIs are reasonably accurate. More absolute scaling factors could further improve the determination of bedrock source units for till samples. It is most likely that the largest source of error in levelling the till data to bedrock is the input bedrock data. For this study, these data were compiled from various sources and required simplification. Bedrock data interpreted at a consistent scale and defined using similar units with information of geochemical concentrations would provide the necessary information to refine the simplifications. Nonetheless, the consistency of the till geochemistry in the bedrock subpopulations suggests the unlevelled till data could be used to inform bedrock mapping where glacial drift limits bedrock outcrop. The till AOIs and the differences in geochemical signatures of the bedrock, plus changes in till geochemistry, could be used refine the location of lithological unit contacts.

The WS analysis relies on the accuracy of the deposit model RIS to effectively identify anomalies related to specific mineralization styles. Initial efforts to determine RISs for nine deposit models from existing drill core and trench sample data were unsuccessful. This is likely due to the inclusion of multiple mineralization styles in the input data, or the inaccurate categorization of the deposit type. More refined input data may provide the precision necessary to determine geochemical deposit signatures for more deposit types. The data and resources available for this study limited the evaluated deposits to epithermal, porphyry, and Fenton-type. Ninety-one anomaly clusters are identified in the till and lake sediment WS indices determined from these three deposit types. The anomaly levels for many of the clusters were similar for the three indices, likely related to the complexity of the determined RISs, or the occurrence of different mineralization types in close proximity. The differences in anomaly levels were significant enough to determine specific mineralization signatures for many anomaly clusters. The correlation of these identified signatures to known associated mineralization supports that the WS analysis could discriminate mineralization types. Further efforts to improve the RISs could enhance the discrimination of mineralization style based on till geochemical data. In total, 56% of anomaly clusters were enhanced by levelling the till data to bedrock, while 28% were unaffected, and 12% were reduced. The remaining 4% were not composed of till data, and thus were not affected by the levelling. This indicates that levelling the till data to bedrock enhances the geochemical signature associated with mineralization.

The results of this study indicate that the methodology tested here is effective in enhancing the geochemical signal of mineralization in a regional data set. Of the 91 anomaly clusters identified by the study, most do not have known mineralized sources, or are likely to have additional unidentified sources. This indicates that the TREK project area still has significant potential for undiscovered economic mineralization.

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Appendix A

PDF maps of weighted sums results and associated potential targets

A1. Weighted Sums Index for Porphyry Mineralization Using Standardized Data

A2. Weighted Sums Index for Porphyry Mineralization Using Standardized Data Levelled to Bedrock

A3. Weighted Sums Index for Epithermal Mineralization Using Standardized Data

A4. Weighted Sums Index for Epithermal Mineralization Using Standardized Data Levelled to Bedrock

A5. Weighted Sums Index for Fenton-type Mineralization Using Standardized Data

A6. Weighted Sums Index for Fenton-type Mineralization Using Standardized Data Levelled to Bedrock

Provided separately in PDF format

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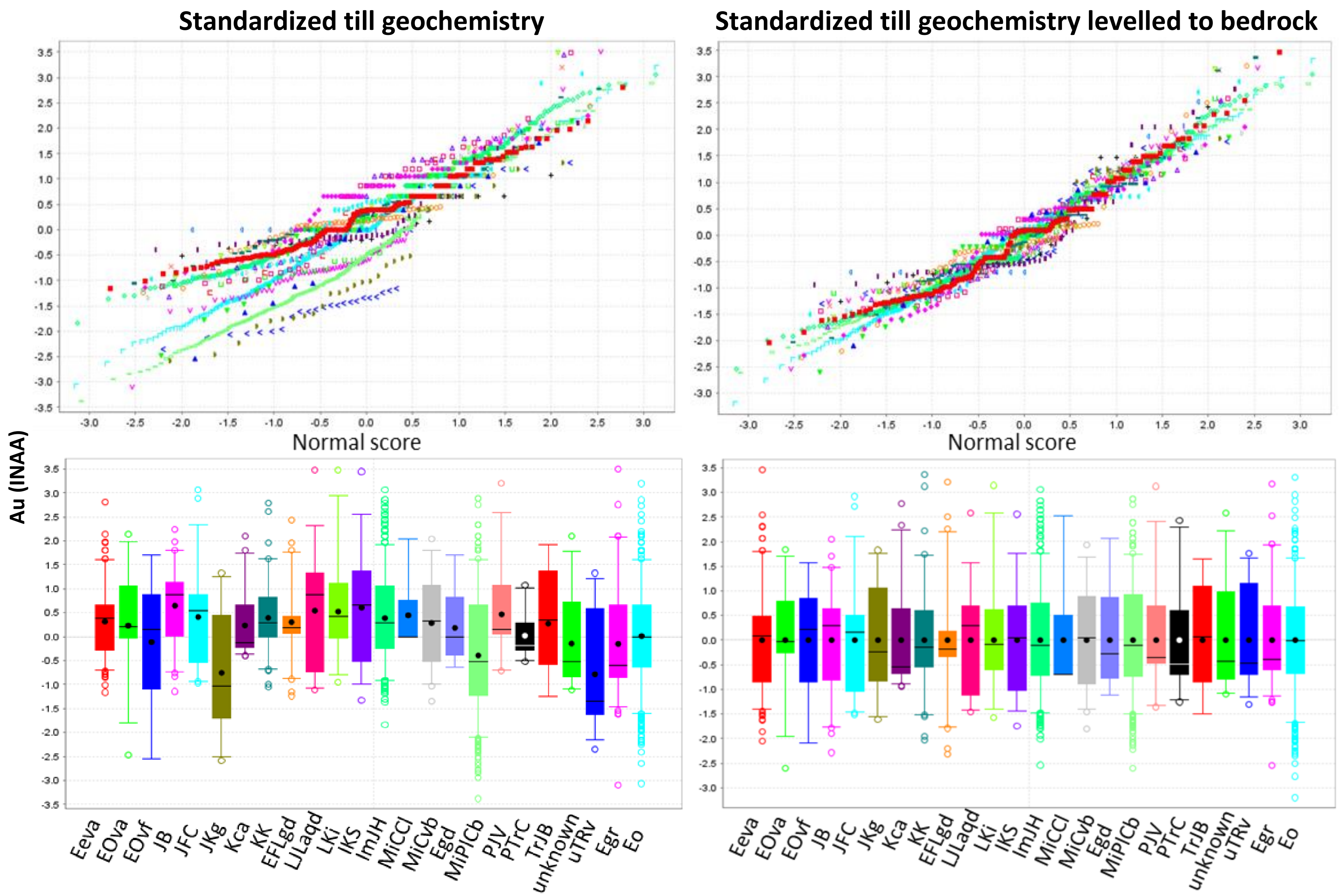
Appendix B

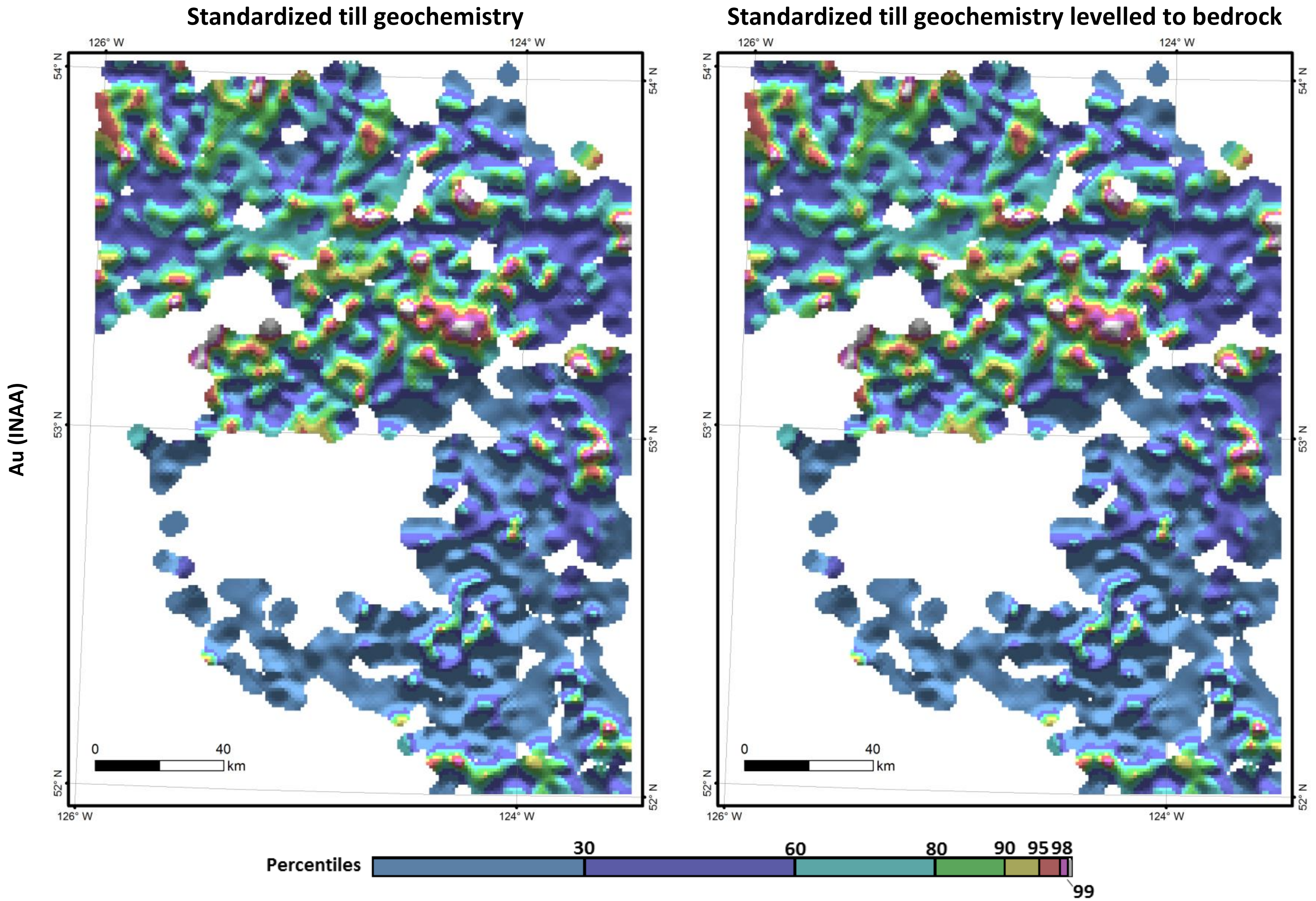
Probability plots, box plots, and gridded results for standardized till geochemical data and standardized till geochemical data levelled to bedrock

Appendix B

LEGEND

Unit symbol	Simplified unit code	Dominant rock type	General description
	Eeva	volcanic	Andesitic volcanic rocks
	EFLgd	intrusive	granodioritic intrusive rocks
	Egd	intrusive	Dioritic intrusive rocks with some gabbroic rocks
	Egr	volcanic	undivided volcanics; basalt to rhyolite
	Eo	volcanic	rhyolitic volcanics; minor andesite
	EOva	volcanic	andesitic volcanics
	EOvf	Intrusive / volcanic	Dacite, rhyolite, andesite and undivided felsic intrusives
	JB	Sedimentary / volcanic	undivided sedimentary and volcanic rocks
	JFC	intrusive	quartz dioritic and monzonitic to monzogranitic rocks
	JKg	Intrusive / metamorphic	Quartz diorite, granodiorite, gneissic granodiorite
	Kca	volcanic	hyaloclastite
	KK	volcanic / sedimentary	andesitic volcanic rocks; minor coarse clastic rocks
	LJLaqm	intrusive	quartz monzonitic to monzogranitic
	Lki	intrusive	undivided intrusive, granodiorite, mafic sills and dykes
	lKS	sedimentary	undivided sedimentary rocks; minor andesite
	lmJH	volcanics / sedimentary	Felsic-basaltic volcanics; coarse clastic sedimentary rocks
	MiCCl	volcanic	basalt plugs and flows
	MiCvb	volcanic	basalt; basalt breccia; hyaloclastite
	MiPlCb	volcanic	basaltic volcanics; minir andesite and sedimentary rocks
	PJV	metamorphic	Granits and biotite quartzo-feldspathitic schist, granodiorite orthogneiss
	PTrC	volcanic / metamorphic	Mafic volcanics; peridotite, serpentinite
	TrJB	intrusive	Diorite, monzodiorite, monzonite
	unknown	no data	no data
	uTRv	Sedimentary / volcanic	undivided sedimentary and mafic-intermediate volcanics


Standardized till geochemistry
Standardized till geochemistry levelled to bedrock
Normal score
Normal score
Au (INAA)
Eeva
EOva
EOvf
JB
JFC
JKg
Kca
KK
EFLgd
LJLaqd
LKi
lKS
lmJH
MiCCl
MiCvb
Egd
MiPlCb
PJV
PTrC
TrJB
unknown
uTRv
Egr
Eo


Standardized till geochemistry
Standardized till geochemistry levelled to bedrock
Au (INAA)
126° W
124° W
54° N
53° N
52° N
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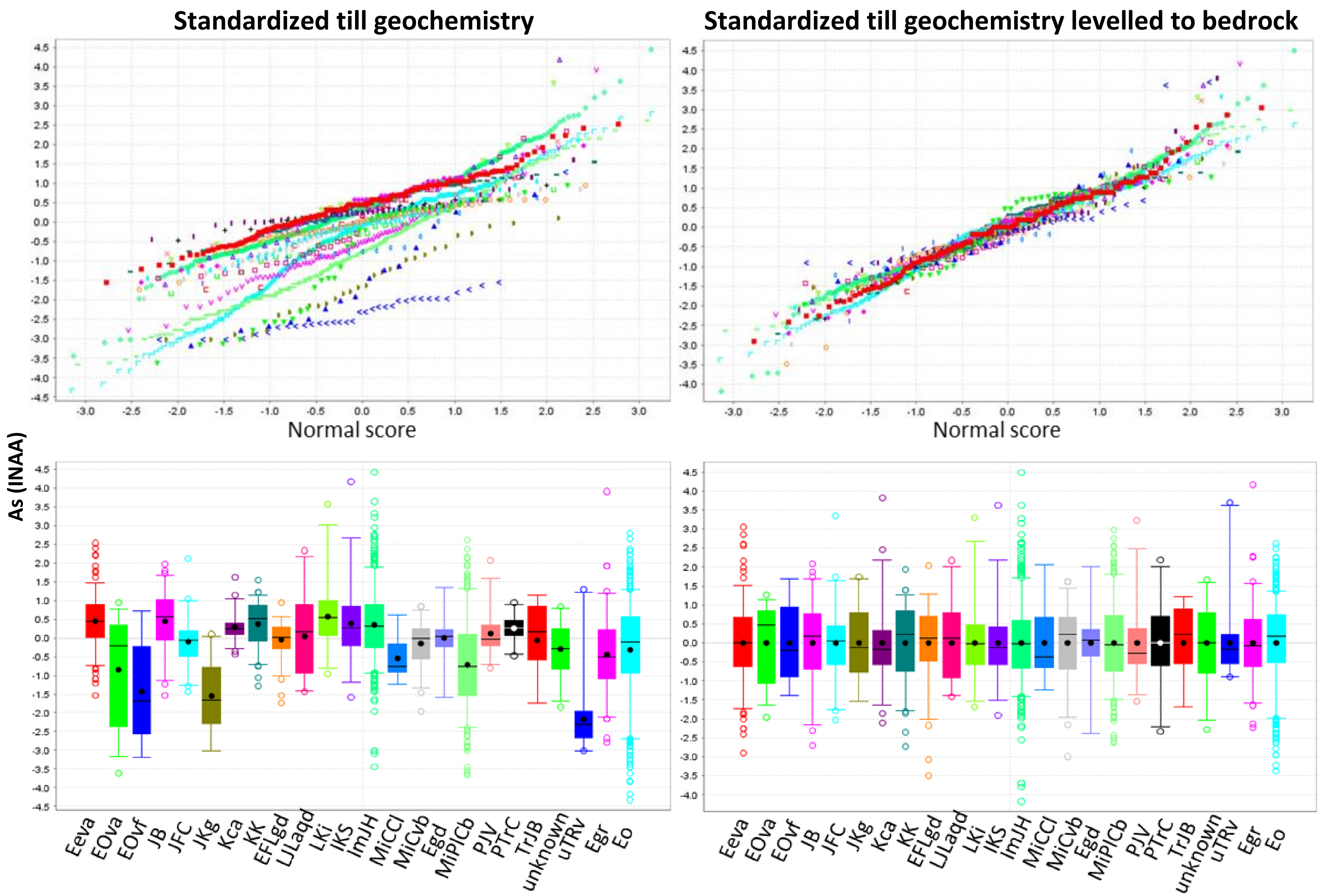
km
Percentiles
30
60
80
90
95
98
99



