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Targeted Geoscience Initiative 4: Increasing Deep Exploration Effectiveness

uOttawa

Principal Component Analysis of the Compositions of Sandstones Overlying Phoenix Uranium Deposits

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Introduction

The Phoenix deposits, located in the eastern Athabasca Basin (Fig.1), currently have resources of 52.3 M lbs (indicated) and 7.6 M lbs (inferred) U_3O_8 (Roscoe, 2012). They consist of the A, B, C and D deposits at ca. 400 meters depth. The deposits occur both at the unconformity and along steeply dipping fault zones within the basement.

In the fall of 2013, a Principal Component Analysis (PCA) was applied to evaluate the elements spatially and genetically associated with the uranium mineralization. The results of this analysis may be useful in exploration for deeply buried uranium deposits.

Objectives

(1) To evaluate element assemblages that can indicate the uranium mineralization at depth,
(2) To obtain a vertical pattern of PCA scores of sandstones that are likely associated with uranium mineralization at depth.

Methodology

The PCA was carried with R, a language and environment for statistical computing and graphics. A method of PCA known as simultaneous RQ-mode principal component analysis (Zhou et al. 1983) was applied, which has the advantage of presenting the principal component scores of the observations (samples in this study) and the variables (elements in this study) at the same scale. This permits plots of the observations and variables on the same diagram.

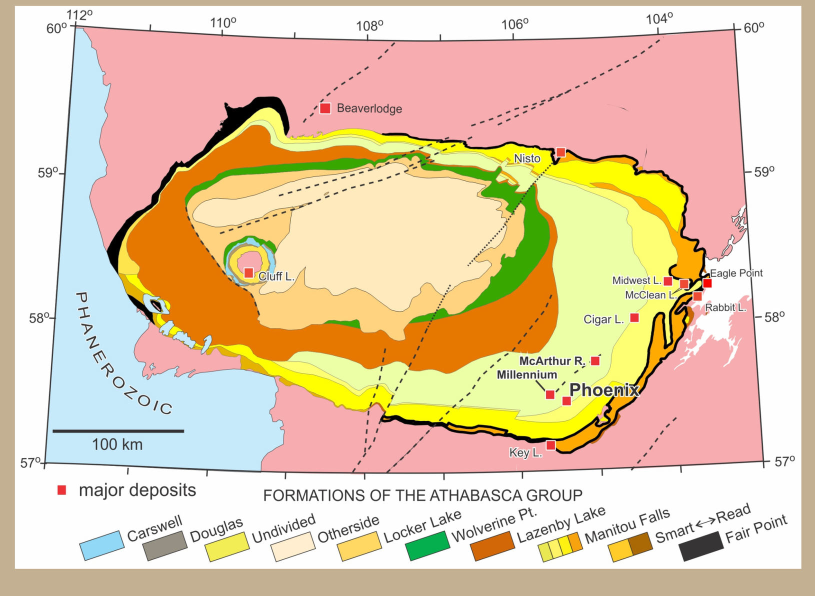

Fig 1: Geological map of the Athabasca Basin, northern Saskatchewan, Canada (Simplified after Jefferson et al., 2007). The Phoenix deposit is located in its southeast corner.

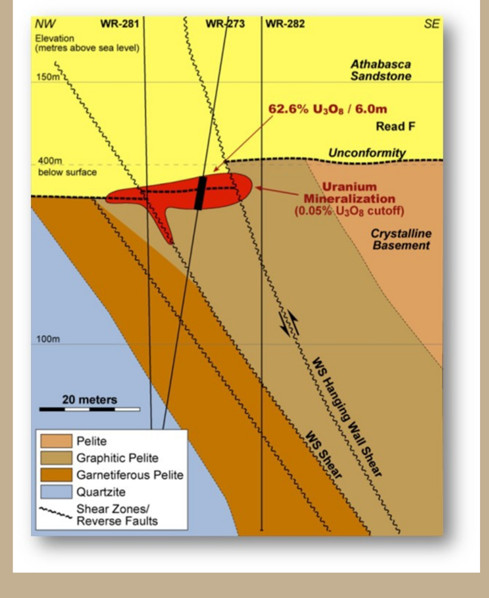

Fig 2: Schematic vertical section showing the geology of the Phoenix deposits. (modified after Gamelin et al., 2010)

