Predictive Geologic Mapping and Assessing the Mineral Potential in NTS 65A/B/C, Nunavut, with New Regional Lake Sediment Geochemical Data

GEM

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Introduction

Government geological surveys and mineral exploration companies collect large amounts of geochemical data that are used in search for mineral commodities or environmental studies. These surveys consist of many thousands of samples (observations) with as many as 50 elements determined for each. Because the nature of the data is compositional, they must be treated according to the protocols established by Aitchison (1986). This contribution details an approach based on the application of the alr and clr transforms for process discovery and validation.

This poster highlights the value of multi-element geochemical data as an aid to regional geological mapping and potential base- and precious metal deposits through the collection and evaluation of regional geochemical survey data over NTS 65A, B and C, the Nueltin lake area of Nunavut, Canada (Figure 1). Figure 2 shows a generalized geological map for the area derived from GSC Open File 5441 (Tella et al., 2007). Figure 3 shows geological maps for NTS Sheets 65A and 65B (Eade, 1973a,b). The geology of Figure 3 has been used as the basis against which the lake sediment survey data has been classified and used for prediction of the geology in NTS Sheet 65C. These map sheets also identify the geochemically distinctive Nueltin and Hudson granites. Using known geology from sheets 65A and 65B, the geological units of 65C have been predicted using multivariate statistical techniques.

The Nueltin Lake area is located within the Southern Hearne Province, a poorly-understood terrane between the Central Hearne supracrustal terrane, which is dominated by ca. 2.7-2.65 Ga mafic-to-felsic, oceanic volcanic rocks and younger tonalite to granite plutons, and the trans-Hudson orogen which forms the northern boundary of the Superior Province. The Southern Hearne is dominated by Archean tonalitic and charnokitic gneisses, approximately 2.8 Ga. However, strong evidence for fragments of much older crust, up to 3.3 Ga, has been found in the form of inherited Archean zircons and Sm-Nd model ages, both obtained from Proterozoic post-orogenic plutons of the Hudson Suite, intruded at about 1.83 Ga.

A younger granite suite, the Nueltin rapakivi granites (ca. 1.75 Ga) is also present in the area. Previously, Proterozoic plutons in this area were distinguished by van Breemen et al (2005, attached) on the basis of archived hand samples, field descriptions, and partial geochronological data. East of Nueltin Lake, identification of individual plutons was hampered by poor exposure and a lower frequency of archival material. The lake sediment data shows a strong, 1 to 1 correspondence between the Nueltin suite and positive sediment anomalies in certain incompatible elements, notably REE and Y, in the well-characterized area around Nueltin Lake. High geometrical correspondence between REE-Y anomalies and pluton boundaries in the more eastern area indicates that some of the plutons previously identified as Hudson are in fact Nueltin.

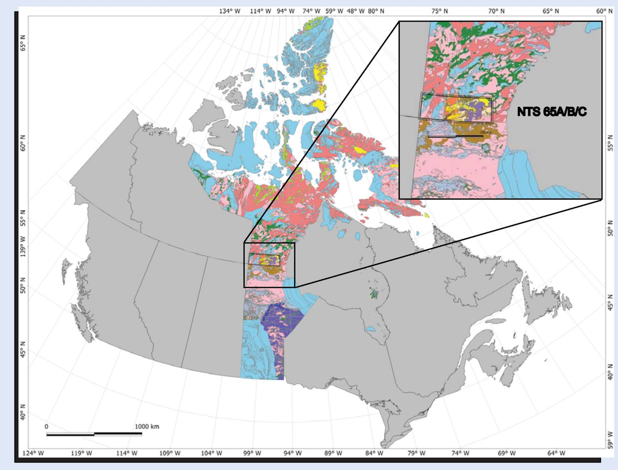
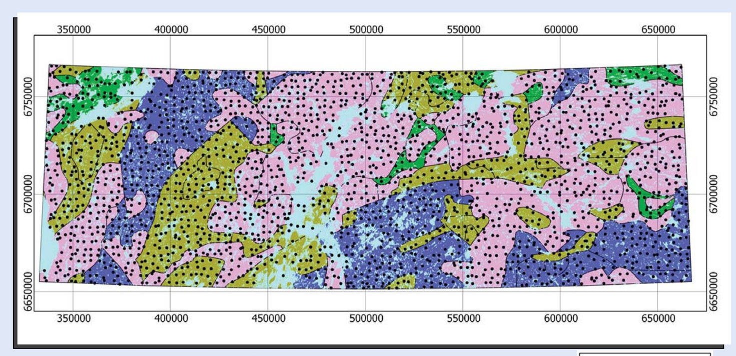