Standardized till geochemistry
Standardized till geochemistry levelled to bedrock
Normal score
Normal score
As (INAA)
Eeva
EOva
EOvf
JB
JFC
JKg
Kca
KK
EFLgd
LJLaqd
LKi
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unknown
uTRv
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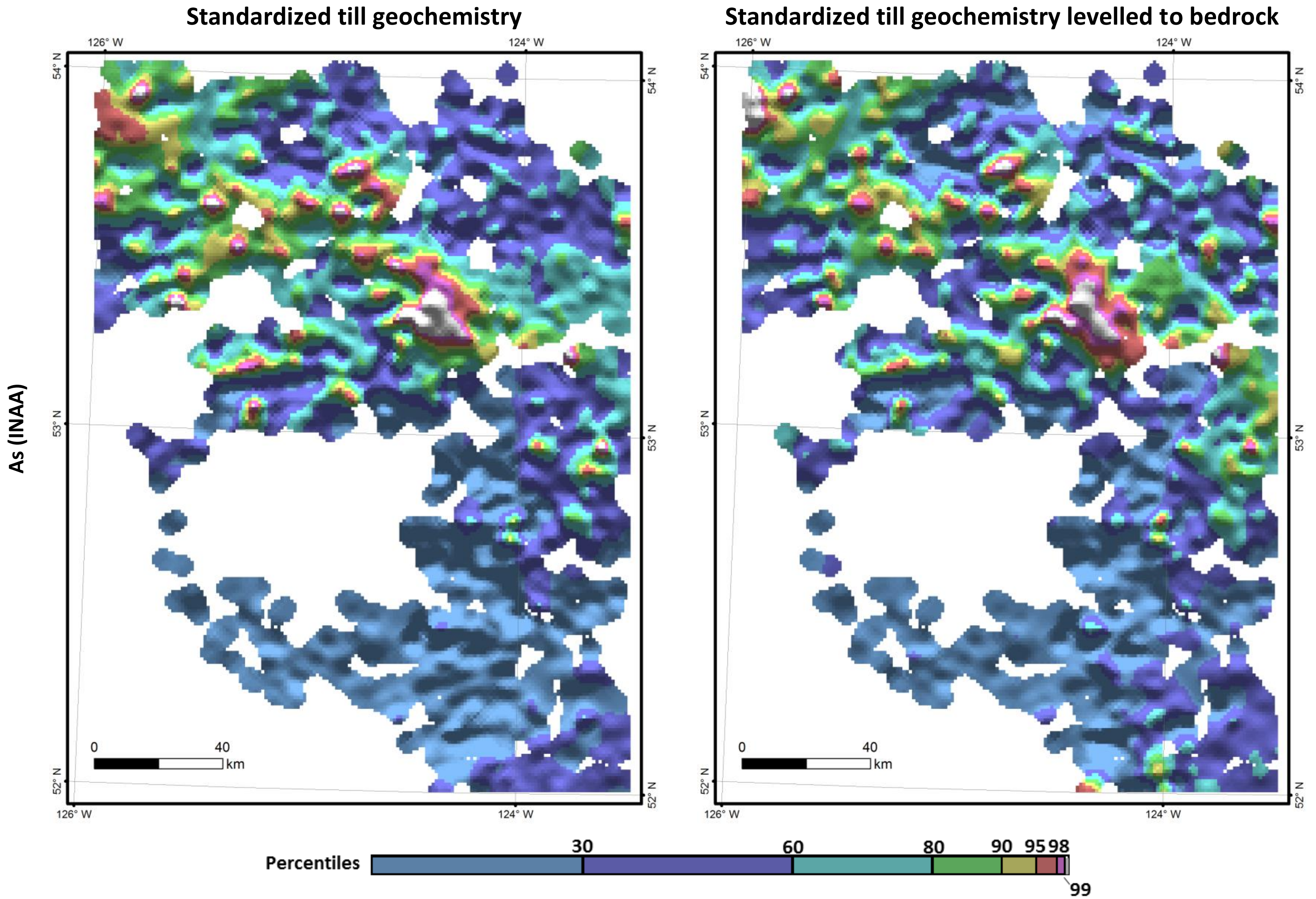
Standardized till geochemistry
Standardized till geochemistry levelled to bedrock
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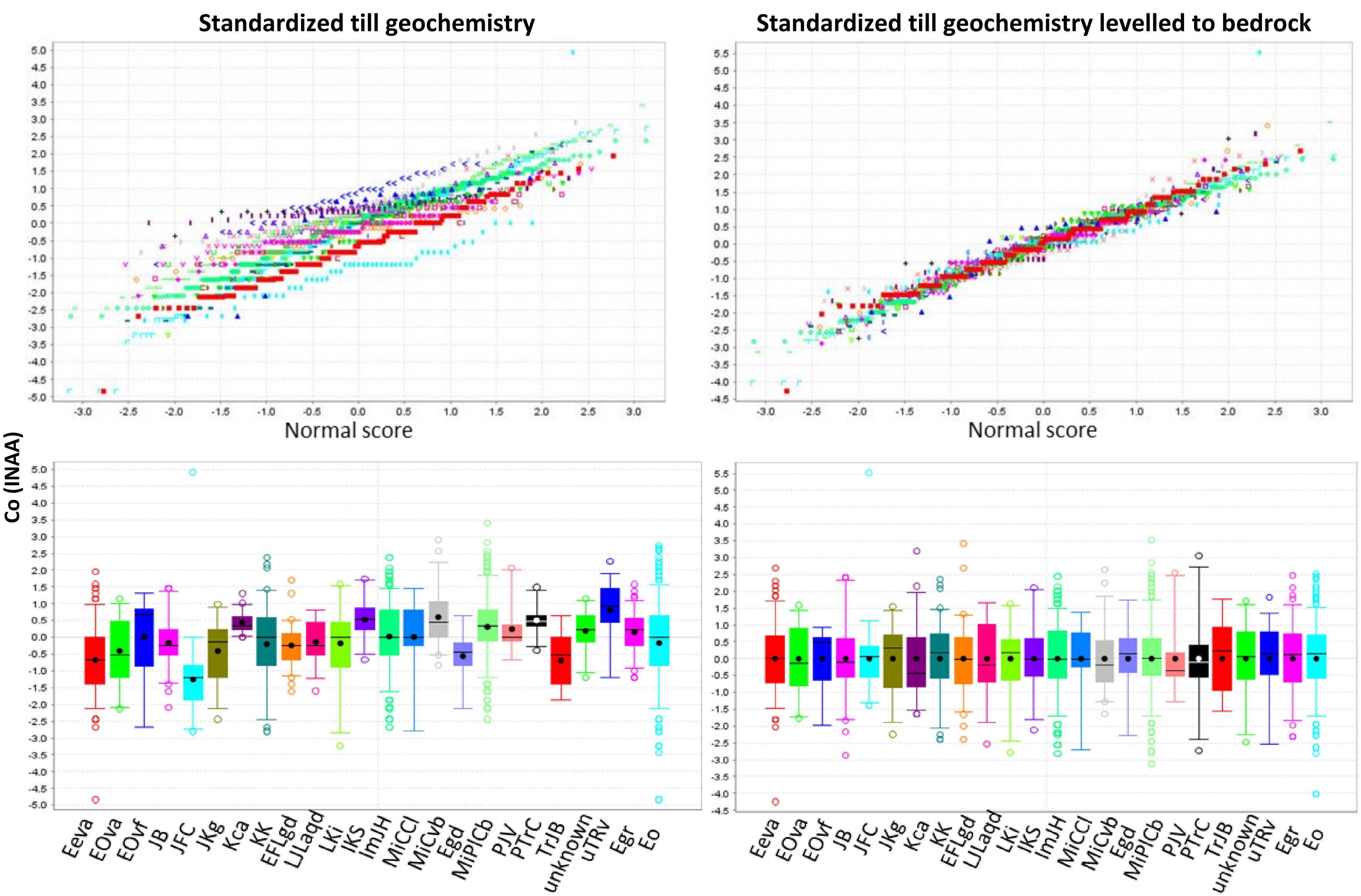
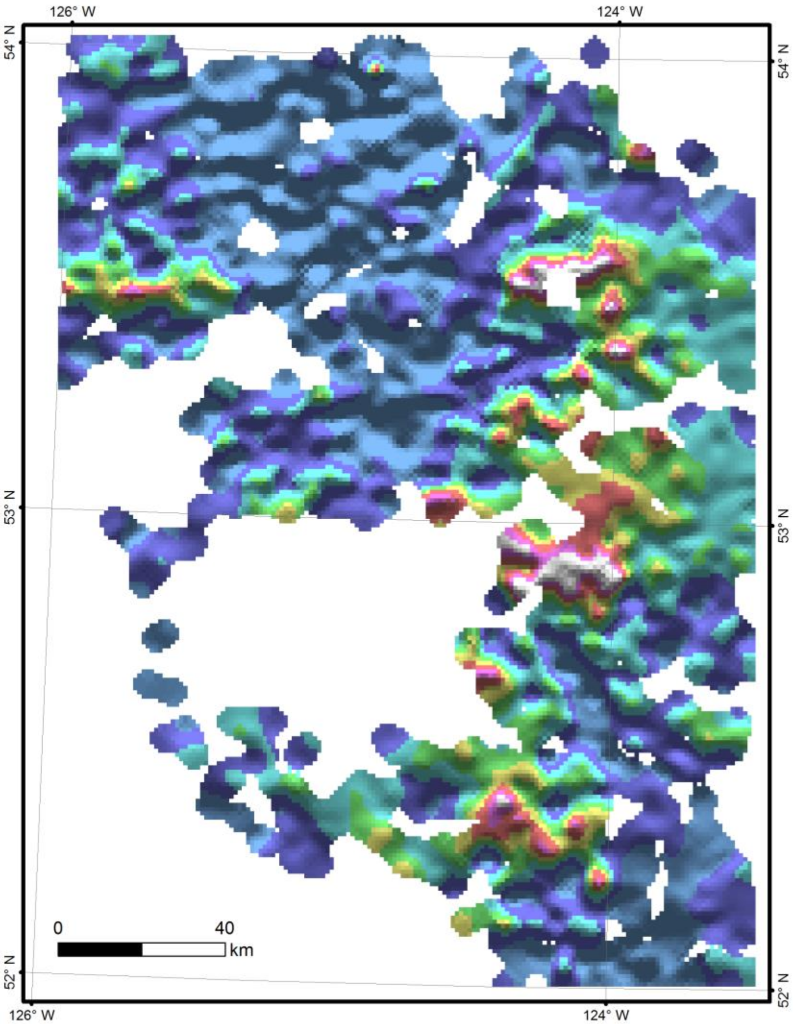

Standardized till geochemistry
Standardized till geochemistry levelled to bedrock
Normal score
Normal score
Co (INAA)
Eeva EOva EOvf JB JFC JKg Kca KK EFLgd LJlaqd LKi lKS lmJH MiCCl MiCvb Egd MiPlCb PJV PTrC TrJB unknown uTRv Egr Eo

Co (INAA)


Standardized till geochemistry
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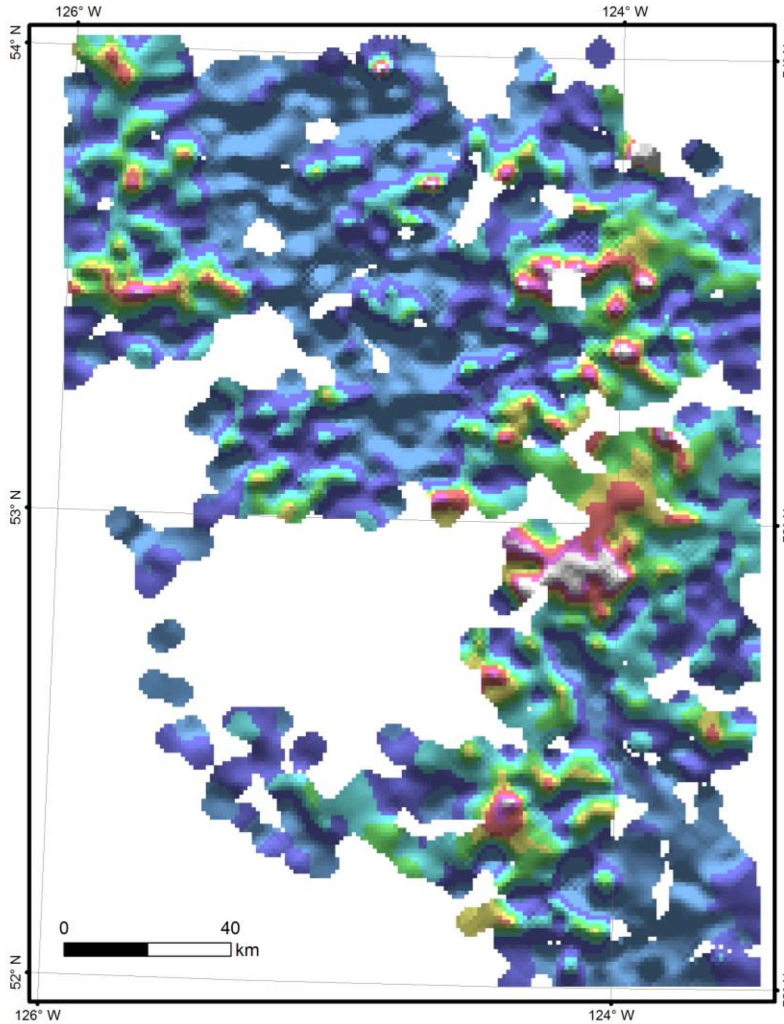
Standardized till geochemistry levelled to bedrock
126° W
124° W
54° N
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Percentiles
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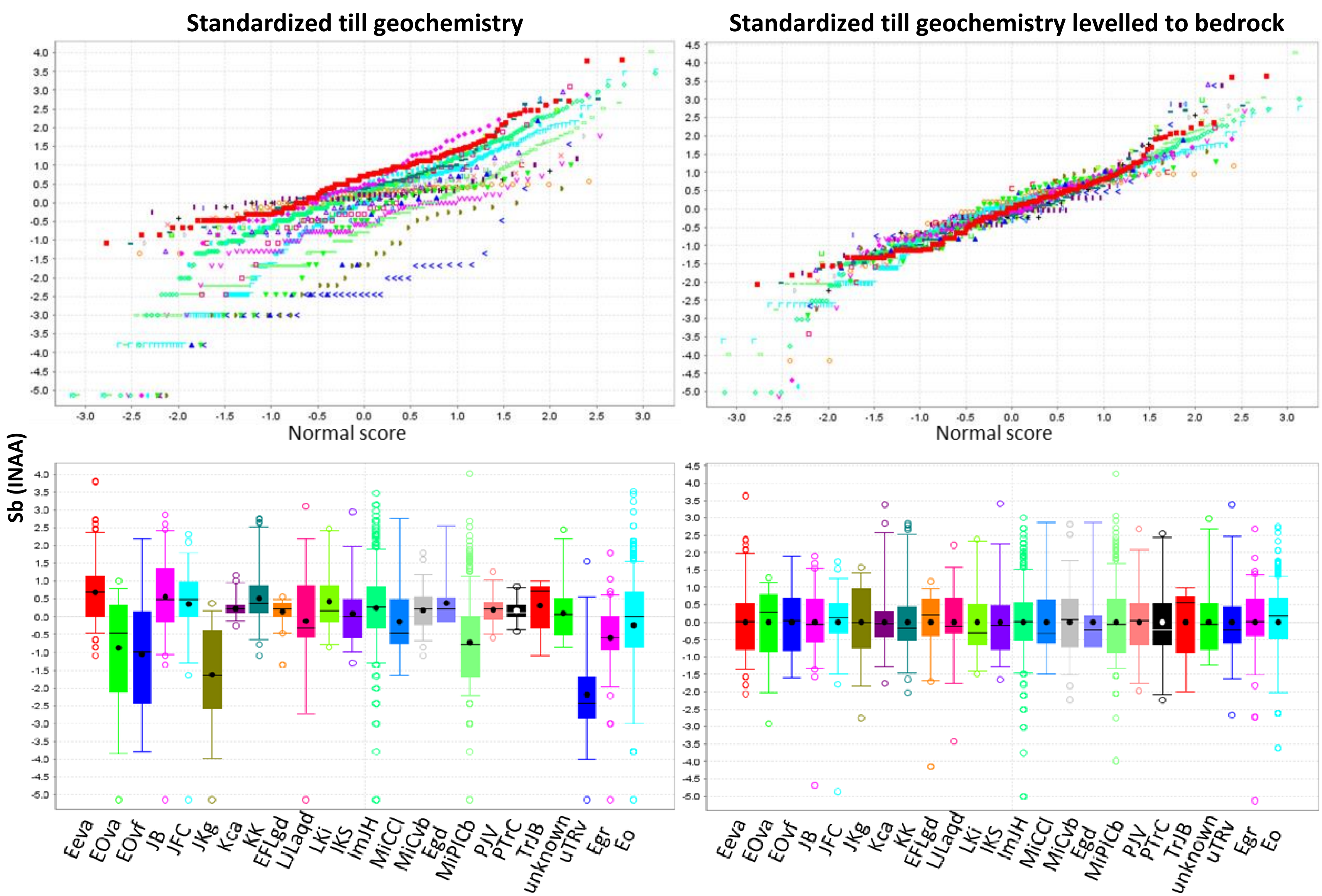
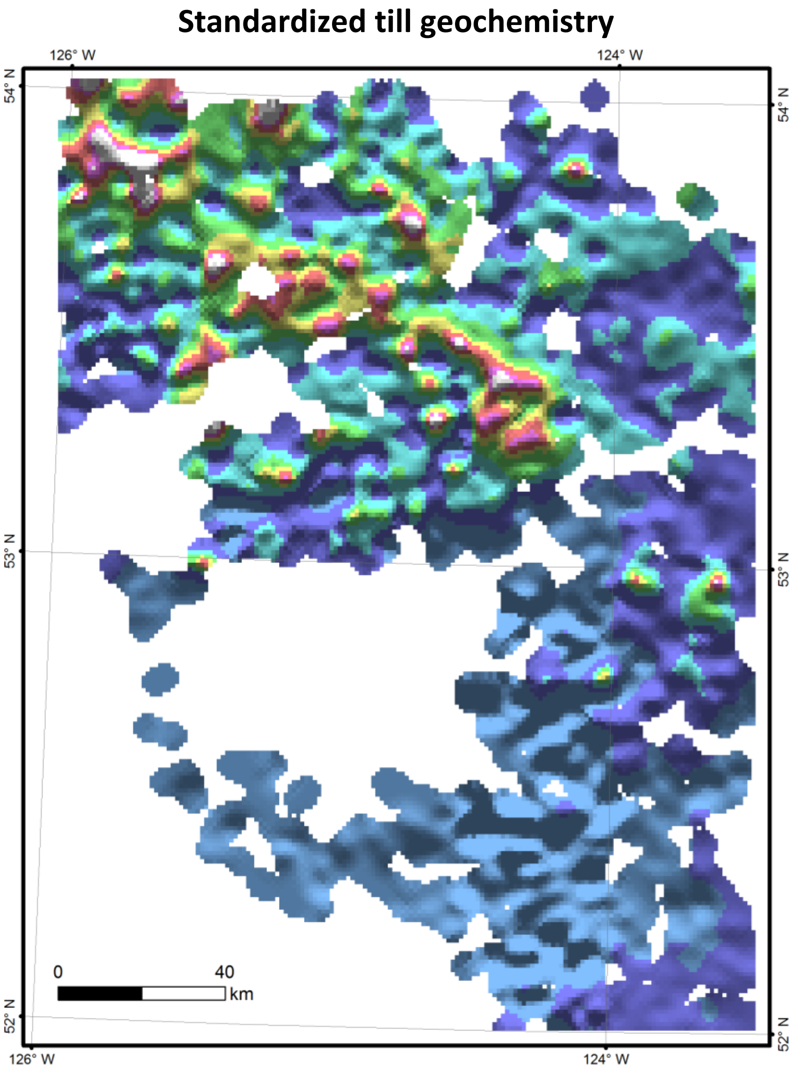

Standardized till geochemistry
Standardized till geochemistry levelled to bedrock
Normal score
Normal score
Sb (INAA)
Eeva
EOva
EOvf
JB
JFC
JKg
Kca
KK
EFLgd
LJLaqd
LKi
lKS
lmJH
MiCCl
MiCvb
Egd
MiPlCb
PJV
PTrC
TrJB
unknown
uTRv
Egr
Eo

Sb (INAA)