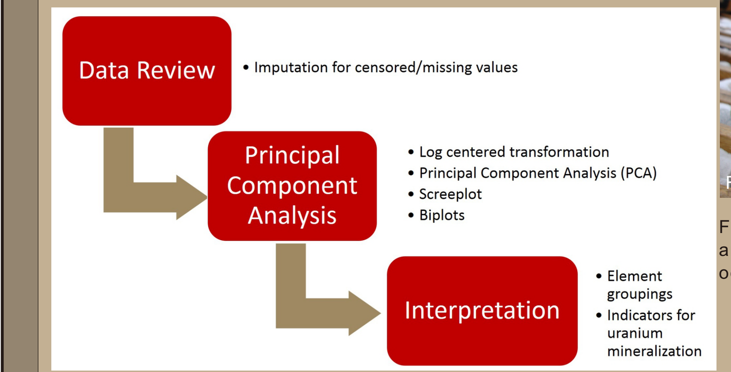

Fig 3: The basic work flow of Principal Component Analysis

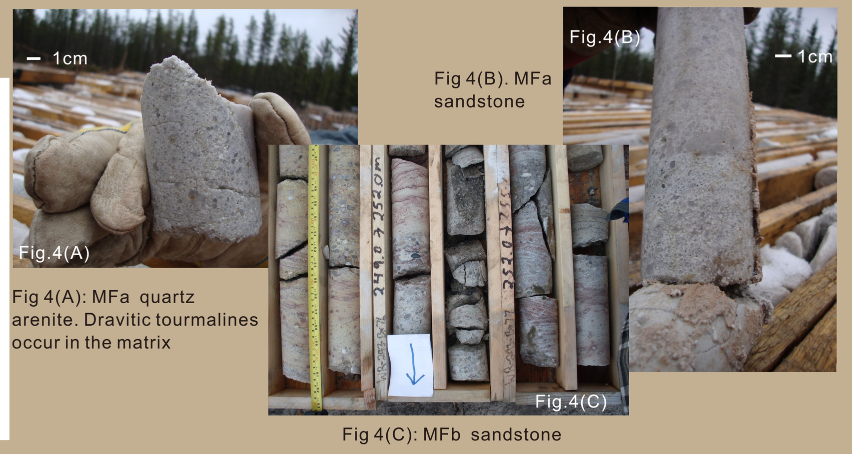

Fig 4: Photographs of sandstones overlying the Phoenix deposits

Results

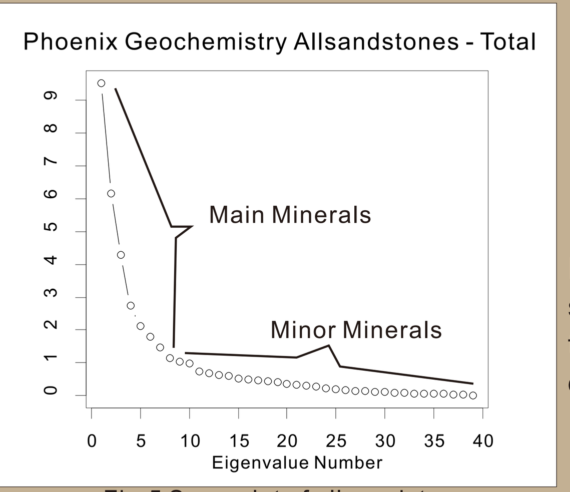

Fig.5 Screeplot of all sandstones

Eigenvalue							
	PC1	PC2	PC3	PC4	PC5	PC6	PC7
λ	9.52	6.15	4.29	2.74	2.12	1.80	1.46
%	24.43%	15.78%	11.00%	7.02%	5.43%	4.61%	3.74%
Σ	24.43%	40.21%	51.21%	58.23%	63.66%	68.27%	72.01%

Table. 1

Fig 5 and Table 1: Eigenvalues of components (all sandstones) are shown for the first seven components only, which accounts for more than 72% of the variation in the data. The accompanying screeplot displays the successive eigenvalues for all of the components.

Fig. 6: Samples and variable scores are projected on to the PC1-PC2 axes, which explain 40.2% of the total variation in the data. The Figure shows distinct groupings between the three sandstone units (MFa, MFb, MFc). Relative U-Yb-Dy-Er-Y-Pb-Ho enrichment occurs along the positive PC1 axis and is associated with the overlap of the MFa, MFc and MFd units. Relative enrichment of Nd-Sm-Cr-La-Pr-Gd-Eu appears to be exclusively associated with the MFa unit. The enrichment of U and REE appears to be inversely associated with Fe-K-Mn-Th-Ti-Al, which may represent oxide minerals.