Figure 1. Location of NTS 65A/B/C (Nueltin Lake).



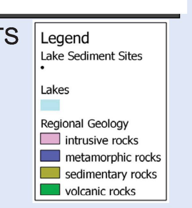


Figure 2. Regional Geologic Compilation over NTS 65A/B/C (Tella et al., 2007)
Location of NTS 65A/B/C (Nueltin Lake).

Lake Sediment Geochemisty and Data Analysis

The results presented here are from a campaign to re-analyze sample pulps using modern analytical methods including Inductively Coupled Plasma Mass Spectrometry (ICP-MS). At the time of this poster assembly Instrumental Neutron Activation Analysis (INAA) results were not yet available. In cases where elements have been analyzed using two or more methods, the elements were evaluated in terms of detection limit suitability and visual examination of the correlation of the element with each method. The elements B, Ge, In, Pd, Re, Ta and Te were dropped due to large numbers of observations that were reported at less than the detection limit (< lld). Figure 4 shows quantile-quantile plots for the elements (raw data) prior to adjustments for censored values.

One of the primary purposes of geochemical data analysis is the recognition of geochemical/geological processes. Processes are recognized by a continuum of variable responses and the relative increase/decrease of these variables. The presence of censored data (values < lld) can, in some cases, affect the results of a process recognition investigation. In the compositional data analysis framework, the problem of censored data was recognized early (Aitchison, 1986). Martin-Fernandez et al. (2003) discusses various replacement options based on the nature of the censored data. Recognizing the difference between missing values and censored data is crucial in deciding how a replacement value, if any, should be estimated. More recently, Hron et al. (2010) describes a method based on neural networks that provides estimates of replacement values. This methodology, which is implemented within the R package (R-project, 2011) as **robCompositions** is used in this presentation. Missing values and those reported at less than the detection limit (lld) were imputed using the impKNNa function (Atichison distance option) in

