Elemental Assemblages in Sandstones Overlying the Phoenix U Deposits and REE-rich Maw Zone, Athabasca Basin, Saskatchewan

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Introduction

Denison Mine's Phoenix deposits, with current resources of 52.3 M lbs (indicated) and 7.6 M lbs (inferred) U_3O_8, occur both at the unconformity and along steeply dipping faults in the basement at ~ 400 m depth (Roscoe et al., 2012). Sandstones above the deposits are variably altered by kaolinite, illite/muscovite, clinochlore, sudoite and dravitic tourmaline (Gamelin et al., 2010; MacDougall, 1990;Dann et al., 2013).

The Maw Zone, ~ 6 km SE from Phoenix Zone A, with a surface exposure of 200x200 m, forms a breccia pipe from the unconformity to the surface. The zone consists of highly silicified, hematitized, dravitic tourmaline-rich rocks. The zone does not contain high U (< 0.0031 %), but high REE (< 8.1% TREO), and B (< 2.5%) contents (Agip Canada Ltd, 1985).

Principal Component Analysis (PCA) was applied to evaluate the elements spatially and genetically associated with U and REE mineralization. The results of the analysis may be useful in exploration for deeply-buried U deposits and REE mineralization.

Objectives

(1) To identify elemental assemblages associated with two different styles of mineralization.
(2) To evaluate PCA scores of elements near the surface that are likely associated with U or REE mineralization at depth.

Methods

The analysis used the total digestion data of sandstones. After a centred log ratio transformation of the raw data, the elemental assemblages were evaluated using simultaneous RQ-mode PCA, which has an 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 (*i.e.*, Grunsky, 2009). The first and second components commonly show elemental assemblages, minerals hosting the assemblages, and their distributions. The analysis was carried out with R, a language and environment for statistical computing and graphics.

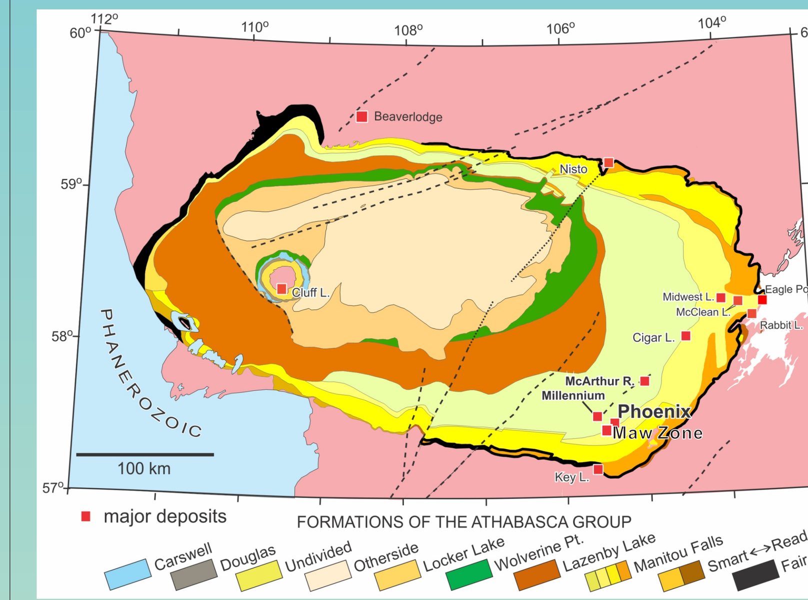

Fig 1: Geological map of the Athabasca Basin, northern Saskatchewan, Canada (after Jefferson et al., 2007). The Phoenix Deposits are located in its SE corner. The Maw Zone is 6 km SW from Phoenix Zone A.