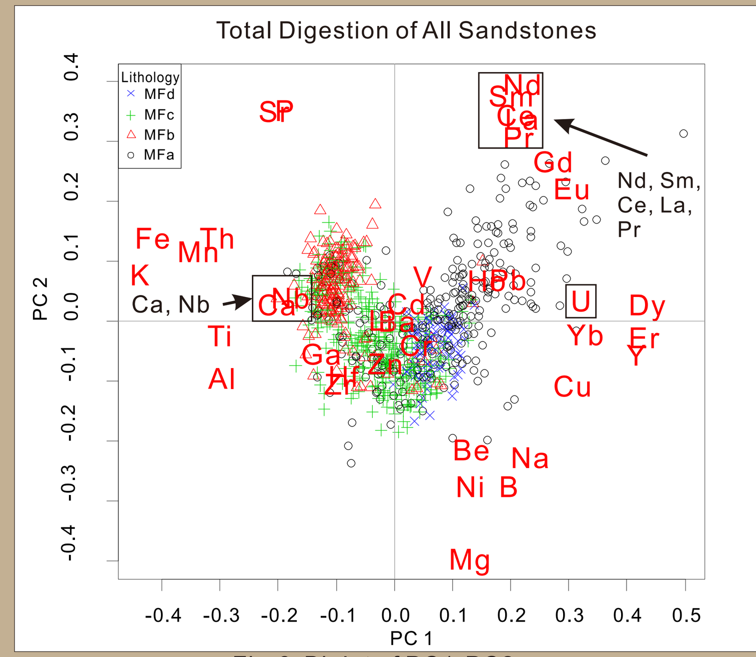

Fig.6 Biplot of PC1-PC2

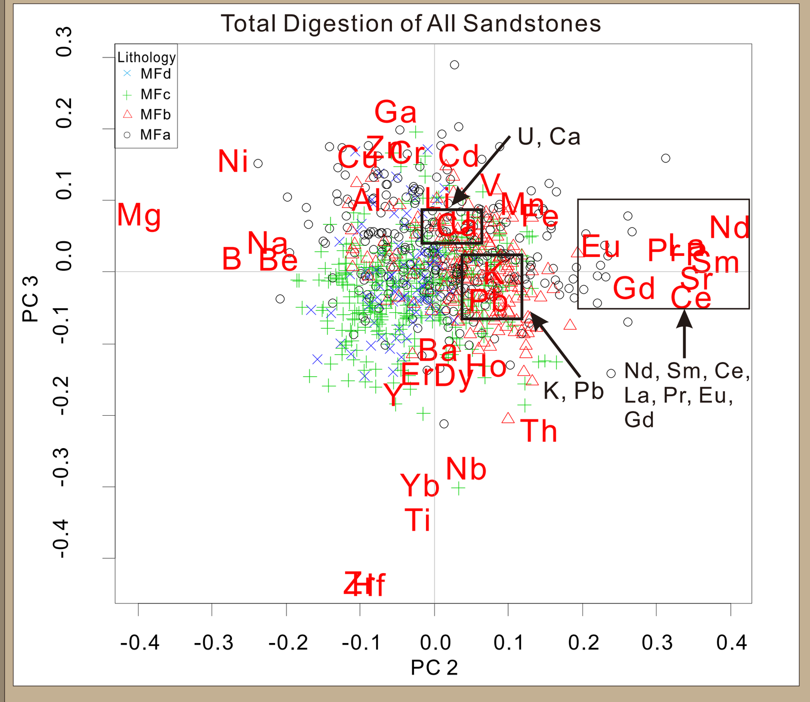

Fig.7 Biplot of PC2-PC3

Fig.7: The biplot of PC2-PC3 shows LREE enrichment along the positive PC2 axis; mostly with the MFa unit. Heavy REEs(Yb-Ho-Y) occur together with high-field strength elements (Zr,Hf, Nb, Tr), along the negative part of the PC3 axis and appear to be associated with MFc, MFa and MFb units, although the association is weak, with only a few sample exhibiting this feature.