Standardized till geochemistry
126° W
124° W
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53° N
52° N
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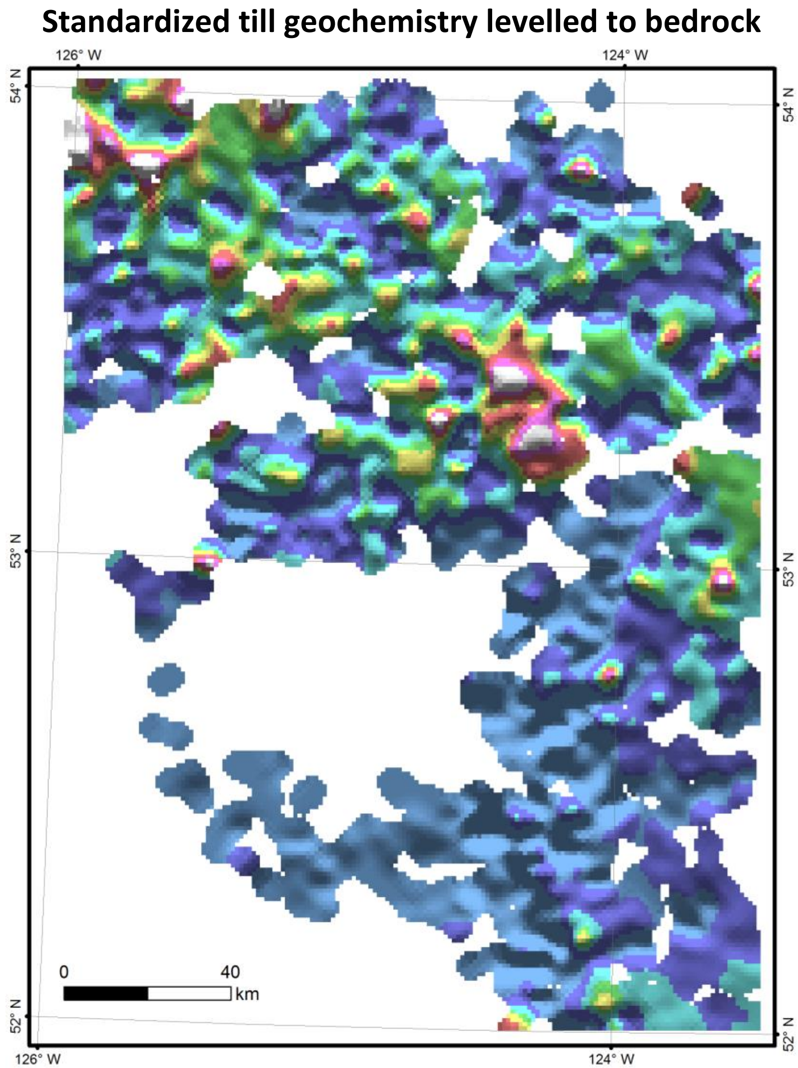
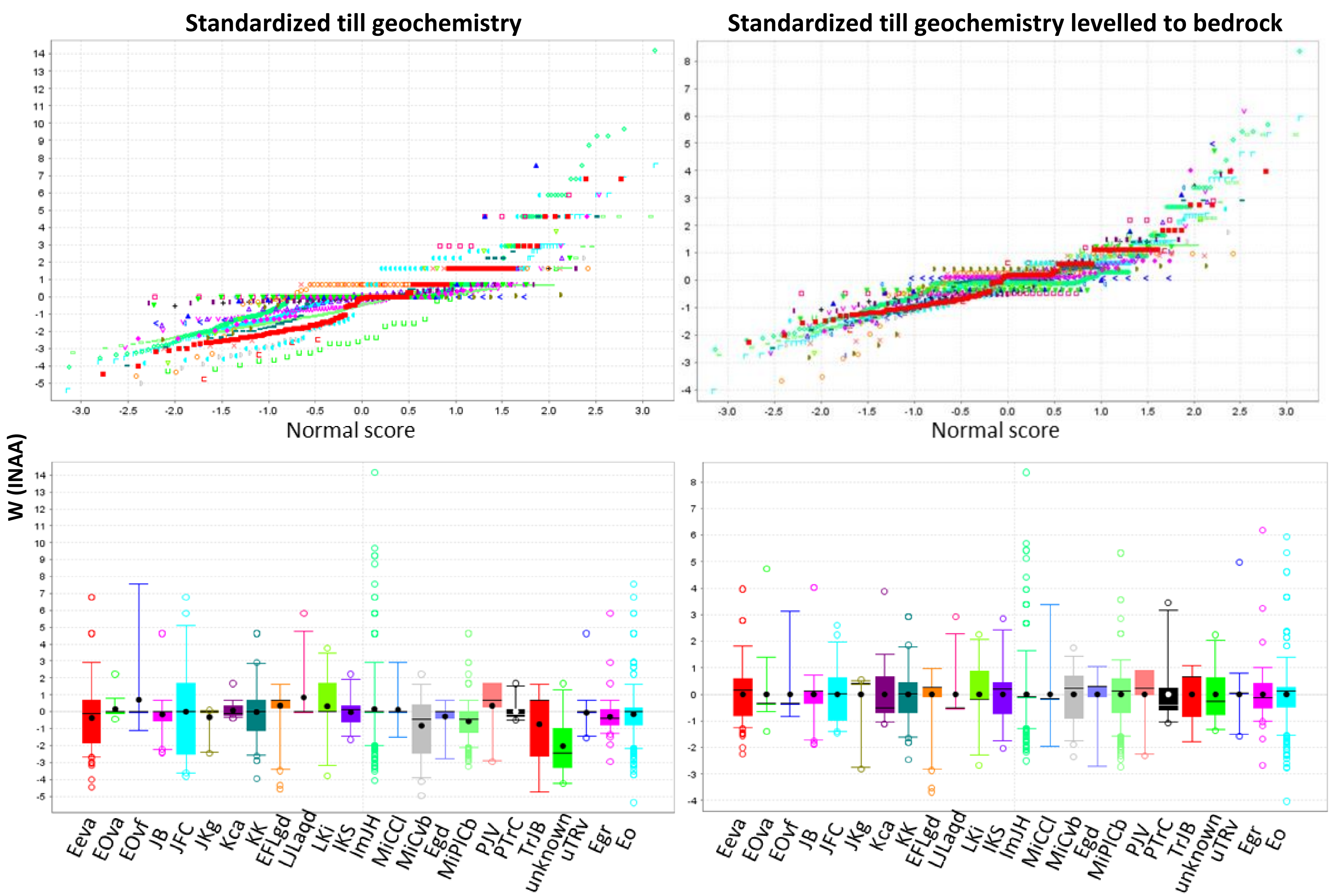
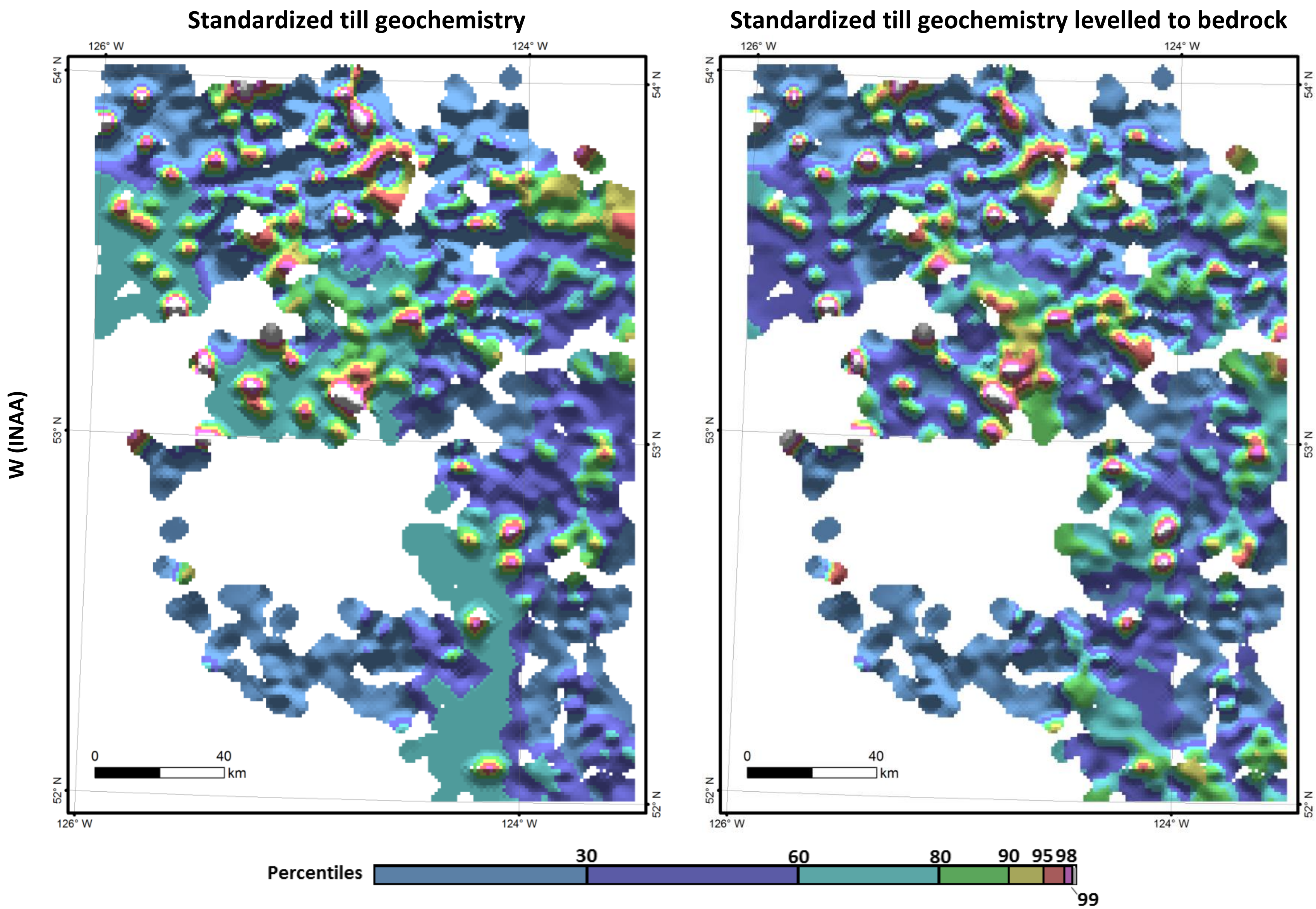
40
km

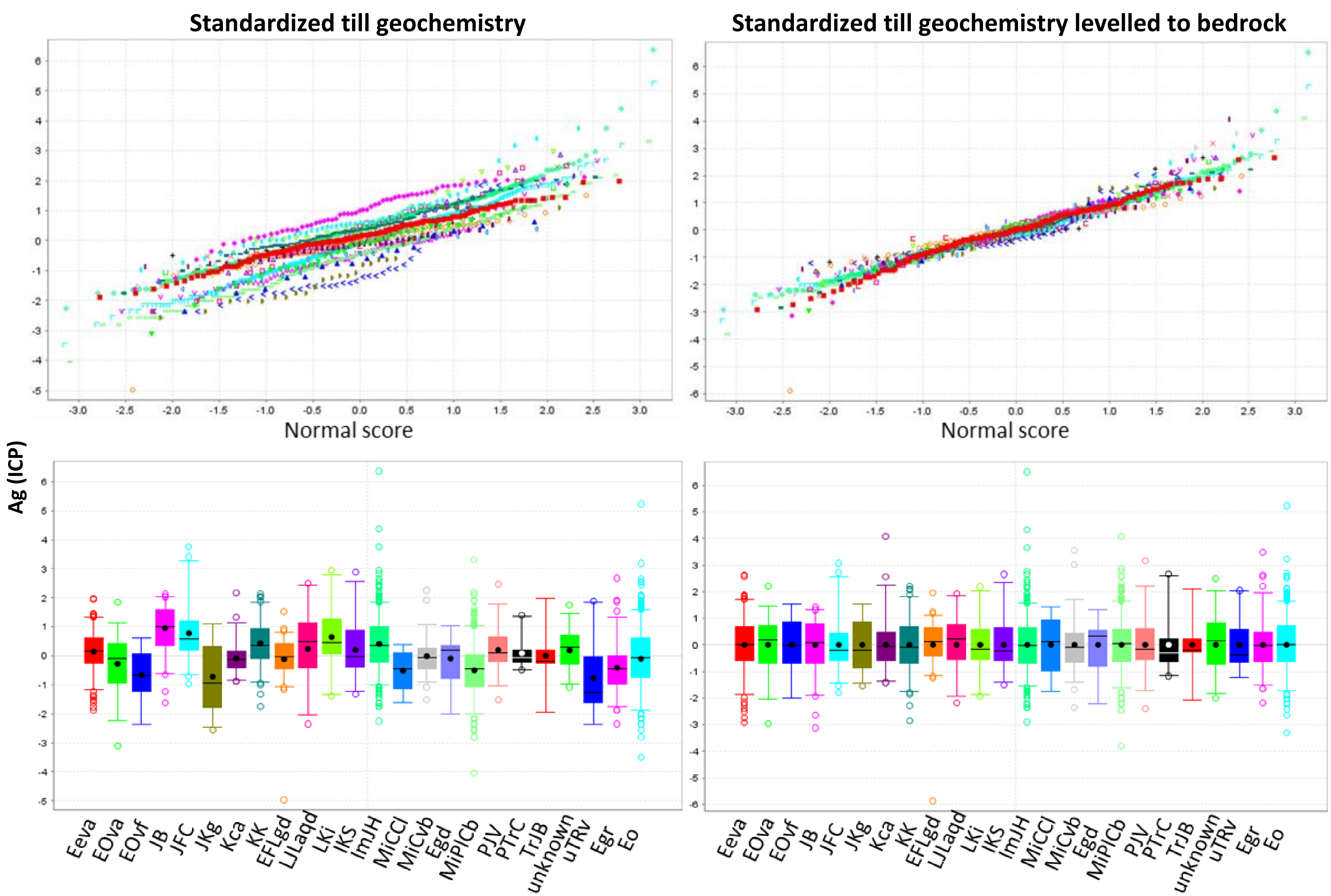

Standardized till geochemistry levelled to bedrock
126° W
124° W
54° N
53° N
52° N
0
40
km


Percentiles
30
60
80
90
95
98
99


Standardized till geochemistry
Standardized till geochemistry levelled to bedrock
Normal score
Normal score
W (INAA)
Eeva
EOva
EOvf
JB
JFC
JKg
Kca
KK
EFLgd
LJLaqd
LKi
lKS
lmJH
MiCCl
MiCvb
Egd
MiPlCb
PJV
PTrC
TrJB
unknown
uTRv
Egr
Eo



Standardized till geochemistry
Standardized till geochemistry levelled to bedrock
W (INAA)
126° W
124° W
54° N
53° N
52° N
0
40
km
Percentiles
30
60
80
90
95
98
99


Standardized till geochemistry
Standardized till geochemistry levelled to bedrock
Normal score
Normal score
Ag (ICP)
Eeva
EOva
EOvf
JB
JFC
JKg
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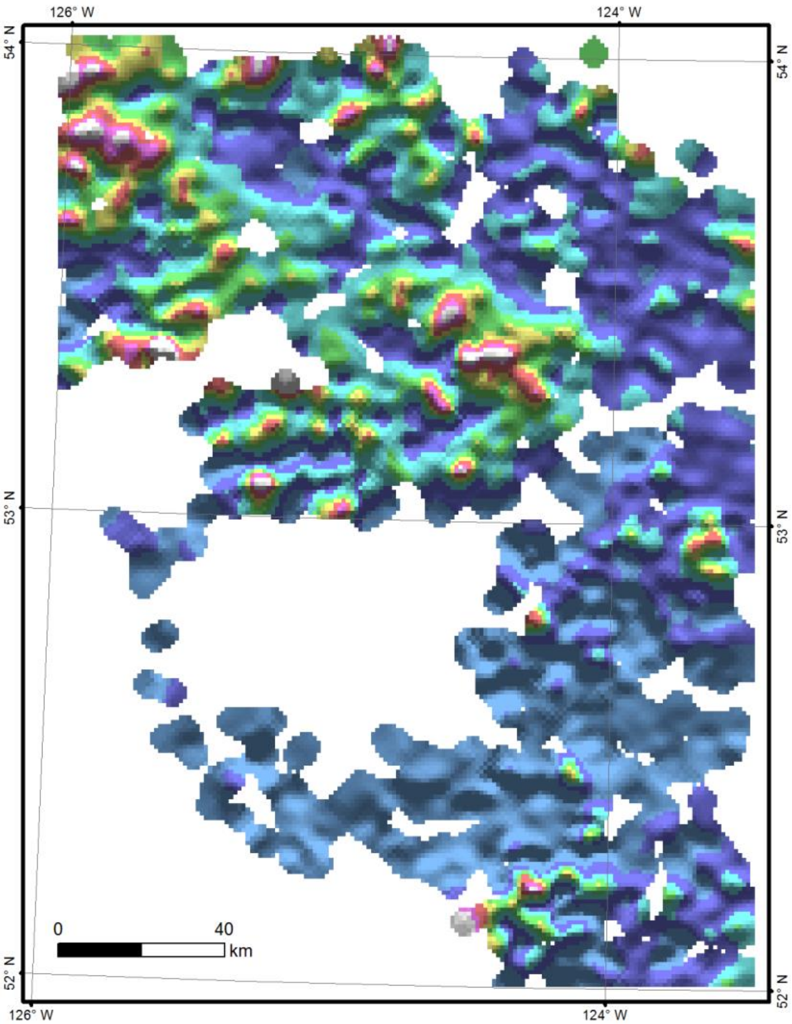
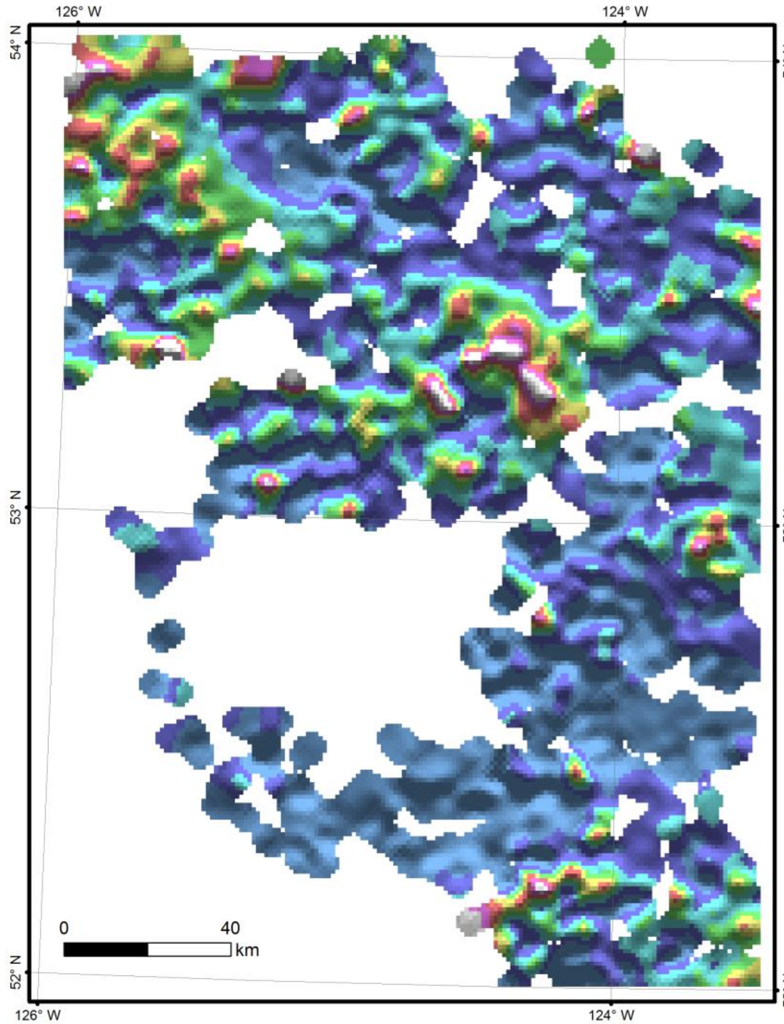
KK
EFLgd
LJLaqd
LKi
lKS
lmJH
MiCCl
MiCvb
Egd
MiPlCb
PJV
PTrC
TrJB
unknown
uTRv
Egr
Eo