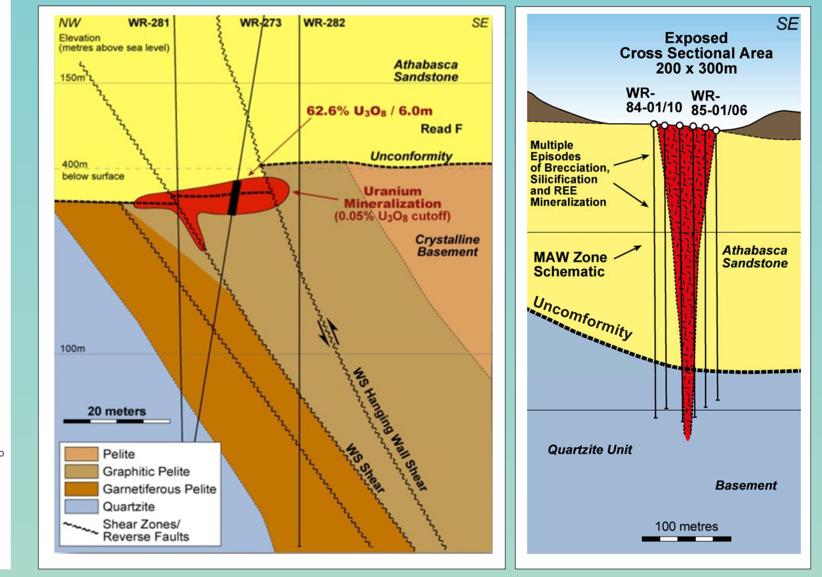

Fig 2: Schematic vertical section showing the geology of the Phoenix Deposits and the Maw Zone. (modified after Gamelin et al., 2010)

Athabasca Group sandstones at Phoenix & Maw (top to bottom): MF=Manitou Falls Formation, MFd=Dunlop member, MFc=Collins member, MFb=Bird member, and RD= Read Formation.

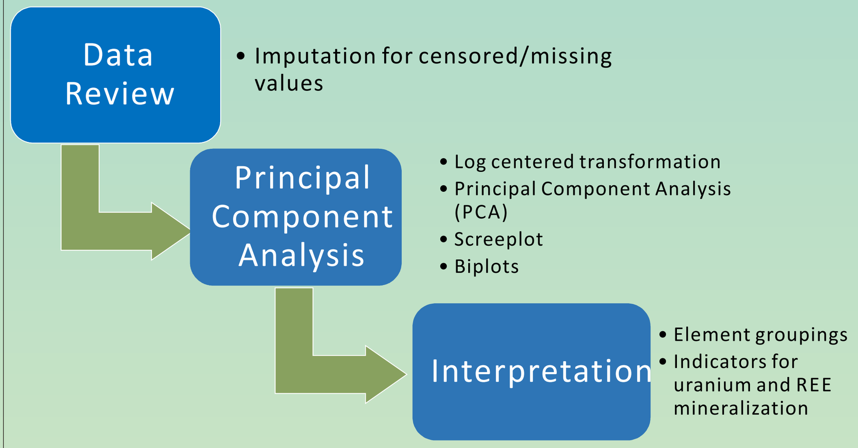

Fig 3: The basic work flow of Principal Component Analysis

Fig 4(A): RD Fm quartz arenite. Dravitic tourmalines occur in the matrix

Fig 4(C): MFb sandstone

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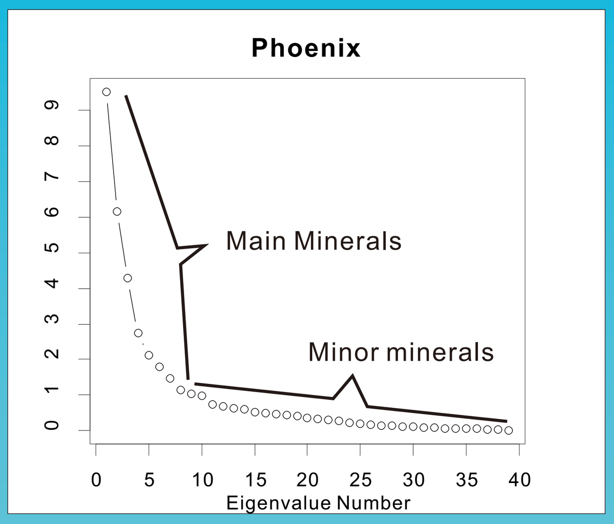
Results