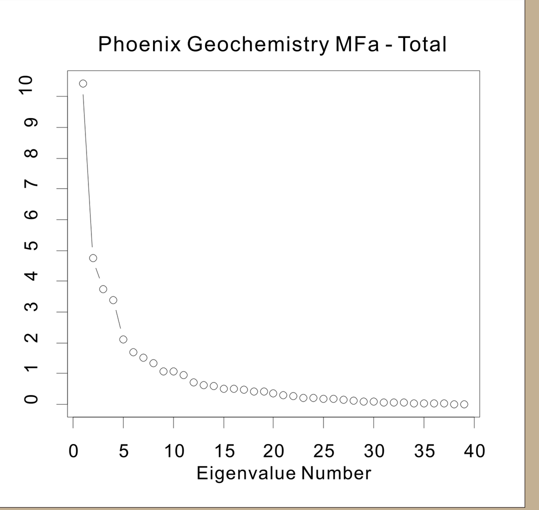

Fig.8 Screeplot of MFa

Eigenvalue							
	PC1	PC2	PC3	PC4	PC5	PC6	PC7
λ	10.43	4.77	3.75	3.39	2.12	1.70	1.52
%	26.84%	12.27%	9.66%	8.73%	5.45%	4.37%	3.92%
Σ	26.84%	39.10%	48.76%	57.49%	62.94%	67.31%	71.23%

Table. 2

Fig 8 and Table 2: The eigenvalues of components in MFa are shown for the first seven components only, which accounts for more than 71.23% of the variation in the data. The accompanying screeplot displays the successive eigenvalues for all of the components.

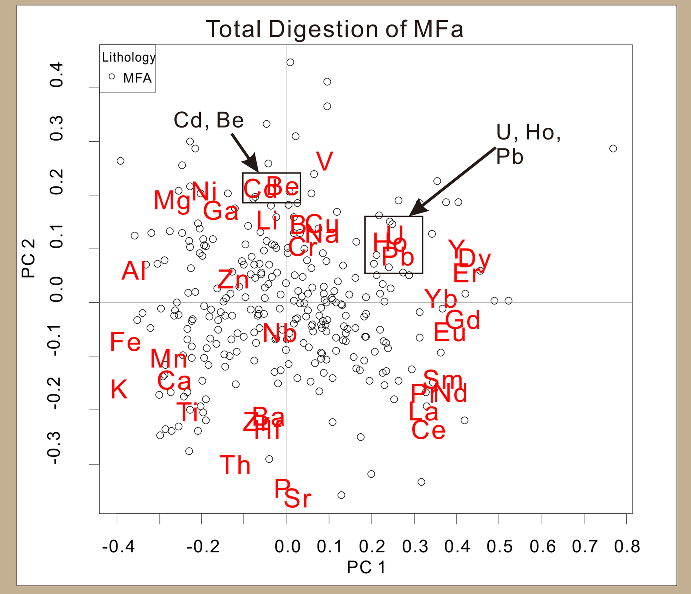

Fig.9 Biplot of PC1-PC2

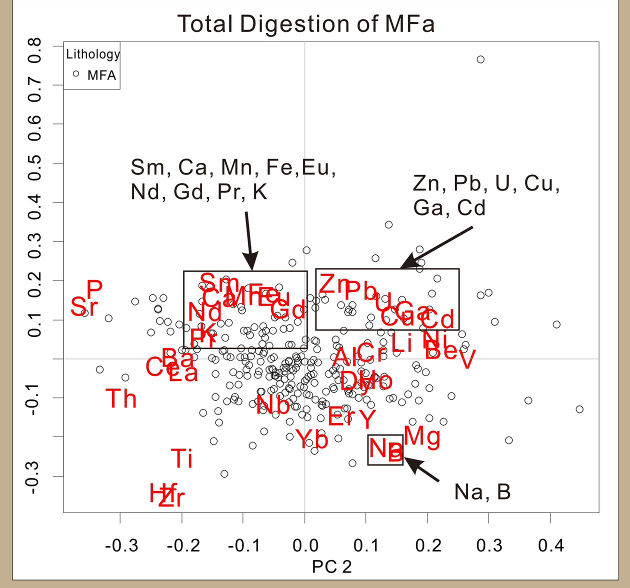

Fig.10 Biplot of PC2-PC3

Fig.9: A biplot of the PC1-PC2 applied to MFa indicates that there is a relative enrichment of U, Y and HREEs along the positive PC1 axis. This enrichment trend is inversely associated with relative enrichment of Al-Mg-Ni-Ga-Zn-Fe-K-Mn-Ca (negative PC1 axis) that likely reflects the presence of sudoite (Mg, Al, Zn, Ga).