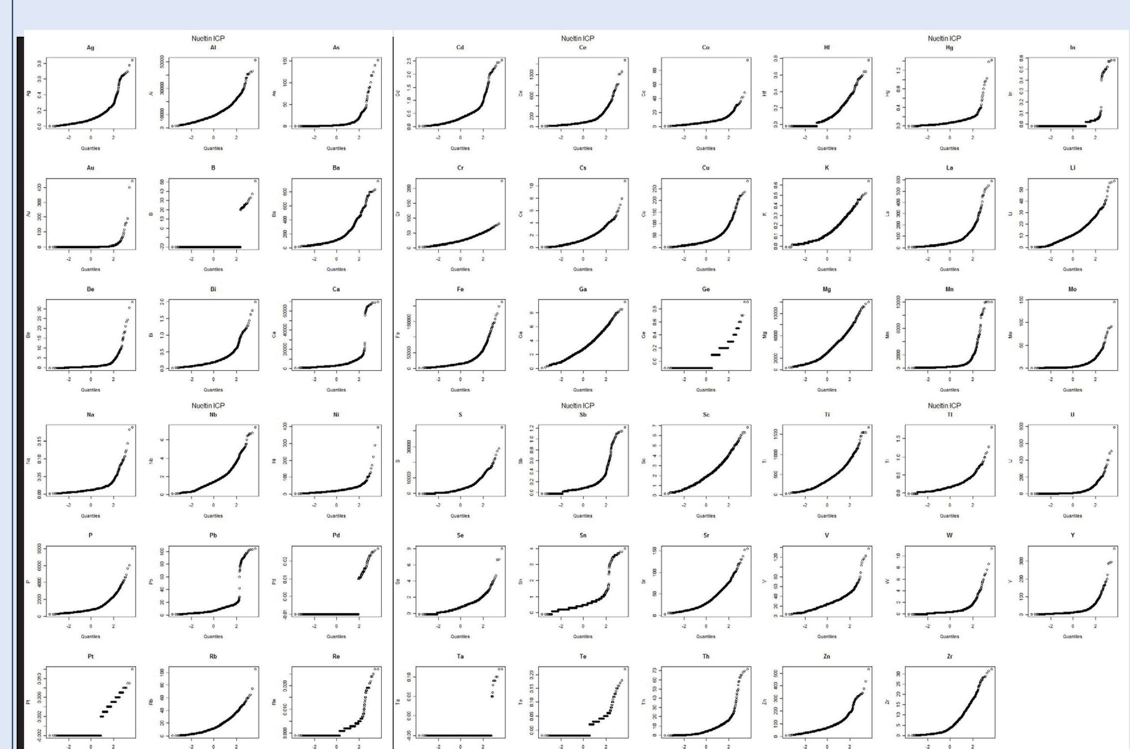


Figure 4. Q-Q plots of the elements. These plots are used to identify outliers and the degree of censoring.

Classification and Prediction of Lithologies

This set of data provides an opportunity to test the ability of the lake sediment geochemistry to predict the underlying geology. Geological maps(Eade, 1973a,b) over NTS 65A/B have been used as a classification standard. Each lake sediment sample site was coded with the geological map unit code. These units and the number of lake sediment sites that are located within these units are shown in Table 1. In sheet 65C, the map code was identified as "unknown".

The data were parsed and 8 classes (excluding Quaternary cover) were extracted for which there were a sufficient number of sites for each class (see Table 1). Using the full range of 48 elements an alr transform was carried out on the data. Cerium was chosen as the divisor. and a linear discriminant analysis (**LDA**) in R was carried out. The LDA was carried out using a cross-validation procedure of repeated sampling (20 times) to determine an average accuracy of the classification, which is shown in Table 2. A neural network prediction technique was also applied to the data and yielded similar results.

Figure 5a shows a plot of the linear discriminant scores on the first two linear discriminant axes for lake sediment analyses over NTS 65A/B. The observations are shown by colour and symbol to reflect the underlying geology associated at each point. Although there is overlap between the various lithologies, there are some distinct trends in the results. Archean carbonates and tonalitic rocks (relative Ca enrichment) occur along the positive LD2 axis. The distinctive chemistry of the Nueltin granite (Pp-Ng) extends along the Ld1 axis. Table 2 shows the accuracy of prediction for the 8 map codes. Archean carbonates have the highest accuracy in prediction followed by the Nueltin and Hudson granites. Other units vary from 28 to 45 percent in prediction accuracy. These accuracies are shown in Figures 6a-h where the predicted probabilities for each map unit were imaged the **gstat** package in R.

The lake sediment sites from NTS 65C where then classified using the linear discriminant functions derived from the known geology of NTS 65A/B. The results of the prediction are shown in Figure 5b where the predicted samples are displayed as red dots. There is a distinctive trend of lake sediment compositions along the LD1 axis that indicate that many of the samples have characteristics of the Nueltin granite (Pp-Ng). Other units that have been predicted in NTS 65C include Ar-dt (diorite), Ar-s (sediments), Ar-t (tonalite) and Pp-Hu (Hurwitz group sediments). The overall correspondence of the predicted lithologies with the geology of Figure 3 is reasonably good. Of particular interest is the prediction of the Nueltin granite (Pp-Ng, Figure 6h) in NTS 65C. The prediction of this unit is significant in terms of the use of lake sediment geochemistry as a predictive mapping tool in areas where the geology is poorly known.