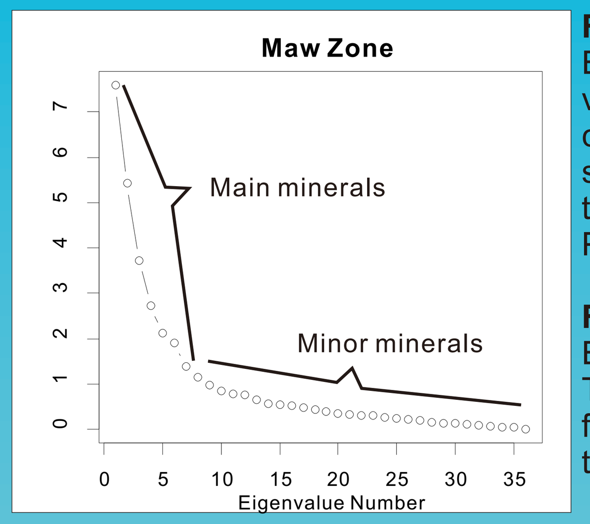


Fig 5: Screeplot of the successive Eigenvalues for all components. The values above 1 represent variations caused by major minerals. The first seven components accounts for more than 72.0% of the variation in the data of Phoenix Deposits.

Fig 6: Screeplot of the successive Eigenvalues for all of the components. The first seven components accounts for more than 72.9% of the variation in the data of Maw Zone.

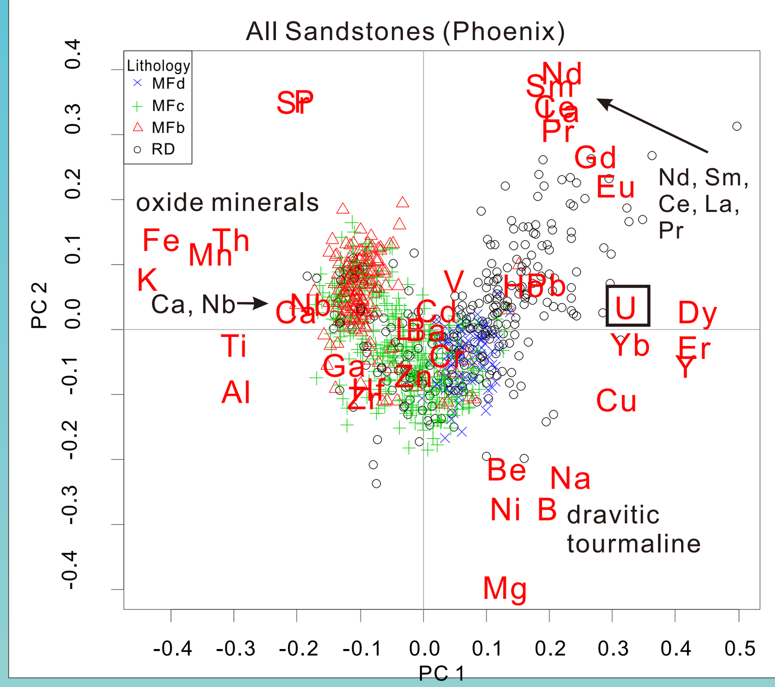


Fig 7 (left): PC1 and PC2 account for 40.2% of the total variation. Three lower sandstone units (RD, MFb, MFc) show distinct geochemical features. Relative enrichment of U-Y-HREE is shown along positive PC1 axis. This enrichment is observed in the RD, MFc and MFd units. Relative enrichment of LREE appears to be exclusively associated with the basal RD Fm. The enrichment of U and REE is inversely associated with Fe-K-Mn-Th-Ti-Al, which likely represent oxides and illite. The enrichment of Na-B-Mg indicates the occurrence of dravitic tourmaline.