Fig.10: The biplot of PC2-PC3 shows an association of U-REE and alteration mineralogy (Al-Mg-Zn-Ga) in addition to Na.

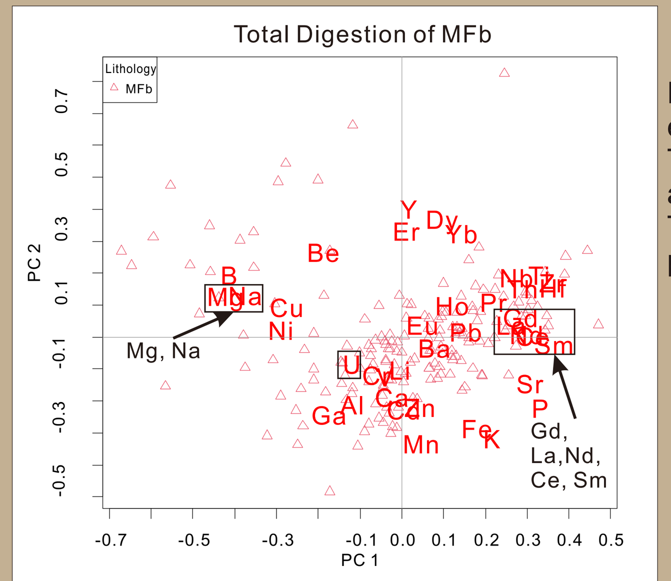

Fig.11 Biplot of PC1-PC2

Fig.11: The biplot of PC1-PC2 indicates relative enrichment of REE's along the positive PC1 axis. There is no relative U enrichment with this association. However, there is a positive HREE-Th-Zr-Ti-Nb association that may reflect the presence of detrital heavy minerals.

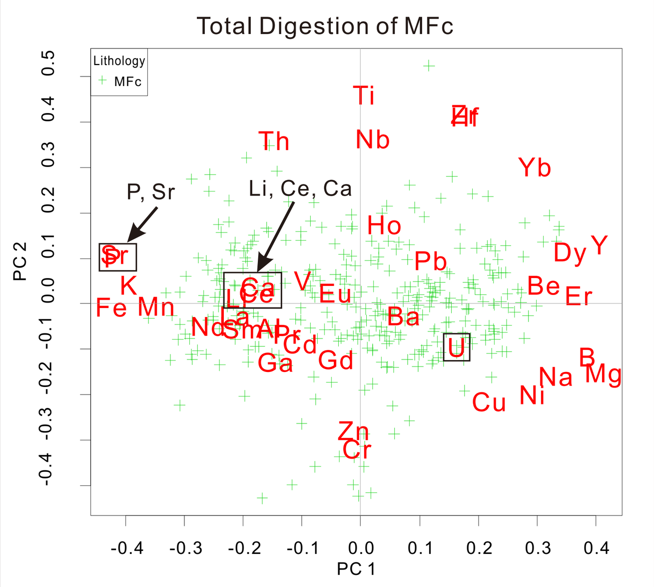

Fig.12 Biplot of PC1-PC2

Fig.12: Relative U-Pb-Y-Dy-Er-Yb-Ho-Hf-Zr-Er-Be and B-Ni-Na-C-B-Mg- enrichment occurs along the positive PC1 axis. This indicates REE and U-Pb association with dravitic tourmaline (B, Na).