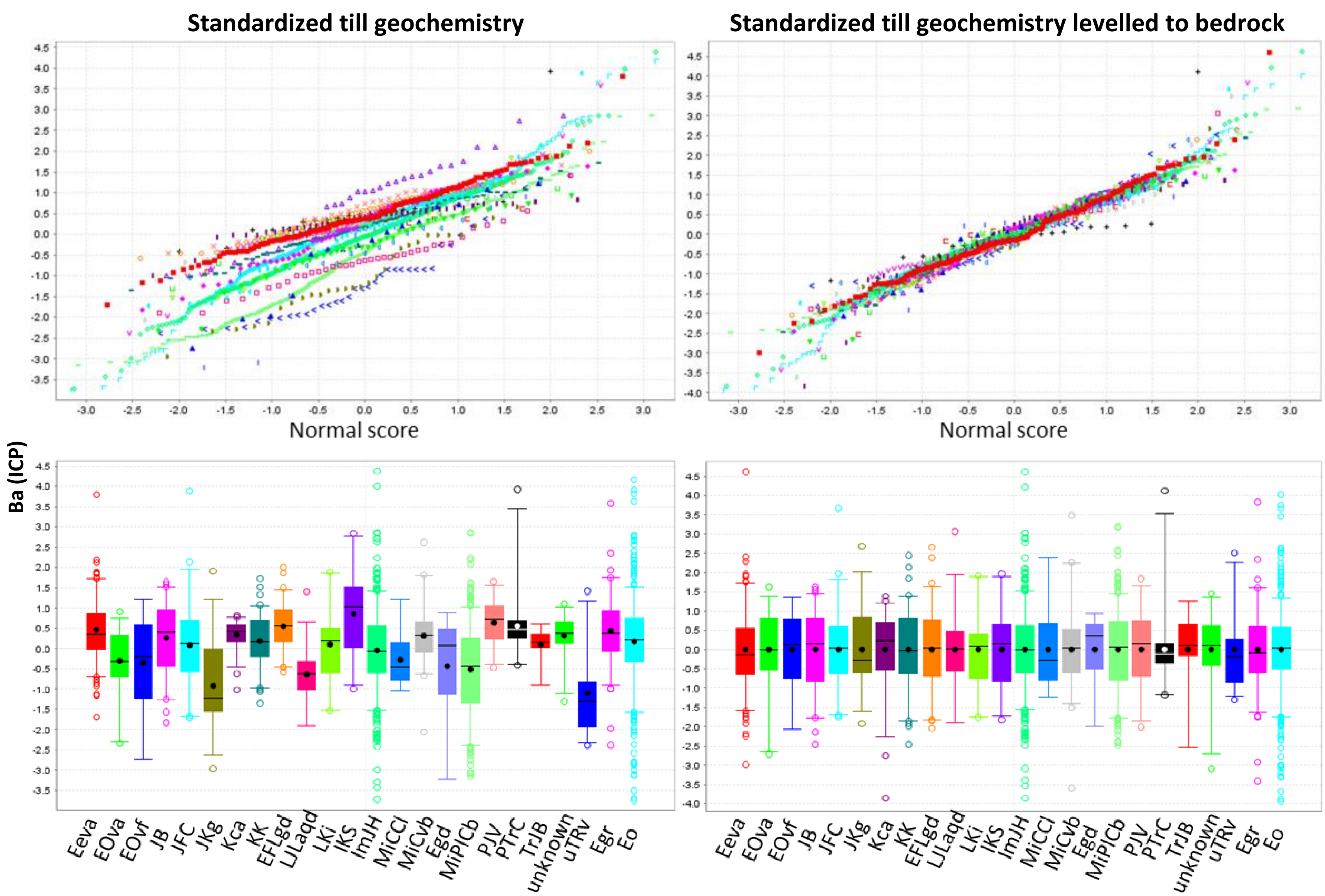
Ag (ICP)

Standardized till geochemistry



Standardized till geochemistry levelled to bedrock




Standardized till geochemistry
Standardized till geochemistry levelled to bedrock
Normal score
Normal score
Ba (ICP)
Eeva
EOva
EOvf
JB
JFC
JKg
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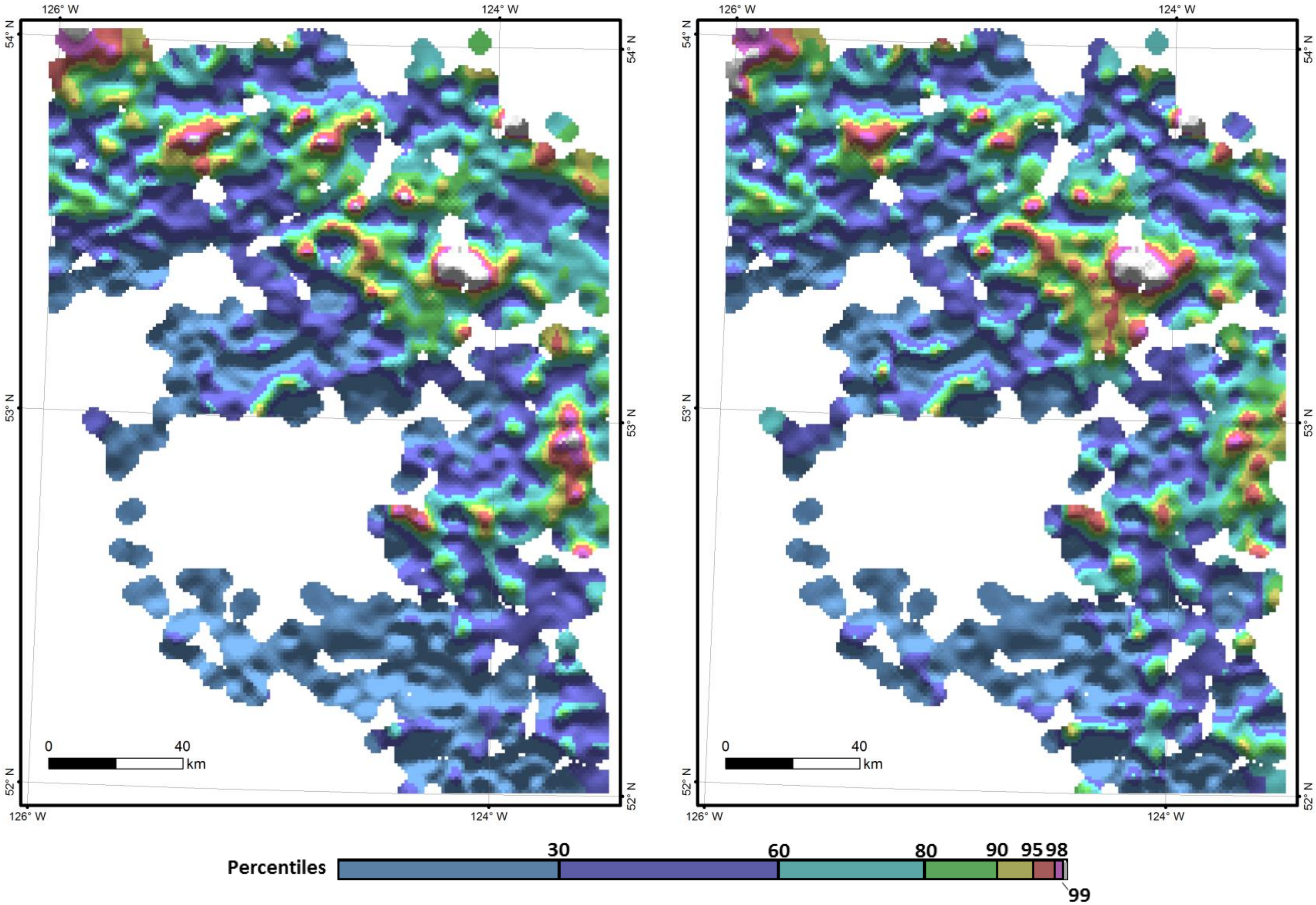
KK
EFLgd
LJLaqd
LKi
lKS
lmJH
MiCCl
MiCvb
Egd
MiPlCb
PJV
PTrC
TrJB
unknown
uTRv
Egr
Eo

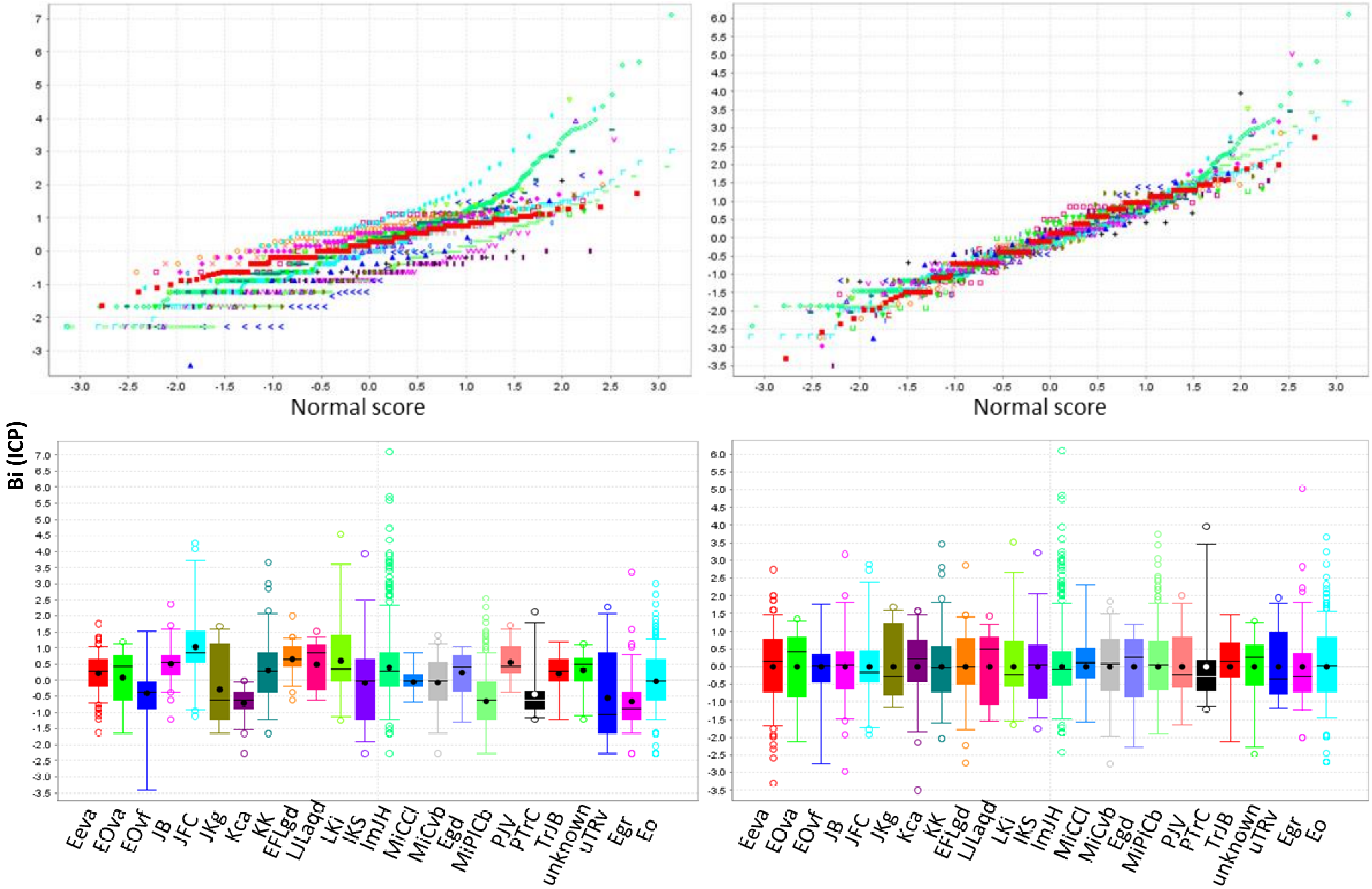
Standardized till geochemistry | **Standardized till geochemistry levelled to bedrock**

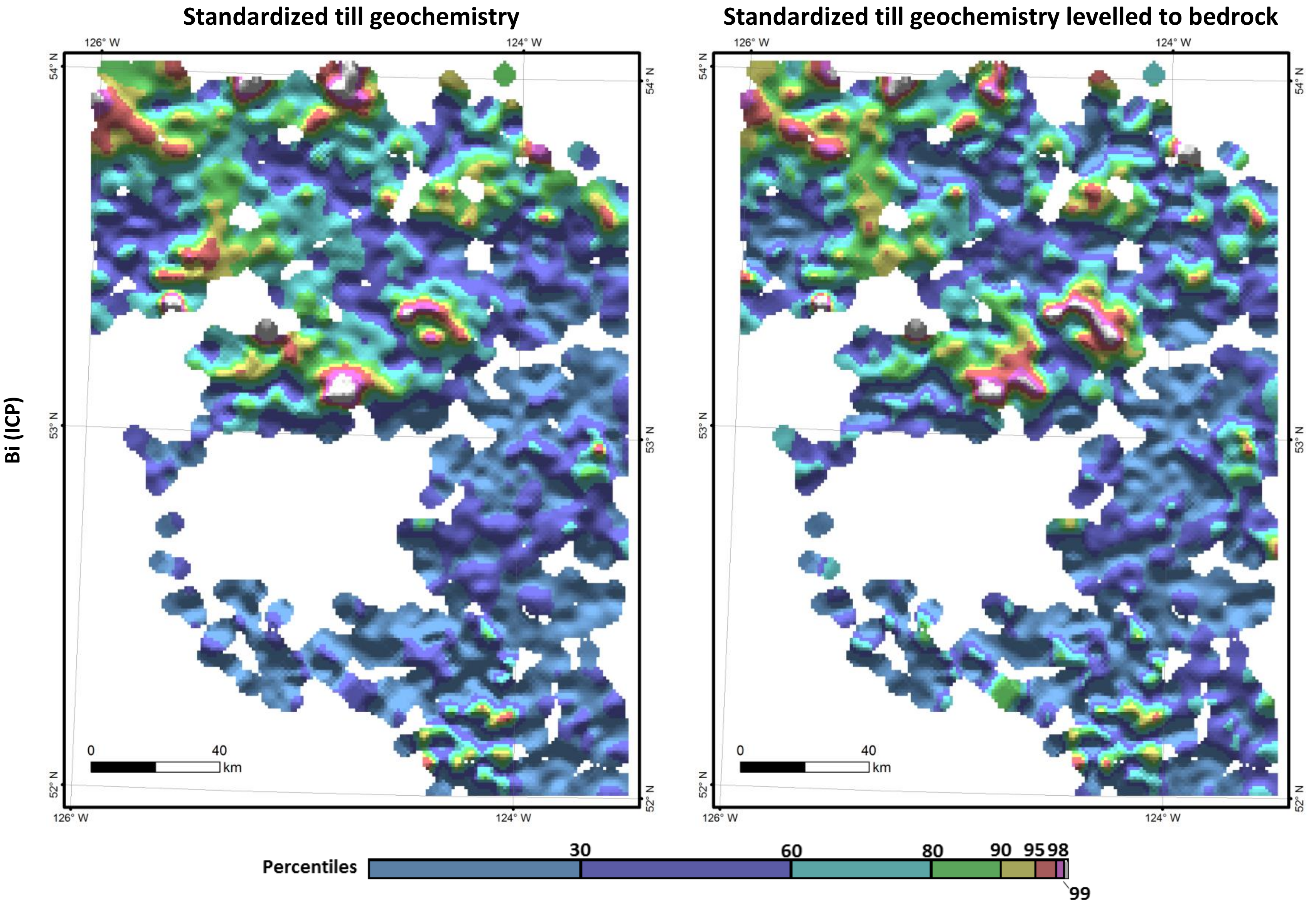
Ba (ICP)

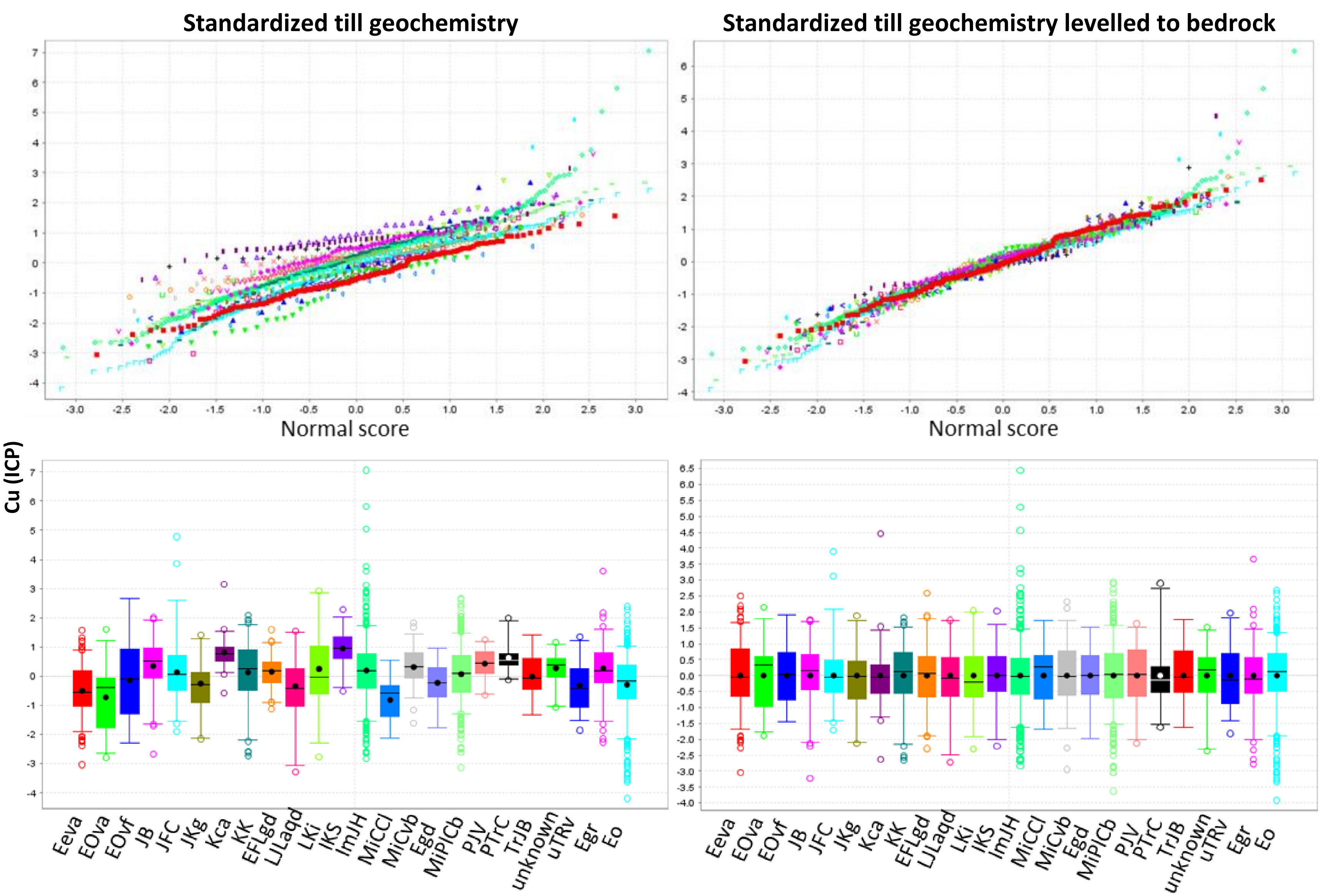


Standardized till geochemistry

Standardized till geochemistry levelled to bedrock




Bi (ICP)
Standardized till geochemistry
Standardized till geochemistry levelled to bedrock
126° W
124° W
54° N
53° N
52° N
0
40
km
Percentiles
30
60
80
90
95
98
99