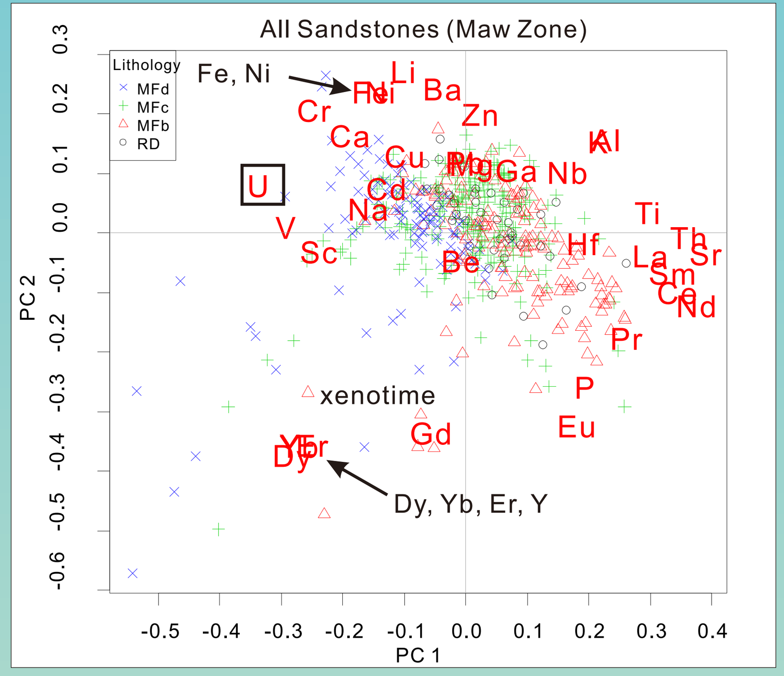
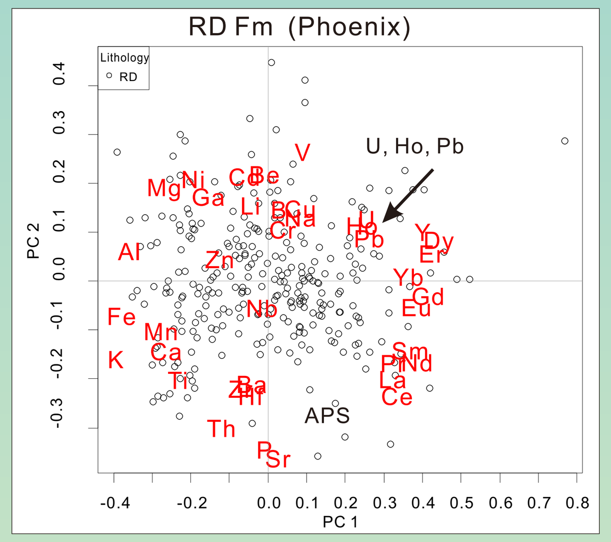


Fig 8 (right): PCA of the Maw Zone. PC1 and PC2 account for 36.3% of the total variation of the dataset. Enrichment of HREE-Y is observed along the negative PC2 axis in upper MFb samples, MFc, and MFd. LREE enrichment along PC1 and the intermediate nature of P (between HREE & LREE) may reflect HREE within xenotime and LREE in monazite. Uranium is positively correlated with Fe and V but inversely with LREE, suggesting that APS or monazite (dominant LREE hosts) are not hosting U.



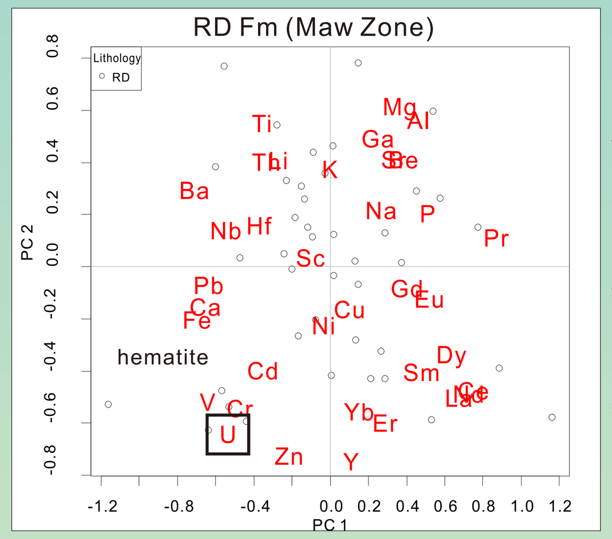
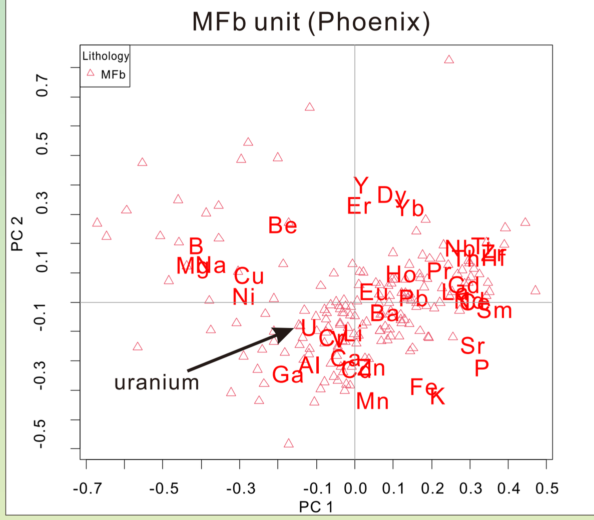