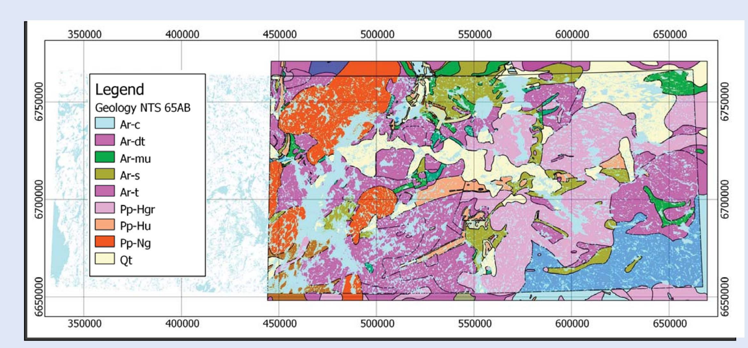


Figure 3. Geologic maps over NTS 65A/B(Eade, 1973a,b).

Table 1 Map units in NTS 65A/B

Legend	#Sites	
Ar_mu	50	undifferentiated mafic volcanic rocks
Ar_c	131	carbonate
Ar_dt	266	diorite
Ar_t	221	tonalite
Ar_s	111	sediments
Pp_Hgr	266	Hudson granite
Pp_Hu	49	Hurwitz sediments
pp_Nq	178	Nueltin Granite
Qt	189	Quaternary

Table 2 Classification Accuracy

Overall Accuracy (%) 58.7

	Ar-c	Ar-dt	Ar-mu	Ar-s	Ar-t	Pp-Hgr	Pp-Hu	Pp-Ng	Qt
Ar-c	107	11	0	1	0	11	0	0	1
Ar-dt	23	127	6	9	39	23	3	5	31
Ar-mu	3	10	14	10	5	3	1	0	4
Ar-s	10	5	4	50	14	13	3	0	12
Ar-t	7	34	2	4	133	9	5	14	13
Pp-Hgr	12	24	0	5	8	187	2	0	28
Pp-Hu	0	6	1	5	6	4	22	0	5
Pp-Ng	0	8	0	0	21	2	1	137	9
Qt	1	28	4	10	18	32	5	11	80

Percentage Classification Accuracy

	Ar-c	Ar-dt	Ar-mu	Ar-s	Ar-t	Pp-Hgr	Pp-Hu	Pp-Ng	Qt
Ar-c	**81.7**	8.4	0.0	0.8	0.0	8.4	0.0	0.0	0.8
Ar-dt	8.7	**47.7**	2.3	3.4	14.7	8.7	1.1	1.9	11.7
Ar-mu	6.0	20.0	**28.0**	20.0	10.0	6.0	2.0	0.0	8.0
Ar-s	9.0	4.5	3.6	**45.1**	12.6	11.7	2.7	0.0	10.8
Ar-t	3.2	15.4	0.9	1.8	**60.2**	4.1	2.3	6.3	5.9
Pp-Hgr	4.5	9.0	0.0	1.9	3.0	**70.3**	0.8	0.0	10.5
Pp-Hu	0.0	12.2	2.0	10.2	12.2	8.2	**44.9**	0.0	10.2
Pp-Ng	0.0	4.5	0.0	0.0	11.8	1.1	0.6	**77.0**	5.1
Qt	0.5	14.8	2.1	5.3	9.5	16.9	2.7	5.8	**42.3**

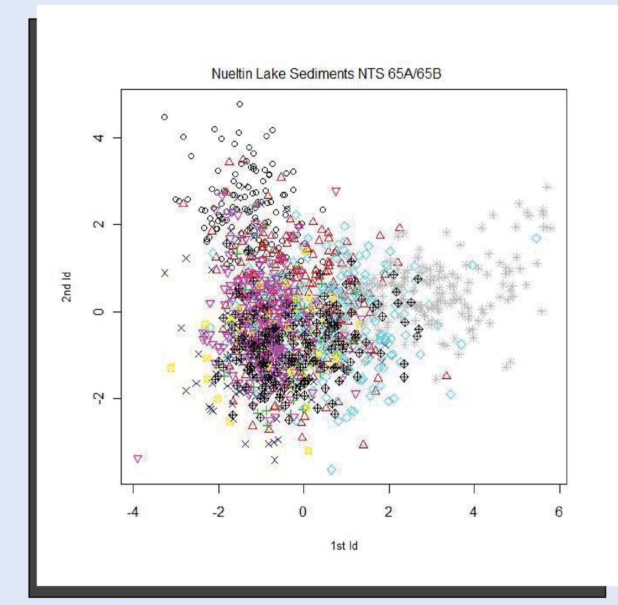
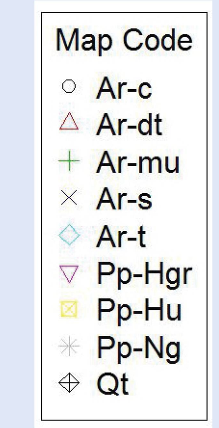