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Standardized till geochemistry levelled to bedrock
Normal score
Normal score
Cu (ICP)
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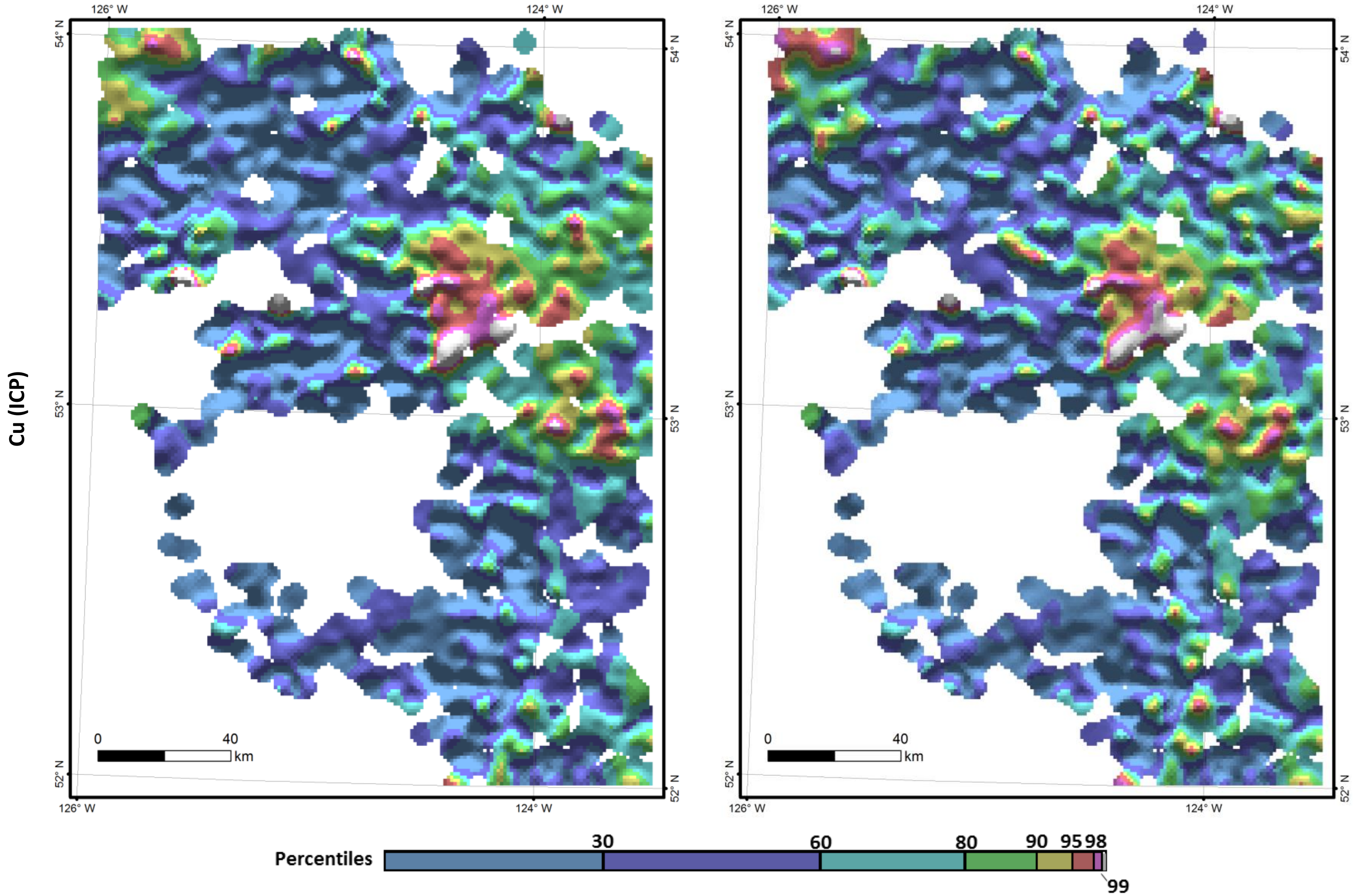
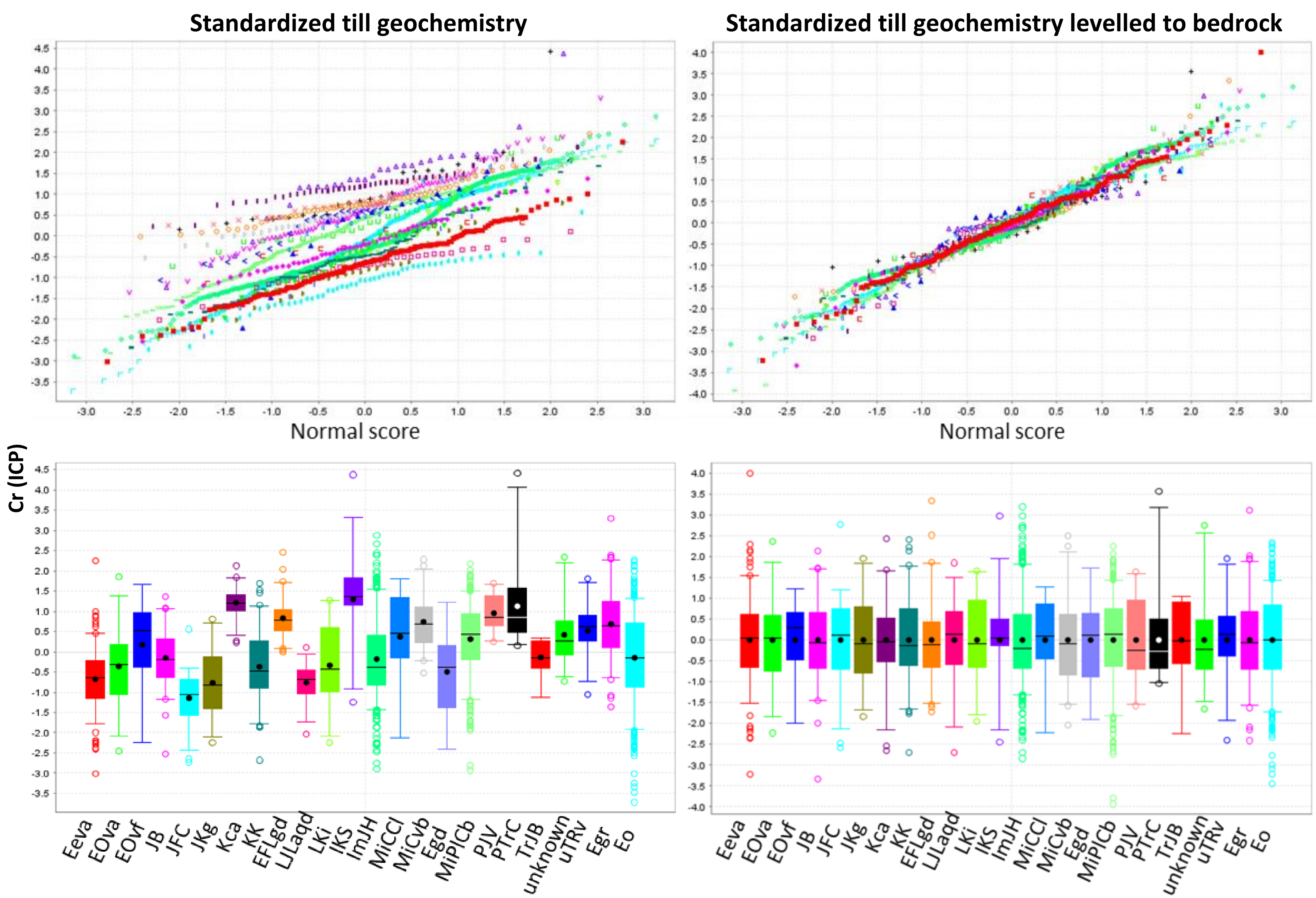
EOva
EOvf
JB
JFC
JKg
Kca
KK
EFLgd
LJLaqd
LKi
lKS
lmJH
MiCCl
MiCvb
Egd
MiPlCb
PJV
PTrC
TrJB
unknown
uTRv
Egr
Eo

Standardized till geochemistry | **Standardized till geochemistry levelled to bedrock**





Standardized till geochemistry
Standardized till geochemistry levelled to bedrock
Normal score
Normal score
Cr (ICP)
Eeva
EOva
EOvf
JB
JFC
JKg
Kca
KK
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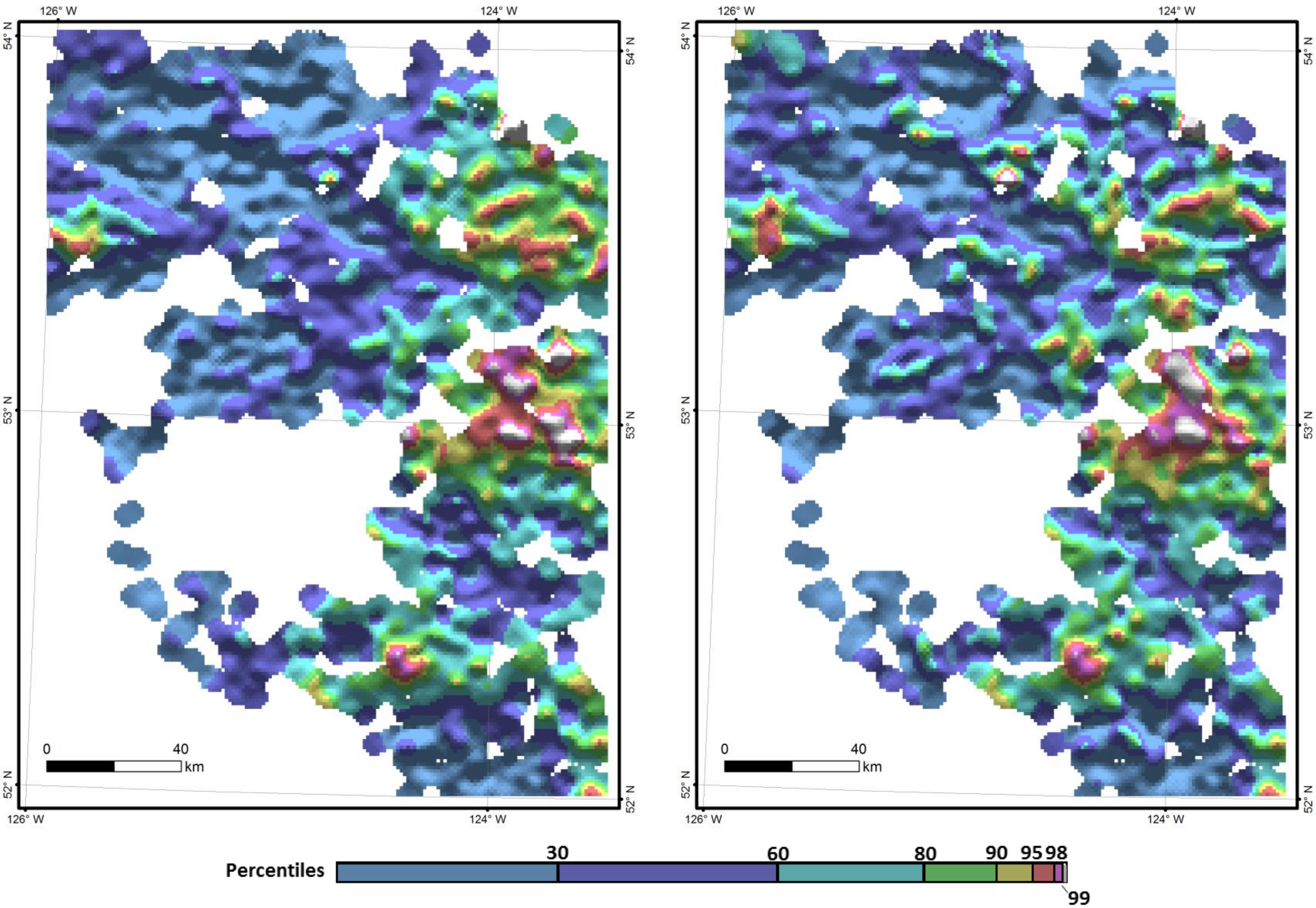
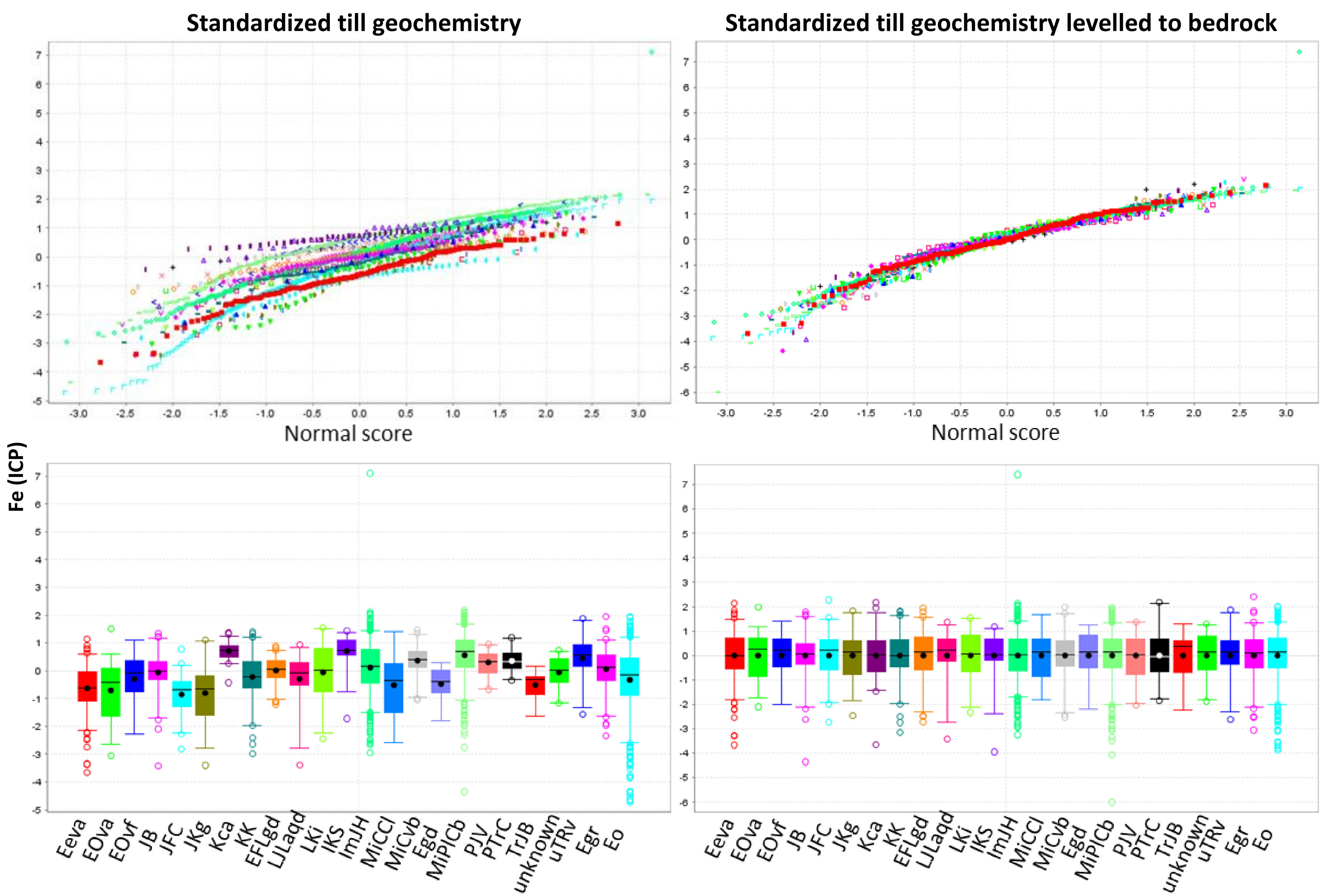
LJLaqd
LKi
lKS
lmJH
MiCCl
MiCvb
Egd
MiPlCb
PJV
PTrC
TrJB
unknown
uTRV
Egr
Eo

Cr (ICP)

Standardized till geochemistry

Standardized till geochemistry levelled to bedrock




Standardized till geochemistry
Standardized till geochemistry levelled to bedrock
Normal score
Normal score
Fe (ICP)
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EOva
EOvf
JB
JFC
JKg
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LJLaqd
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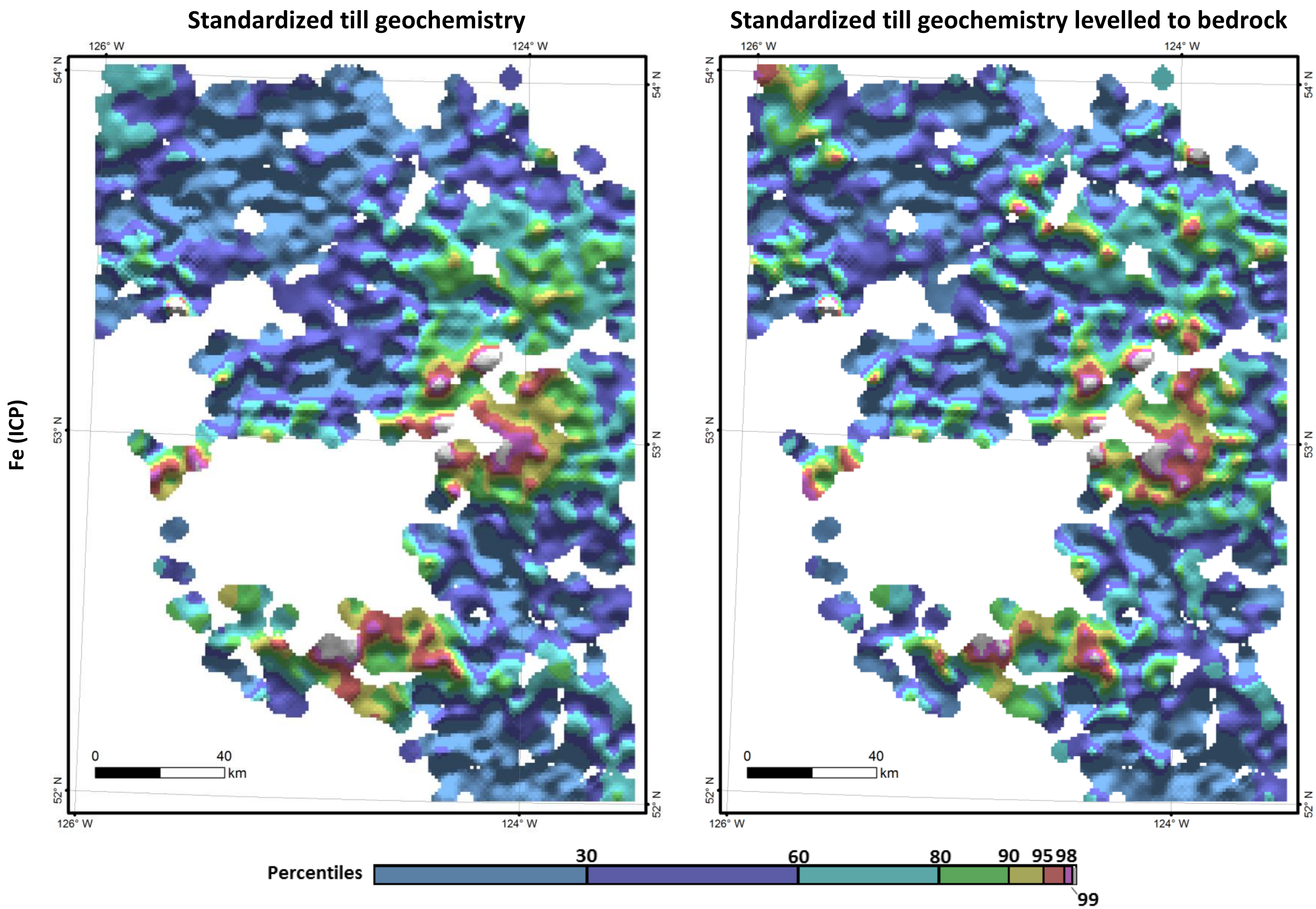
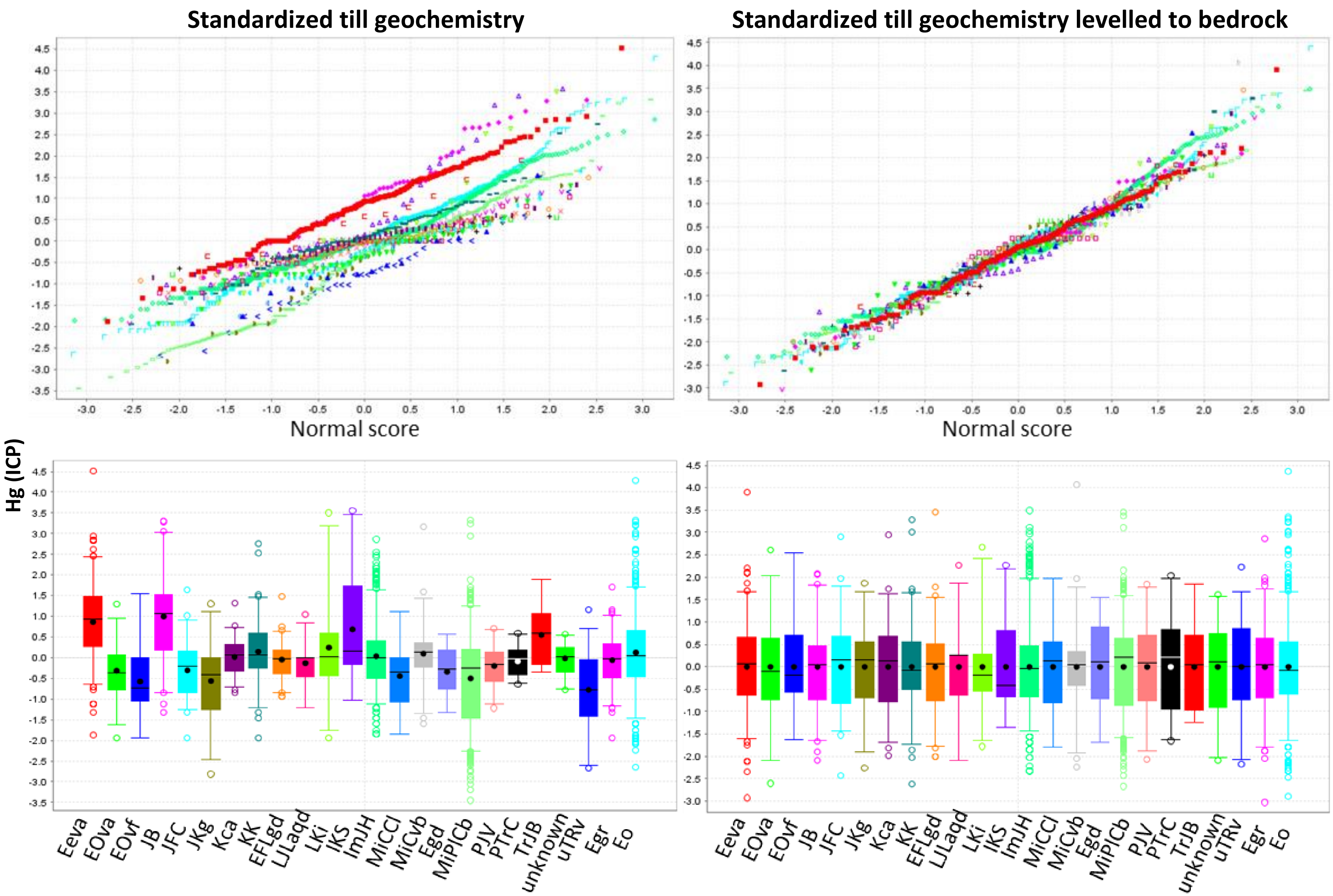
MiCCl
MiCvb
Egd
MiPlCb
PJV
PTrC
TrJB
unknown
uTRv
Egr
Eo