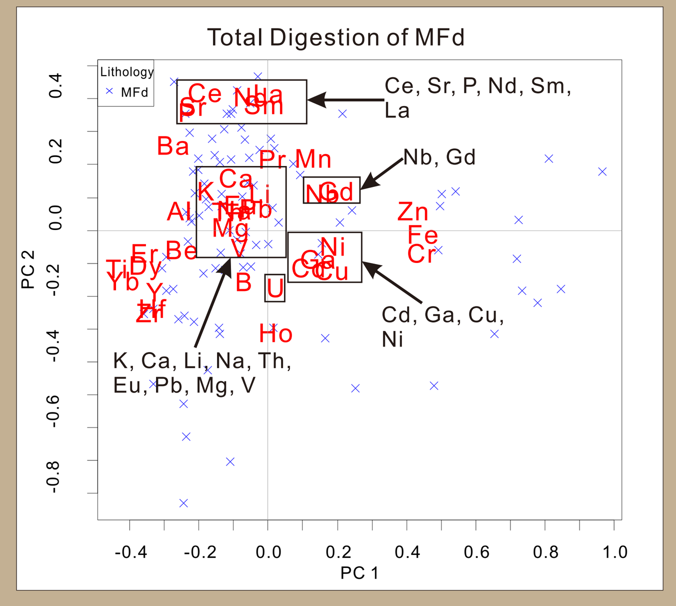

Fig.13 Biplot of PC1-PC2

Fig.13: The biplot of PC1-PC2 for the unit MFd shows relative enrichment of HREE elements along the negative PC1 axis and lighter REE's along the positive PC2 axis. U and Pb do not contribute to the signature. Relative U-Pb enrichment is associated with positive PC5 scores (not shown) but with no relationship with the REE's.

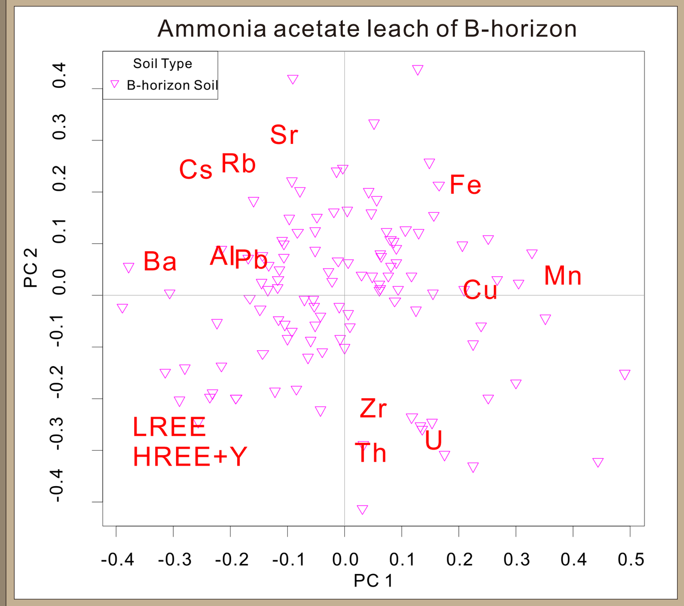

Fig.14 Biplot of PC1-PC2

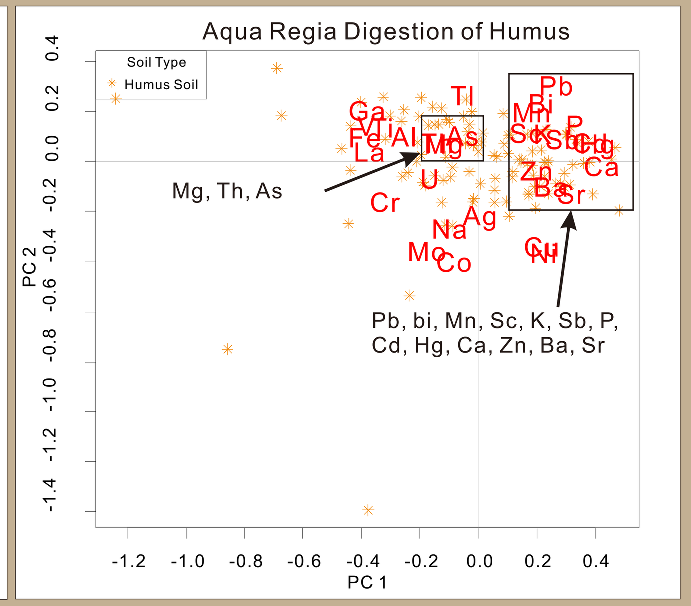

Fig.15 Biplot of PC1-PC2

Fig.14: The PC1-PC2 biplot of B-horizon soils shows relative REE+Y-Zr-Th-U enrichment. This association reflects a trend of detrital minerals, however, the nature of the weak digestion makes this interpretation questionable. The association may be due to adsorption from the elements being liberated from groundwater and/or conditions that lead to the breakdown of heavy detrital minerals.

Fig.15: The biplot of PC1-PC2 for the humus geochemistry indicates that there is a weak association of U with Mg-Th-Al-Cr.