Figure 5a. Linear discriminant plot of LD1-LD2 for lake sediment samples in NTS 65A/B. Lithologic distinction is evident in this plot.



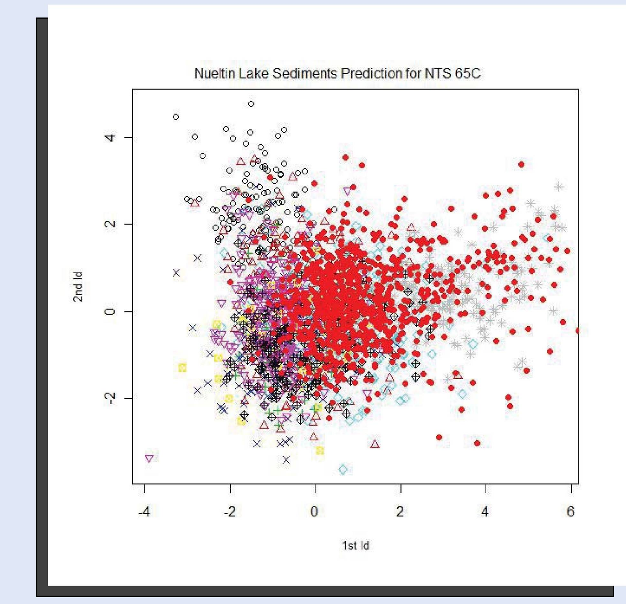


Figure 5b. Linear discriminant plot of LD1-LD2 for lake sediment samples in NTS 65C overlain on the prediction results of Figure 5a.