Standardized till geochemistry
Standardized till geochemistry levelled to bedrock
Fe (ICP)
126° W
124° W
54° N
53° N
52° N
0
40
km
Percentiles
30
60
80
90
95
98
99


Standardized till geochemistry
Standardized till geochemistry levelled to bedrock
Normal score
Normal score
Hg (ICP)
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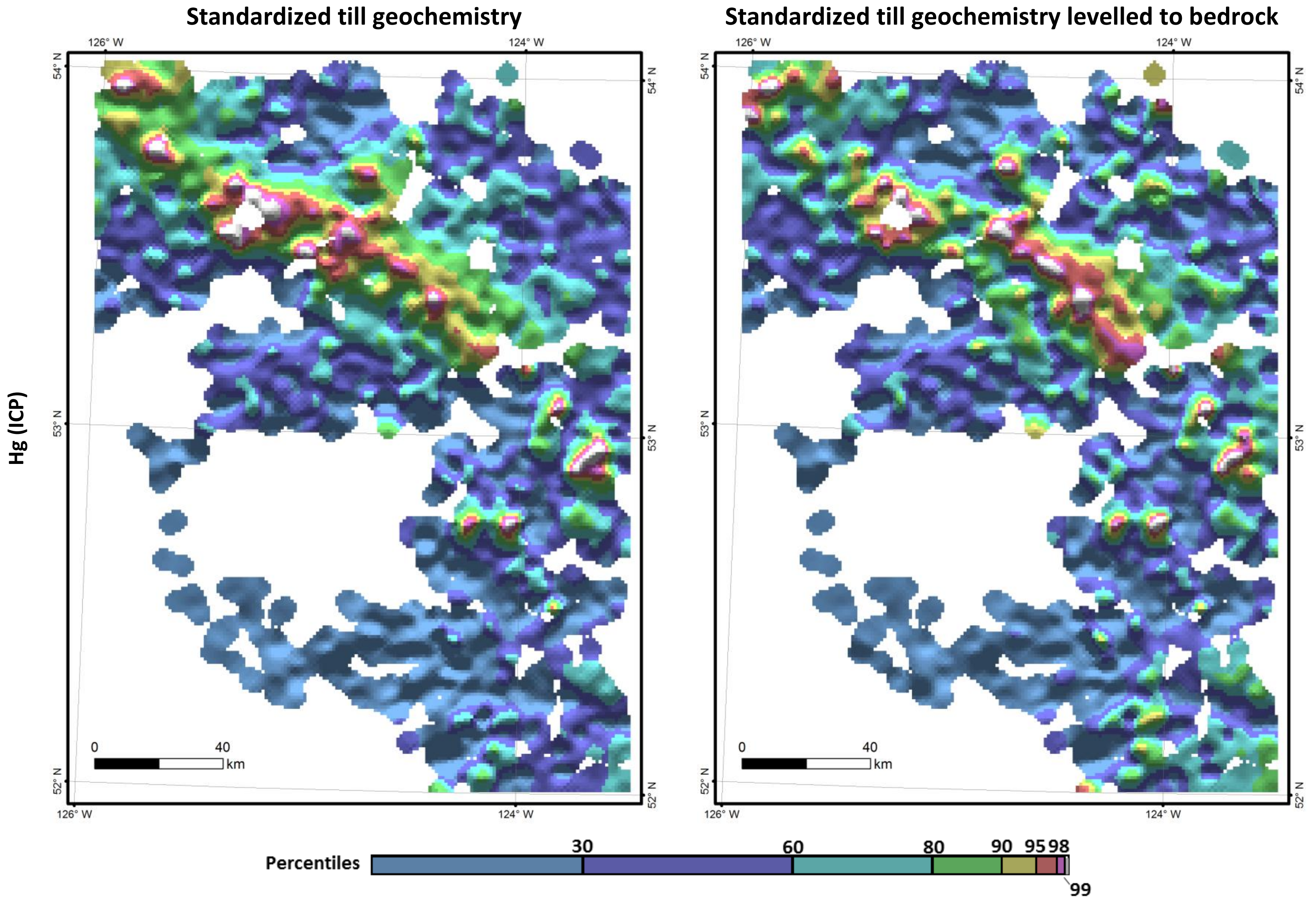
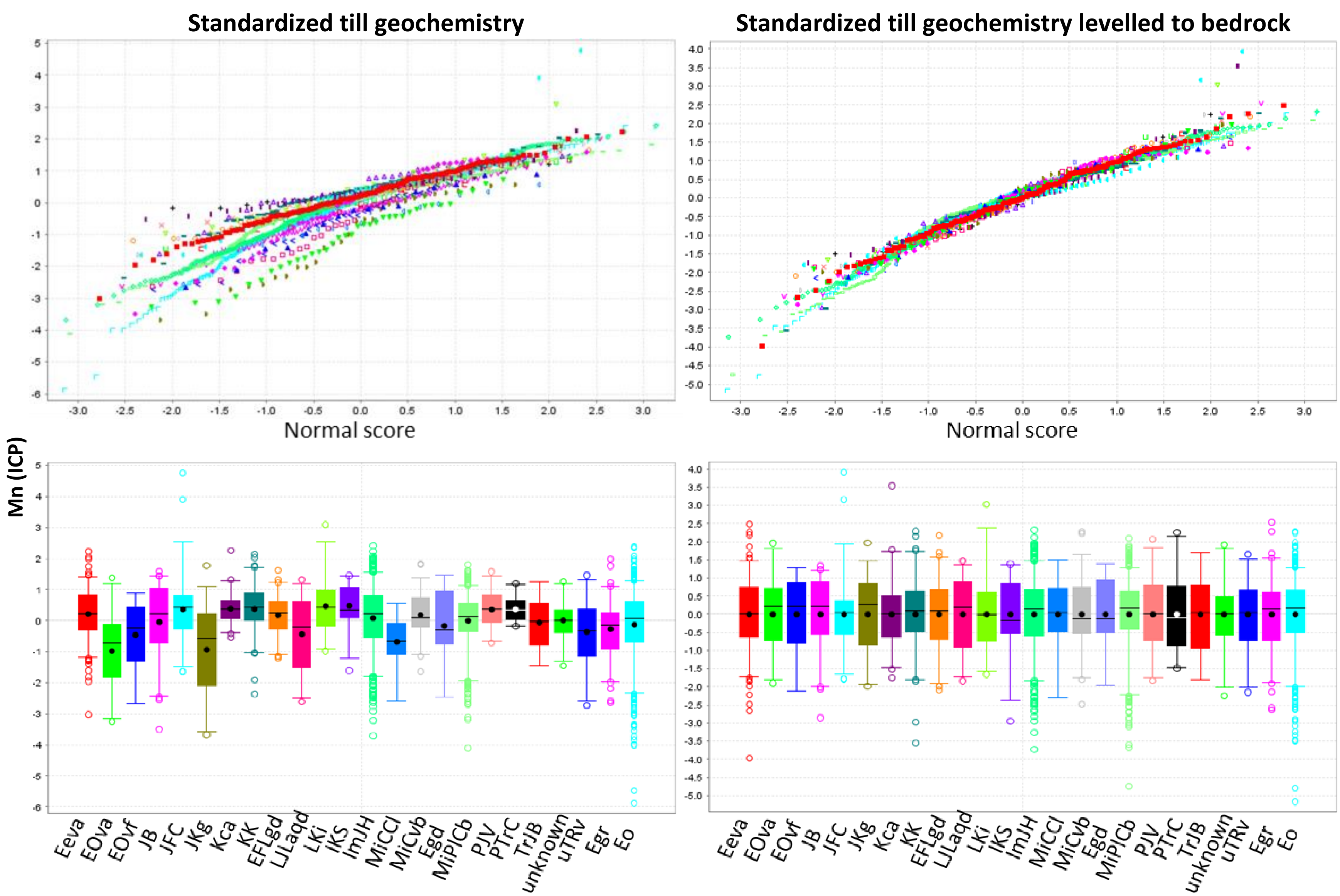
EOva
EOvf
JB
JFC
JKg
Kca
KK
EFLgd
LJLaqd
LKi
lKS
lmJH
MiCCl
MiCvb
Egd
MiPlCb
PJV
PTrC
TrJB
unknown
uTRV
Egr
Eo


Standardized till geochemistry
Standardized till geochemistry levelled to bedrock
Hg (ICP)
126° W
124° W
54° N
53° N
52° N
0
40
km
Percentiles
30
60
80
90
95
98
99


Standardized till geochemistry
Standardized till geochemistry levelled to bedrock
Normal score
Normal score
Mn (ICP)
Eeva
EOva
EOvf
JB
JFC
JKg
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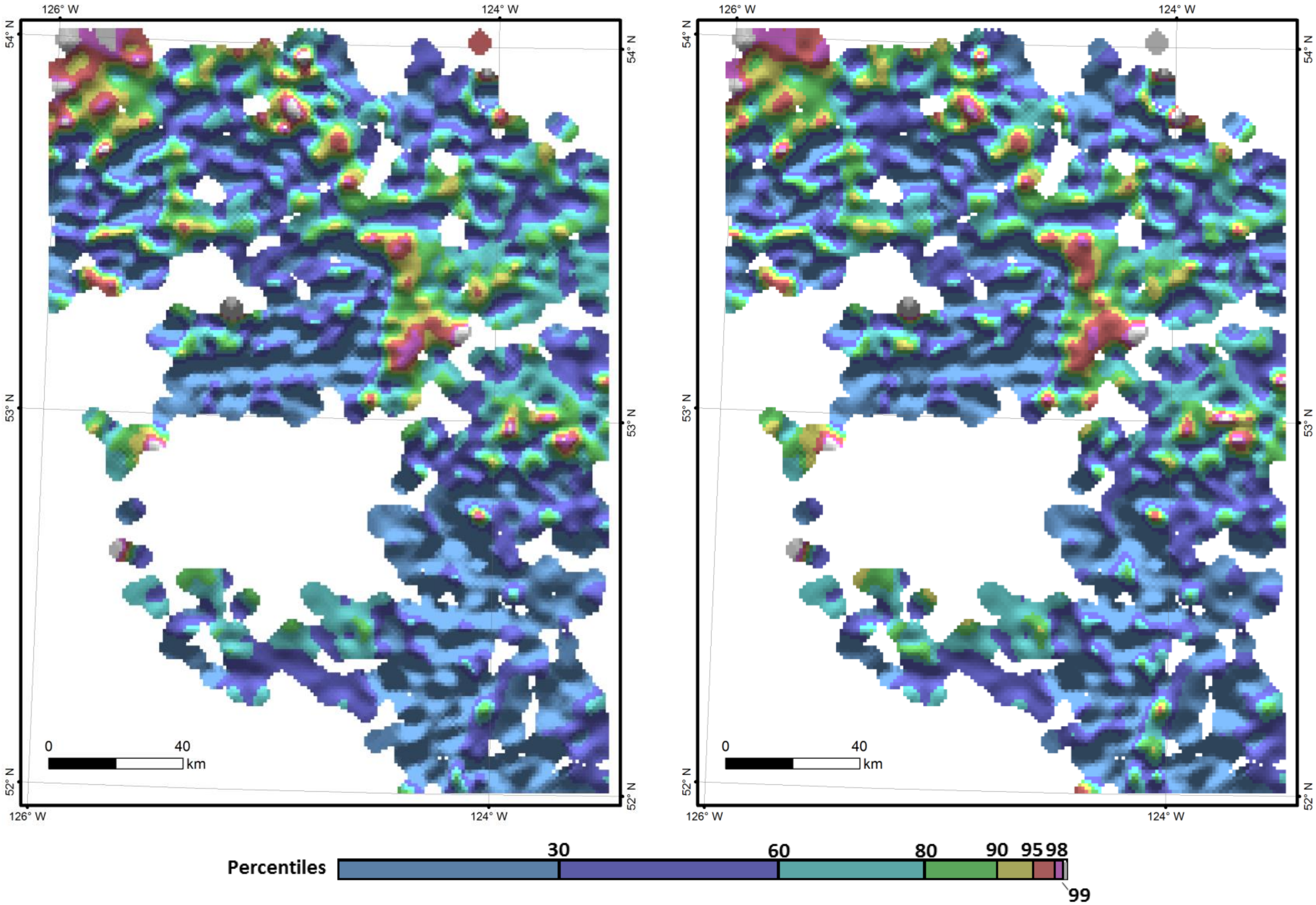
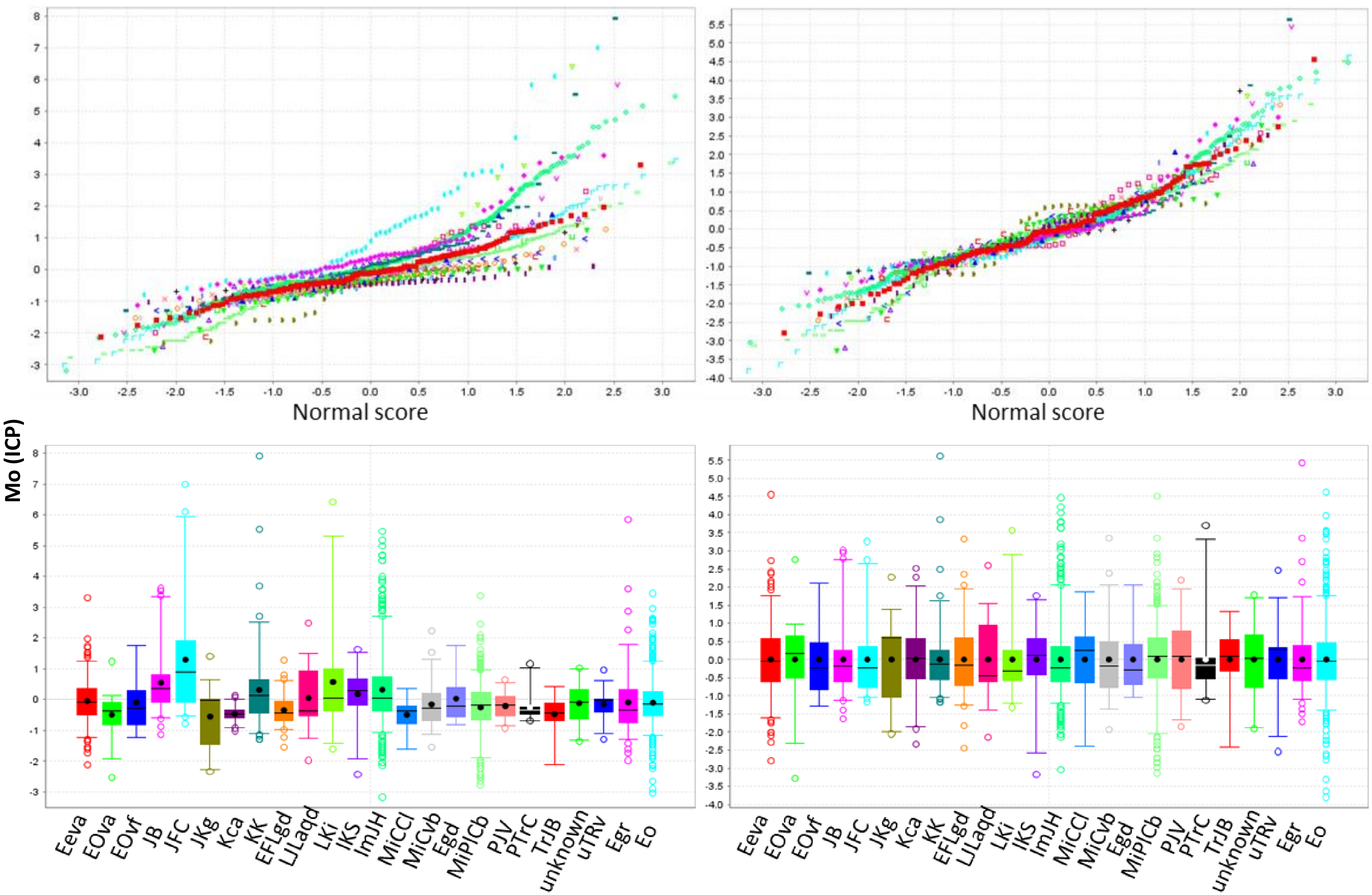
KK
EFLgd
LJLaqd
LKi
lKS
lmJH
MiCCl
MiCvb
Egd
MiPlCb
PJV
PTrC
TrJB
unknown
uTRv
Egr
Eo

Standardized till geochemistry | **Standardized till geochemistry levelled to bedrock**

Mn (ICP)