Summary and Ongoing Work

The PCA shows distinct geochemical properties of different sandstone units, and elemental groups listed below:

Those positively correlated with U: V, Cr, HREE+Y, LREE, Cu, Be, Ni, B, Na, Mg, Li, K, Pb.
Those inversely correlated with U: Ti, Zr, Hf, Al, Th.
Those positively correlated with U in MFa sandstones but inversely in soil: Pb, V, K.
Those inversely correlated with U in MFa sandstones but positively in soil: Th, Zr.

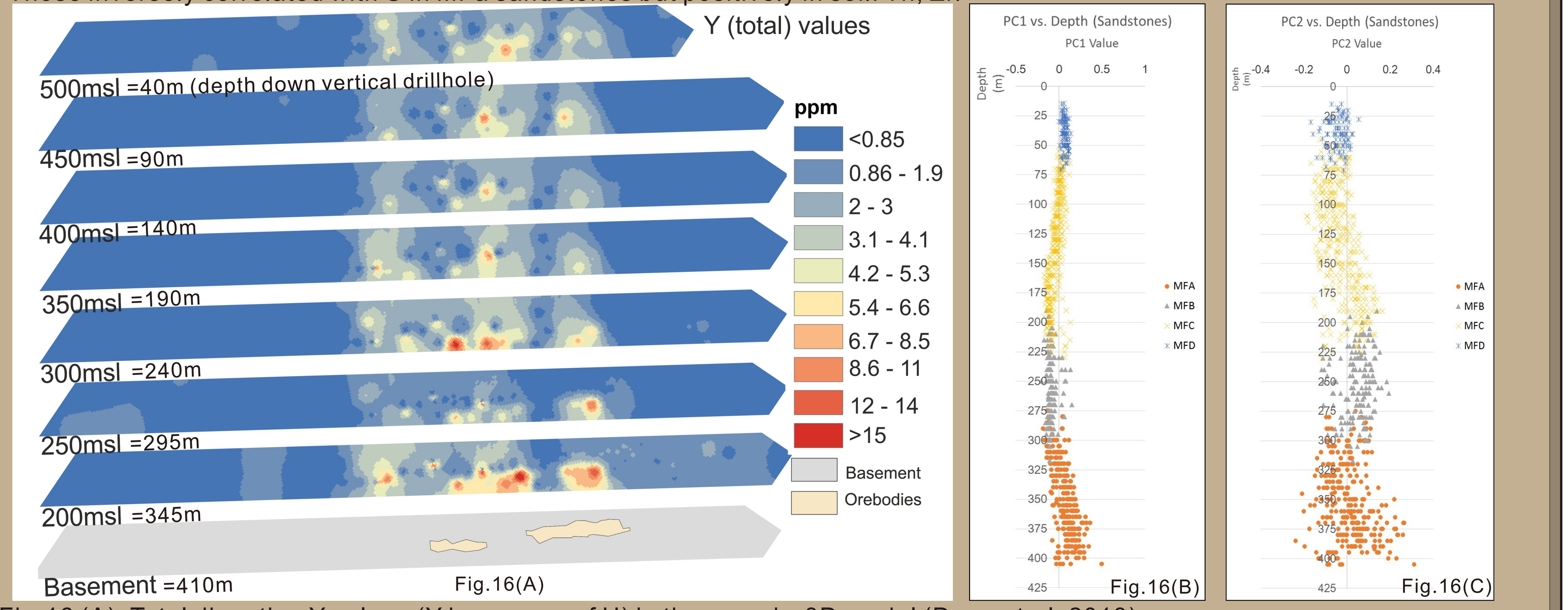

Fig.16 (A): Total digestion Y values (Y is a proxy of U) in the pseudo-3D model (Dann et.al, 2013).
Fig.16 (B) and (C): Vertical variations of PC1 and PC2 values in sandstones. The profile shows generally high PC1 or PC2 values in the deeper sections. Potassium, Dy, Er, Fe, Y, Mn, Yb, U, Th and Cu are top 10 dominate elements accounting for the variation in PC1, and Mg, Nd, Sm, P, Sr, Ce, La, Pr, Ni and B in PC2.
Since PC1 and PC2 contain 40.21% of the total variation, they provide sufficient information on the element groupings and the two represent indicators for the uranium mineralization in the Phoenix deposits.
Ongoing work: Linear discriminant analysis to predict the areas underlain by buried mineralization in the vicinities of the Phoenix deposits.

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