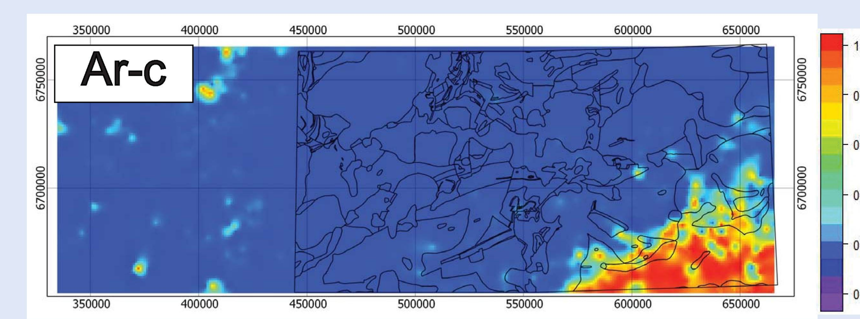


Figure 6a

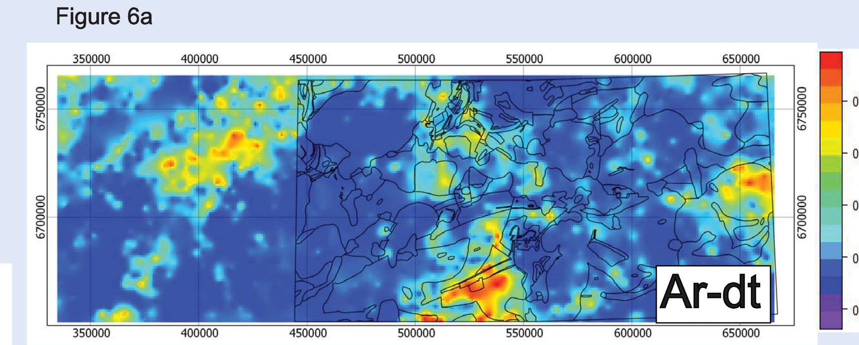


Figure 6b

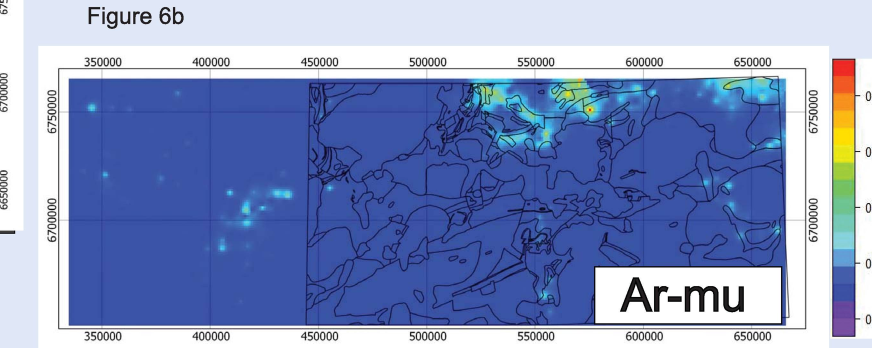


Figure 6c

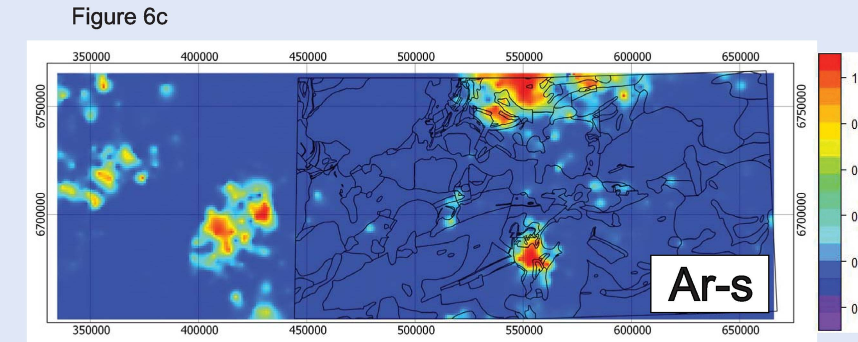


Figure 6d

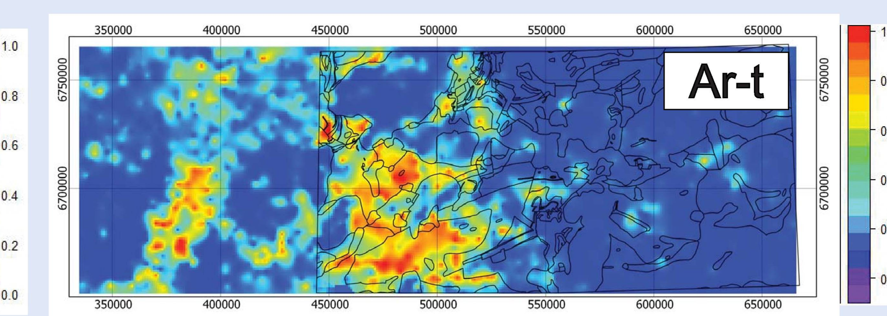


Figure 6e

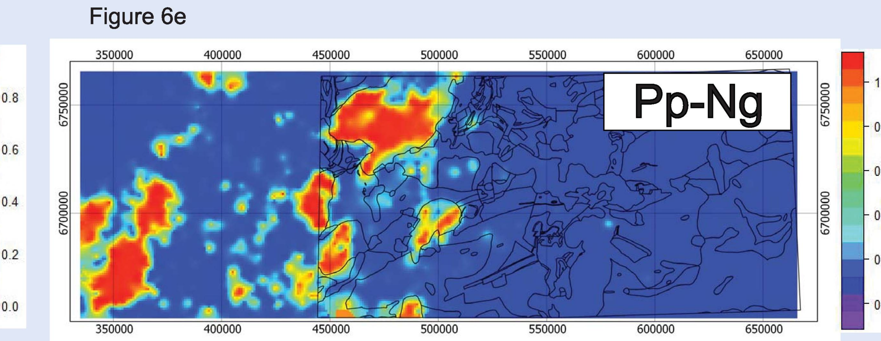


Figure 6f

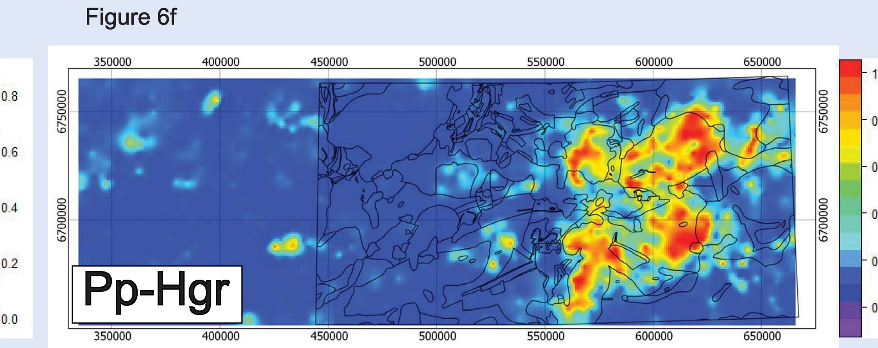


Figure 6g

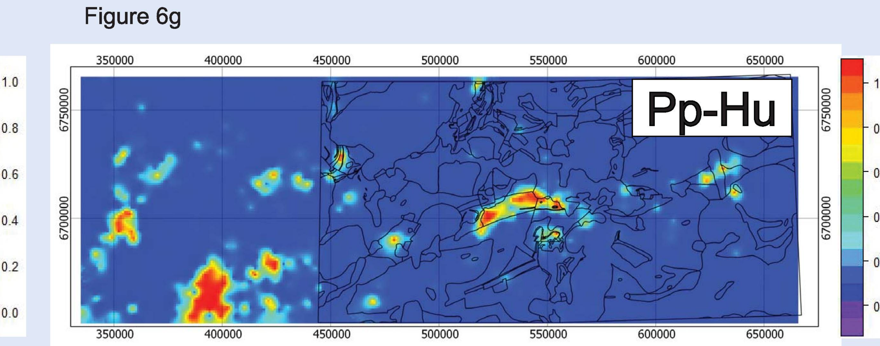


Figure 6h

Figure 6a-h. Interpolated images of posterior probabilities for 8 major lithologies in NTS sheets 65A/B/C. These images correspond closely with the mapped lithologies shown in Figures 2 and 3.

Estimating Potential U/Th Mineralization

Estimating the potential of U/Th mineralization can be done through the application of regression techniques. Principal component analysis is a useful technique that identifies significant trends in the data, within the first few components and these trends are typically associated with underlying lithologies (Grunsky, 2010). The regression of U and Th against the first five principal components derived from the lake sediment survey data provides a potentially useful means for separating background U and Th from U and Th that may be associated with rare events (under-sampled). The left side of Figure 7 shows a plot of predicted versus observed U and Th data. The right side of the plot shows a quantile-quantile plot of the difference (residual) of the observed versus predicted values. These residual values are plotted in Figure 8 where elevated U and Th values appear to be associated with the Nueltin and Hudson (Pp-Ng, Pp-Hgr) granites in NTS 65A/B and the predicted Nueltin granite in NTS 65C. NUMIN occurrences are also shown in Figure 8 where Cu/Au/U/Th/REE occurrences are associated with the Nueltin granite.