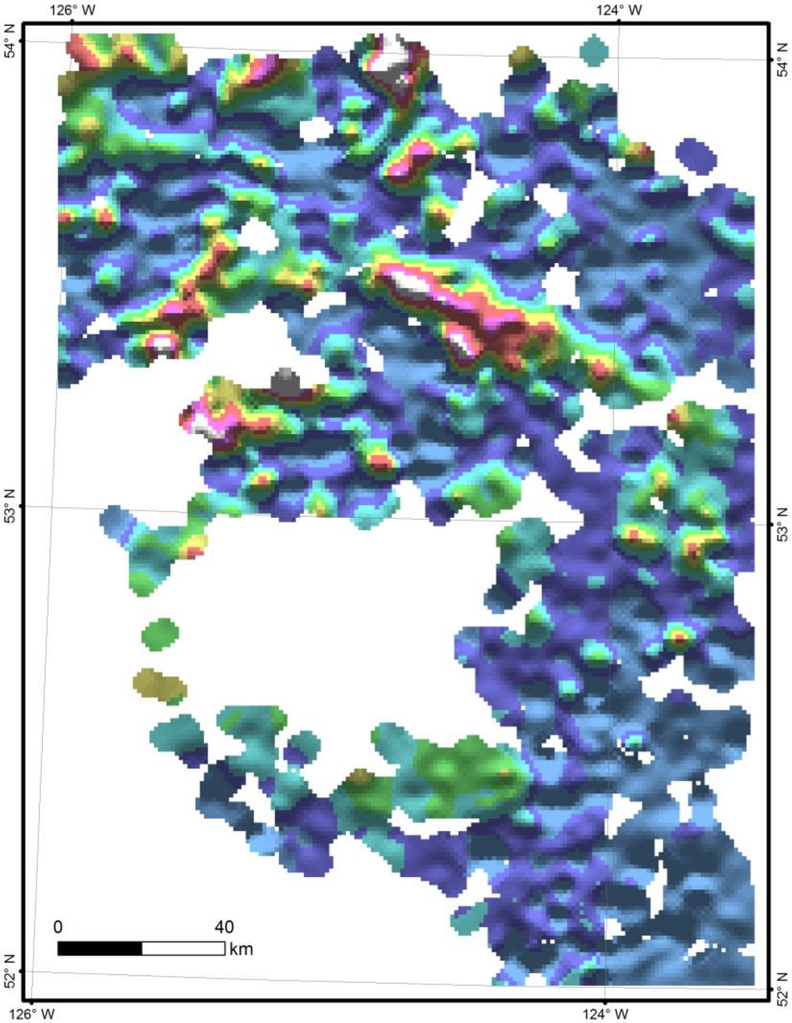


Standardized till geochemistry | **Standardized till geochemistry levelled to bedrock**

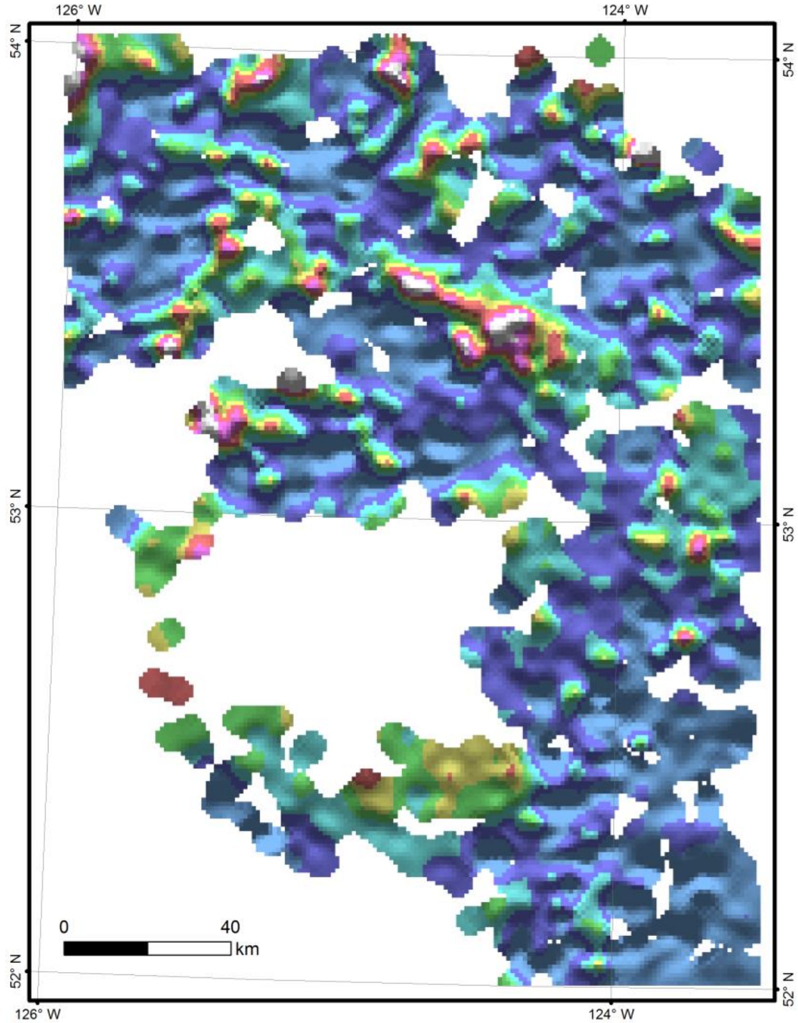

Normal score
Normal score
Mo (ICP)
Eeva
EOva
EOvf
JB
JFC
JKg
Kca
KK
EFLgd
LJLaqd
LKi
lKS
lmJH
MiCCl
MiCvb
Egd
MiPlCb
PJV
PTrC
TrJB
unknown
uTRv
Egr
Eo

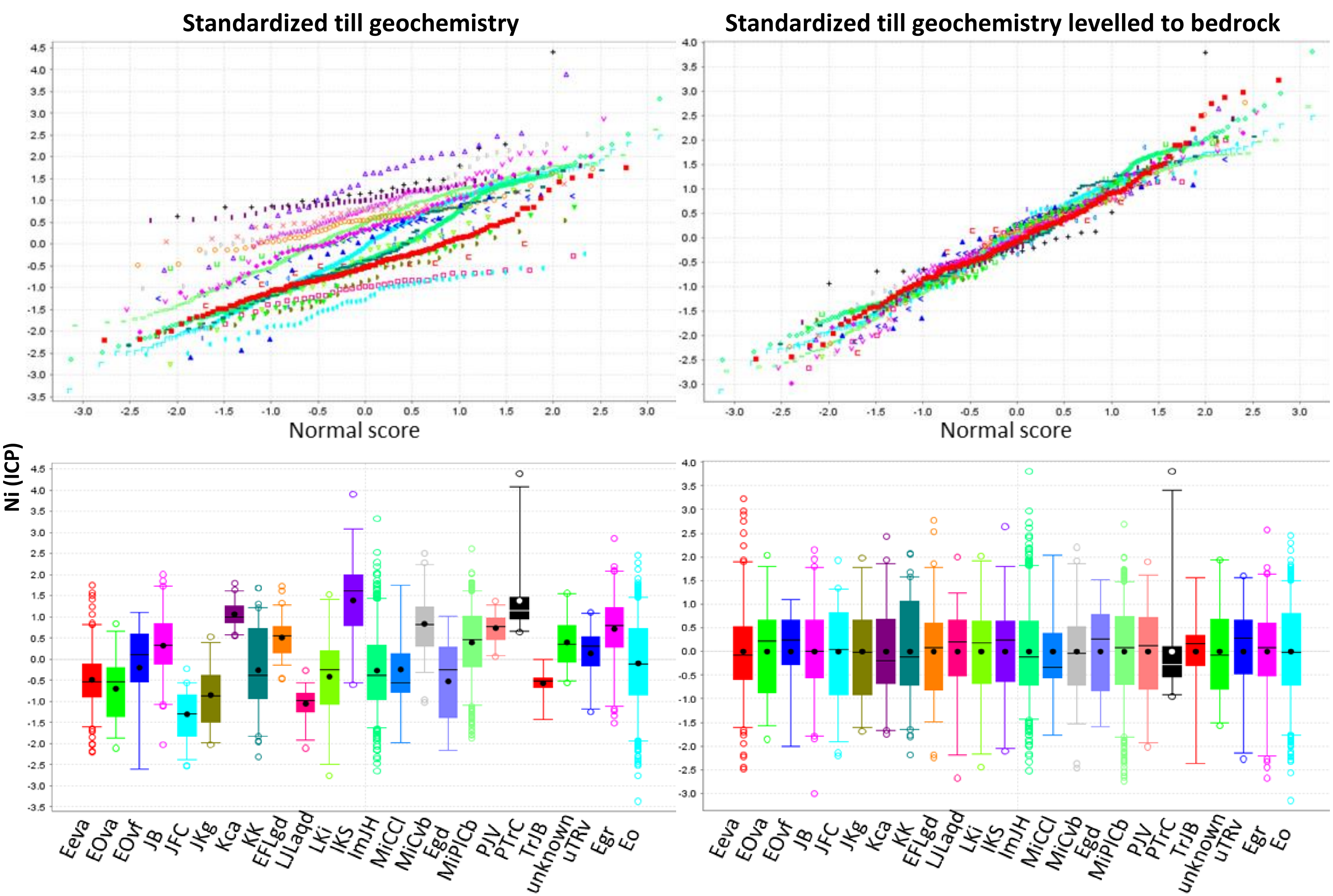
Mo (ICP)

Standardized till geochemistry

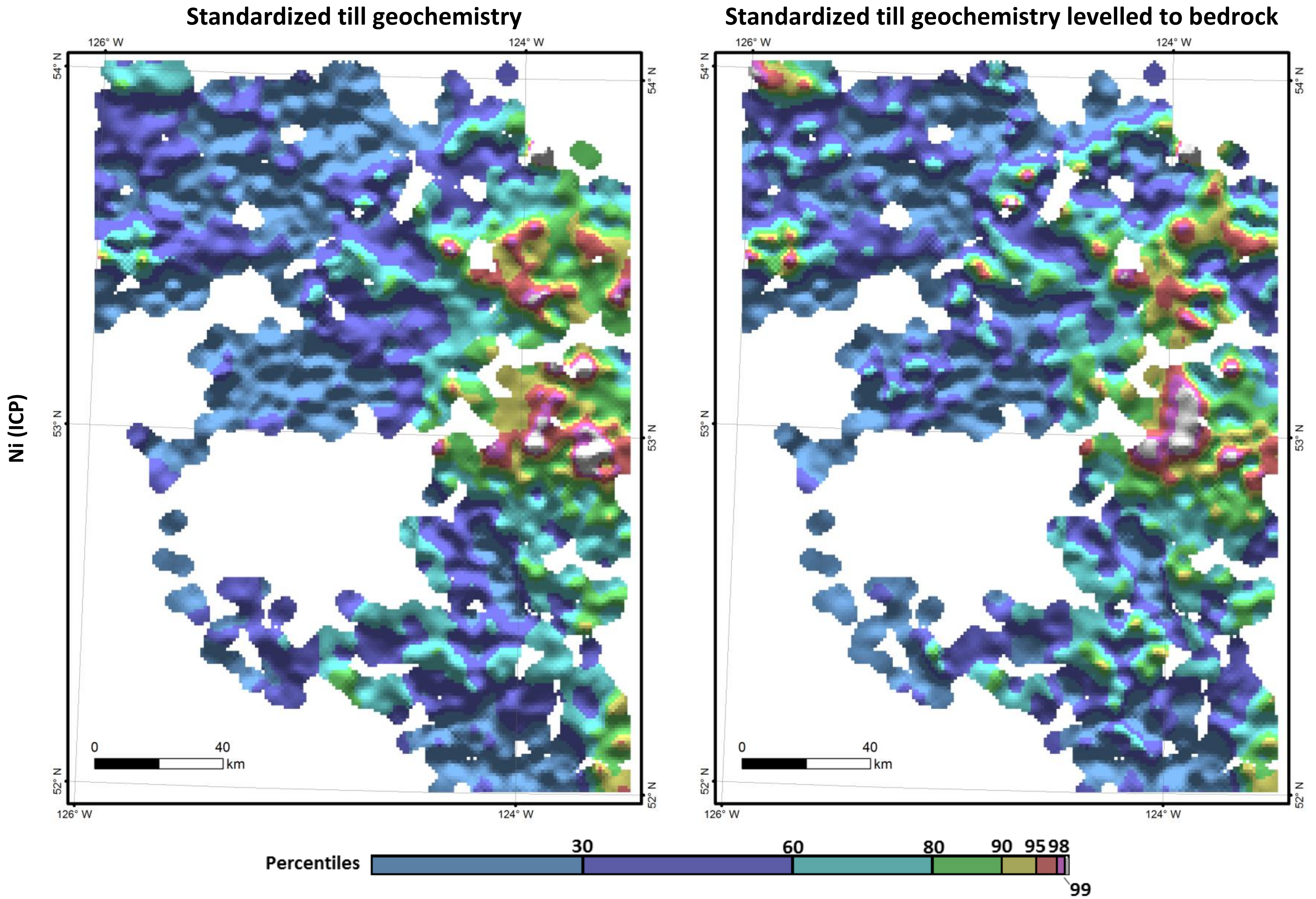


Standardized till geochemistry levelled to bedrock

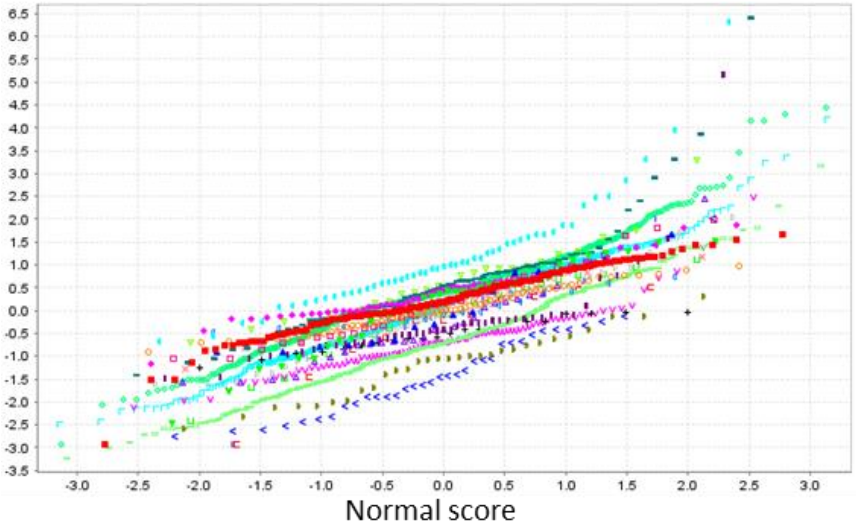




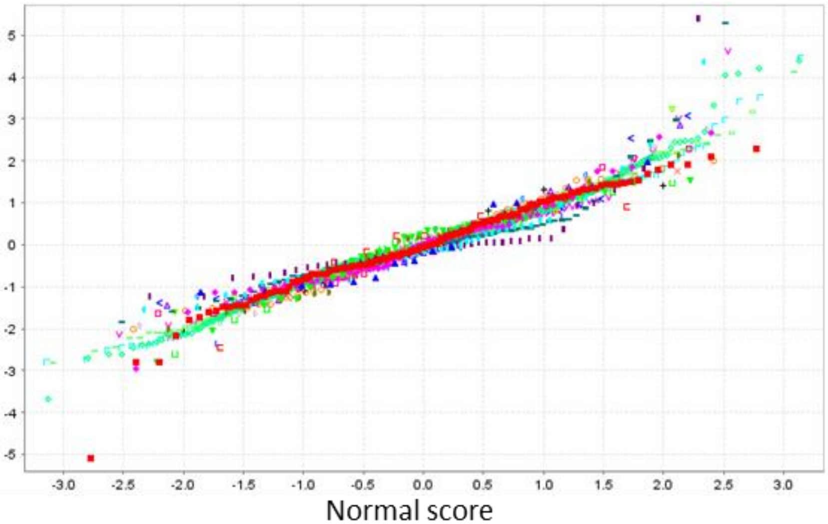
Standardized till geochemistry
Standardized till geochemistry levelled to bedrock
Normal score
Normal score
Ni (ICP)
Eeva
EOva
EOvf
JB
JFC
JKg
Kca
KK
EFLgd
LJLaqd
LKi
lKS
lmJH
MiCCl
MiCvb
Egd
MiPlCb
PJV
PTrC
TrJB
unknown
uTRV
Egr
Eo


Ni (ICP)
Standardized till geochemistry
Standardized till geochemistry levelled to bedrock
126° W
124° W
54° N
53° N
52° N
0
40
km
Percentiles
30
60
80
90
95
98
99