Fig.9 (left): For Phoenix data, relative U-Pb-Y-HREE enrichment is inversely associated with relative enrichment of Al-Mg-Ni-Ga-Zn-Fe-K-Mn-Ca along the PC1 axis. An LREE-P-Sr assemblage may reflect monazite or aluminum phosphate sulphate (APS) minerals while the HREE are grouped with U.
Fig.10 (right):U is associated with V, Cr and exhibits relative enrichment along the negative PC2 axis along with Y and REEs. P is not associated with REEs, potentially indicating a change in the REE mineralogy. In the RD Fm, dominant HREE host is likely uraninite, whereas elsewhere in the system HREE likely phosphates.



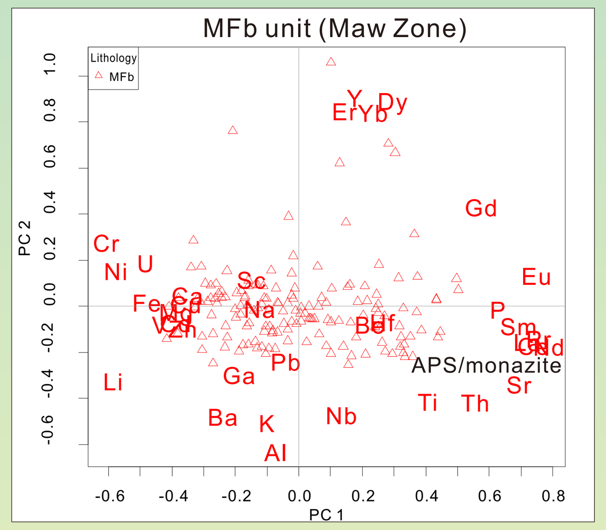
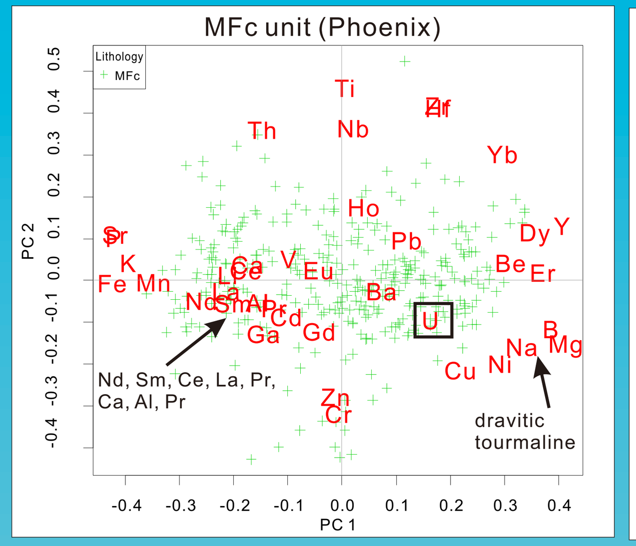


Fig.11 (left): U is inversely associated with REEs. Groupings of LREE-Sr-P suggests presence of APS or monazite, Zr-Th-Nb-Hf detrital phases and B-Mg-Na dravitic tourmaline.
Fig.12 (right): LREE-P-Sr enrichment along PC1 axis indicates the possible occurrence of monazite and/or Sr-rich APS; both of which can be Th-bearing at Maw (Pan et al., 2013). U is grouped with redox-sensitive elements such as Fe, V, Cu, etc.