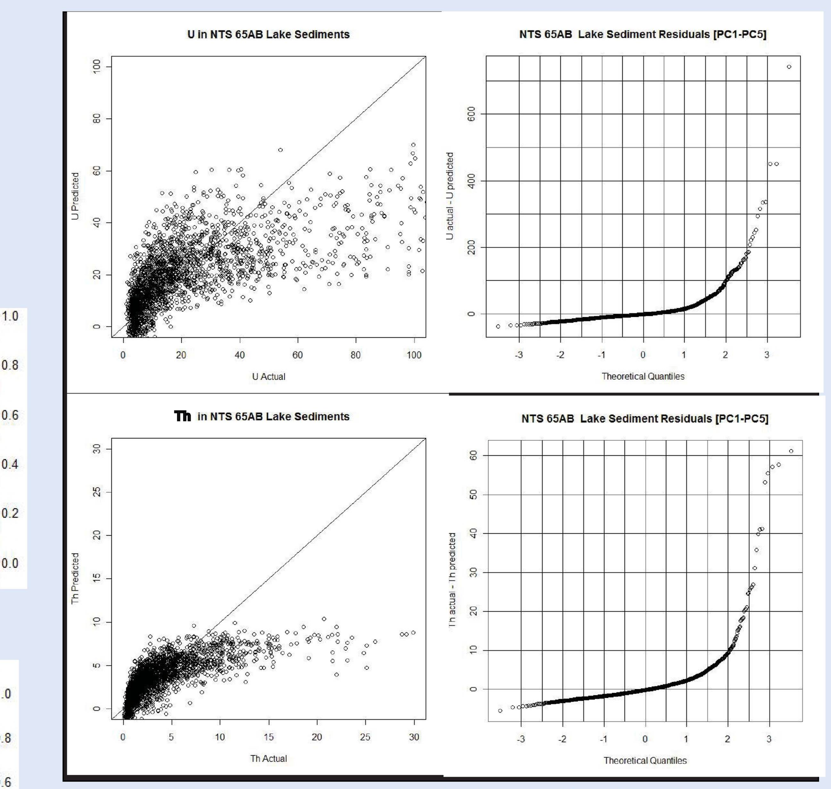
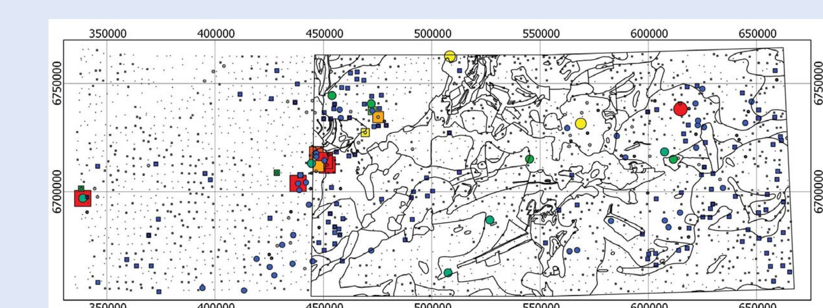


Figure 7. Observed versus predicted values for U and Th. Predicted values are based on a linear regression of U and Th values against the first five principal components.



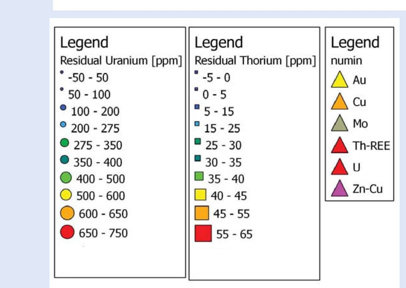


Figure 8. Mapped residuals for U and Th based on the values shown in Figure 7. Elevated residual values of U and Th coincide with the Nueltin and Hudson granites (Pp-Ng & Pp-Hgr) that is observed in NTS 65A/B and predicted in NTS 65C. Commodities from NUMIN are also shown on the map.

Conclusions

This poster summarizes the procedures used to evaluate a lake sediment geochemical survey dataset to enable regional geochemical interpretation. Through the application of data adjustment procedures, compositional data analysis, and the application of statistically based classification procedures, we can successfully interpret compositional (geochemical) data for the purposes of regional geological mapping and estimation of potential mineralization. Based on the lake sediment geochemistry, which represents redeposition of glacial material, the close correspondence of the predicted geology with the mapped geology suggests that glacial transport has not been extensive in this area.

Using multivariate statistical methods such as principal component analysis enables the separation of background and anomalous geochemistry through the calculation of residual values and may be a useful tool in mineral exploration strategies.

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NUMINhttp://nunavutgeoscience.ca/numin_e.html

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