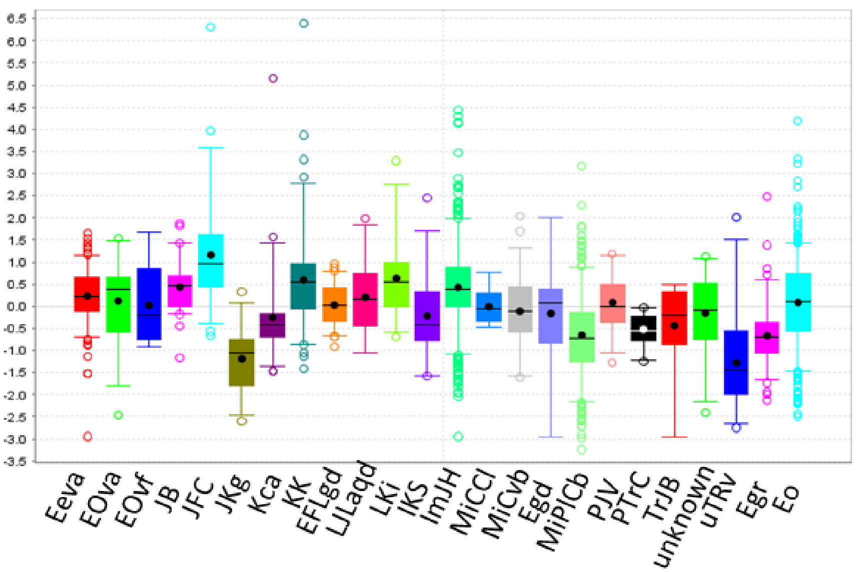
Standardized till geochemistry

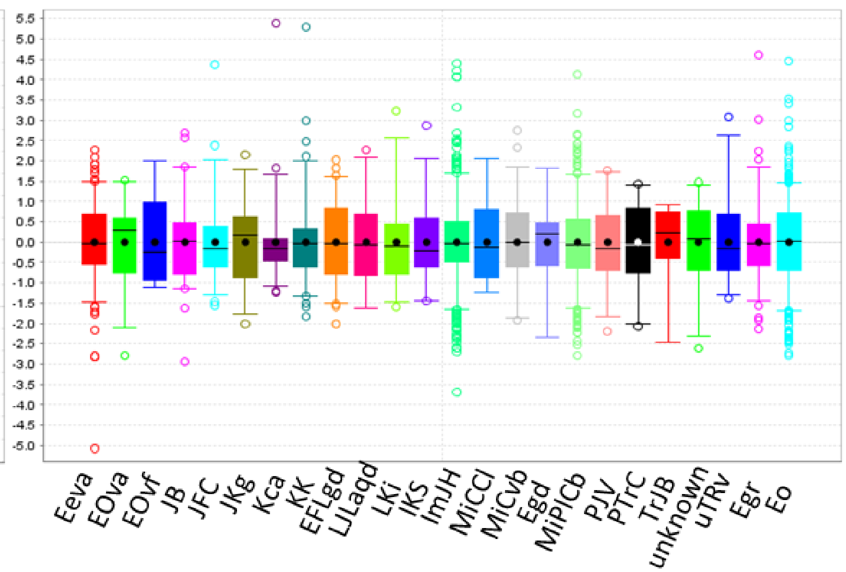


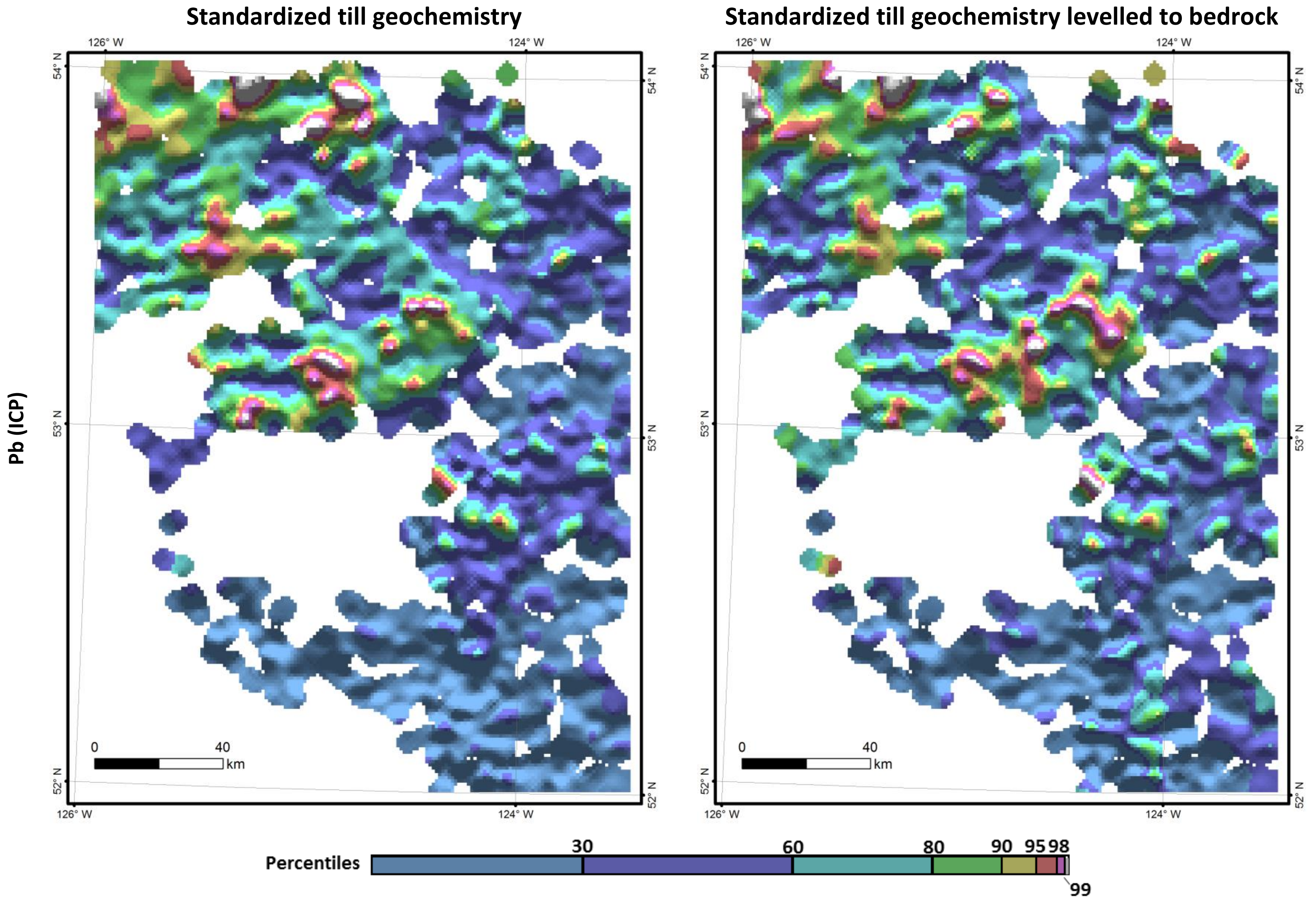
Standardized till geochemistry levelled to bedrock

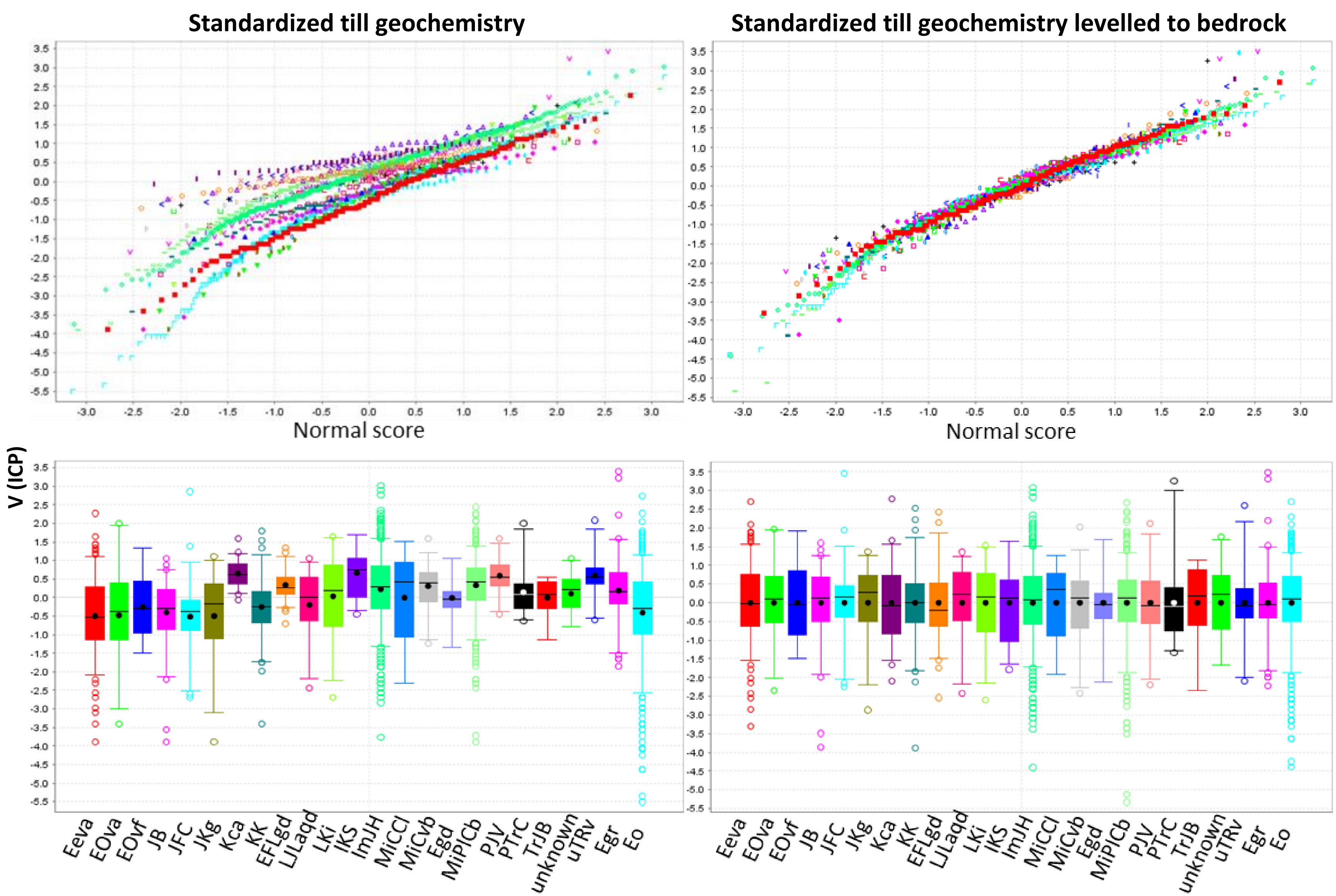


Pb (ICP)






Standardized till geochemistry
Standardized till geochemistry levelled to bedrock
Pb (ICP)
126° W
124° W
54° N
53° N
52° N
0
40
km
Percentiles
30
60
80
90
95
98
99


Standardized till geochemistry
Standardized till geochemistry levelled to bedrock
Normal score
Normal score
V (ICP)
Eeva EOva EOvf JB JFC JKg Kca KK EFLgd LJLaqd LKi lKS lmJH MiCCl MiCvb Egd MiPlCb PJV PTrC TrJB unknown uTRv Egr Eo
Eeva EOva EOvf JB JFC JKg Kca KK EFLgd LJLaqd LKi lKS lmJH MiCCl MiCvb Egd MiPlCb PJV PTrC TrJB unknown uTRv Egr Eo

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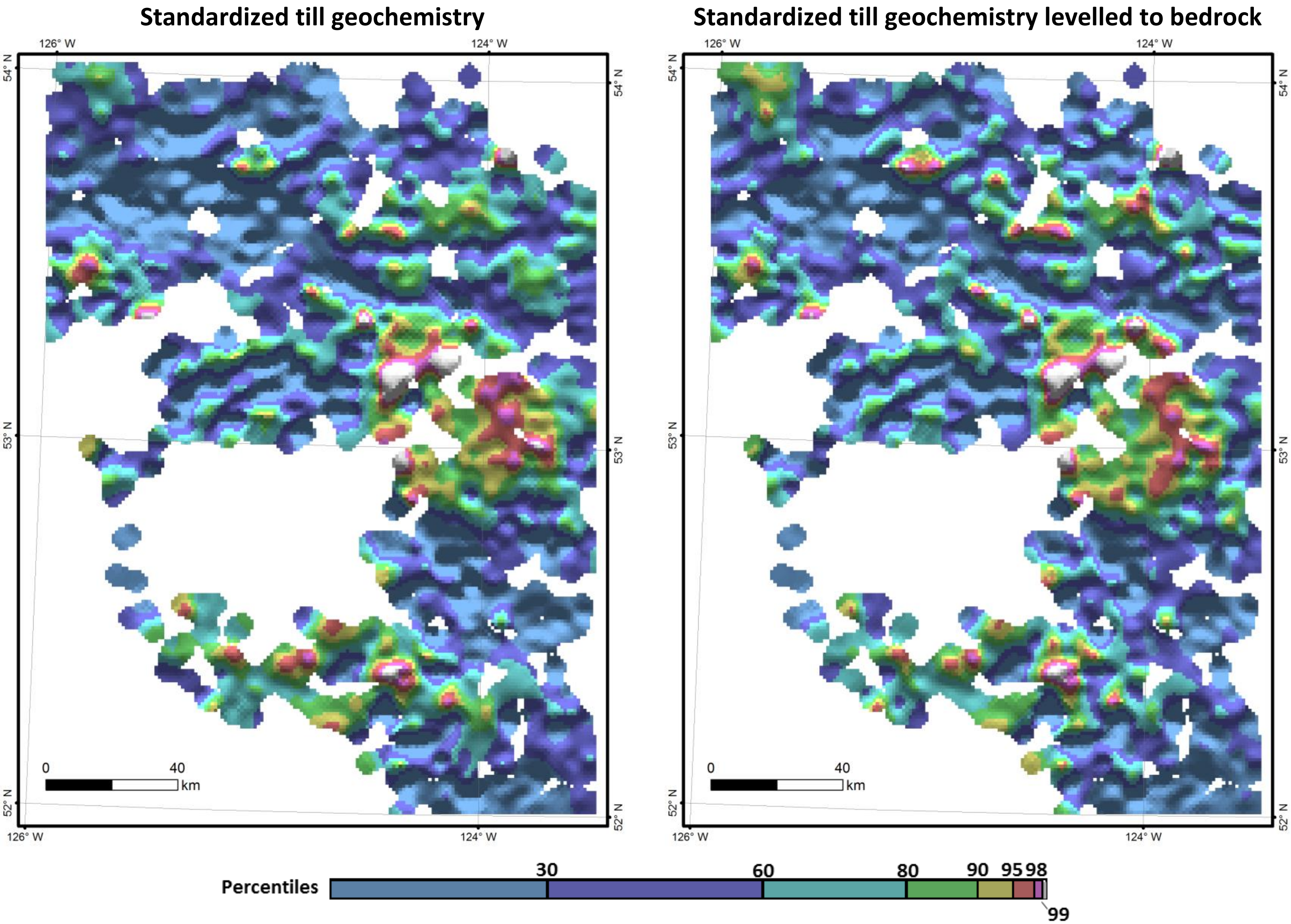
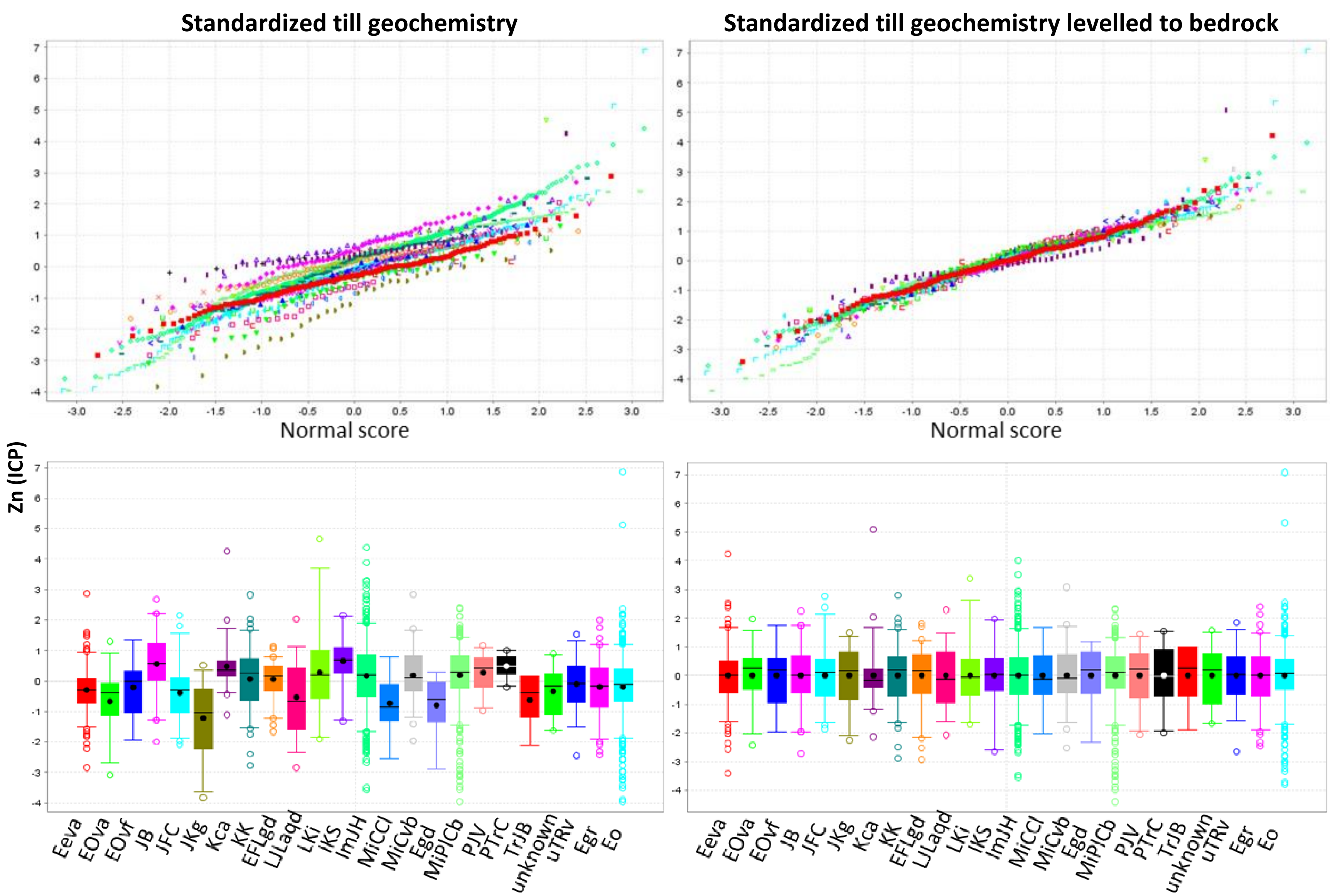
V (ICP)




Standardized till geochemistry
Standardized till geochemistry levelled to bedrock
Normal score
Normal score
Zn (ICP)
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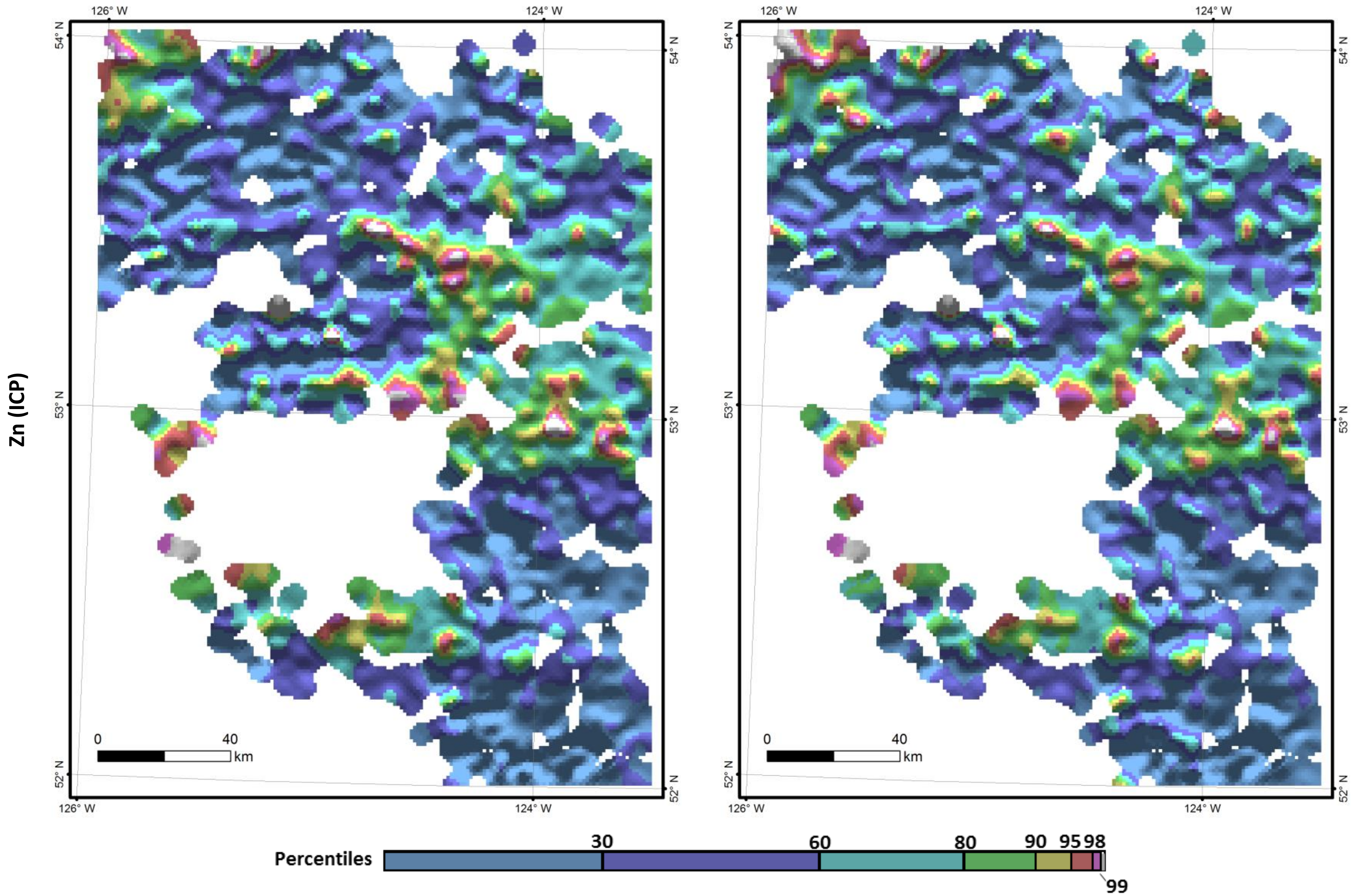
Standardized till geochemistry | **Standardized till geochemistry levelled to bedrock**



Appendix C

Standardized till and lake sediment data, standardized till data levelled to bedrock, and weighted sums indices for porphyry, epithermal, and Fenton-type mineralization

C1. PECG_TREK_AdvancedGeochemical ProcessingData.xlsx

Provided separately in Excel database format

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Appendix D

Spatial files for gridded till geochemistry, anomaly clusters, till and lake sediment areas of influence

D1 PECG_TREK_AdvancedGeochemicalProcessingSpatialData.gdb.zip

D2 PECG_TREK_AdvancedGeochemicalProcessingSpatialData.zip

Provided separately in ESRI geodatabase and shapefile formats