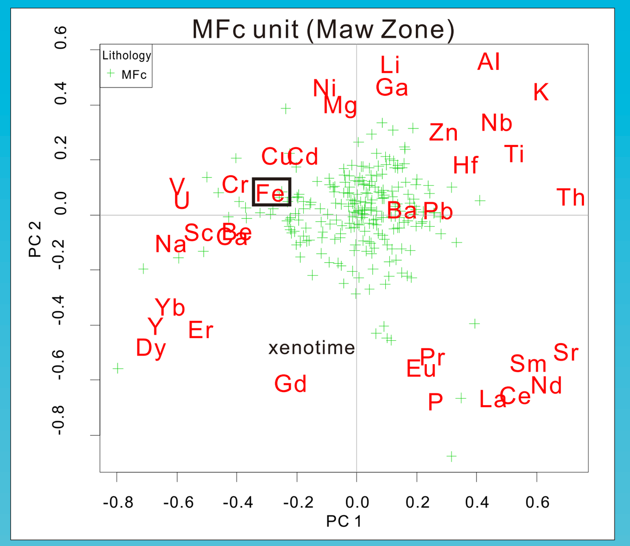
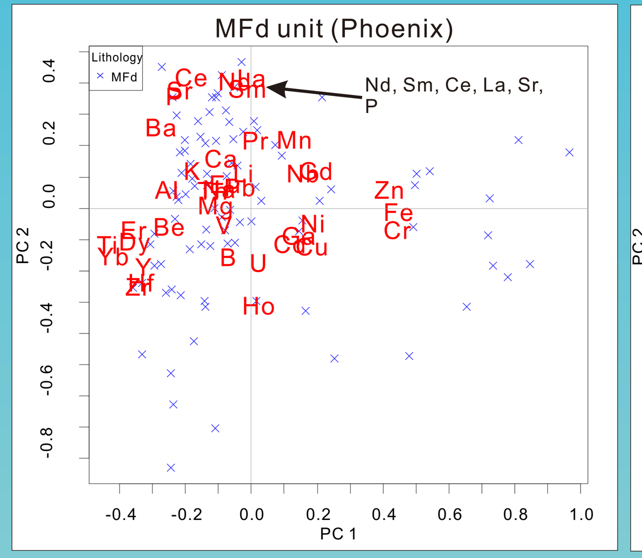


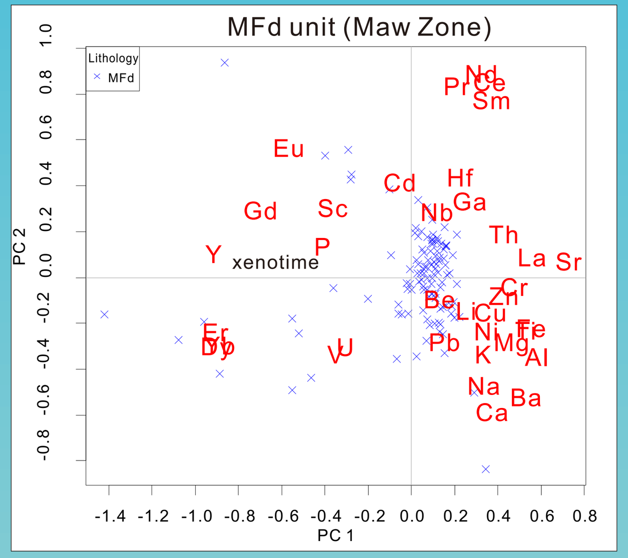
Fig 13 (left): Relative enrichment of U-Pb, Y-HREE, Hf-Zr and B-Ni-Na-Cu-B-Mg occurs along the positive PC1 axis. This indicates REE and U-Pb association with dravitic tourmaline (B-Na-Mg).

Fig 14 (right): U is positively correlated with Fe, Cr, V, Cu. Groupings of Sr-Al-P-LREE and HREE-Y along the negative PC2 axis suggests presence of APS/monazite and xenotime.

Fig 15 (left): Relative enrichment of HREEs along the negative PC1 axis and LREE along the positive PC2 axis. Uranium 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 REEs.

Fig 16 (right): Relative enrichment of Y-HREE-P along PC1 axis may indicates occurrence of xenotime.





Summary

1. For sandstones overlying the Phoenix deposit and Maw zone, each lithological unit (RD, MFb, MFc, MFd) has a distinct elemental assemblage.
2. At Phoenix, U is associated with HREE-Y-B-Na-Mg-Ni-Cr, but inversely correlated with K-Al-Fe-Ti-Th. Relative enrichment of U-Pb-Y-HREE is apparent in the RD Fm, but U decouples from HREE at shallower depths (MFb, MFc and MFd).
3. At the Maw zone, REE+Y enrichment occurs in upper part sandstones (MFb, MFc and MFd). HREE-Y enrichment suggests xenotime as the host of HREEs while LREE-Sr-Th-P may reflect monazite and/or APS minerals.
4. At the Maw zone, the positive correlation between U, Fe, V, Cr suggesting that oxidizing fluids were uraniferous, but the lack of a reductant did not lead to the economic U mineralization (or U precipitation).

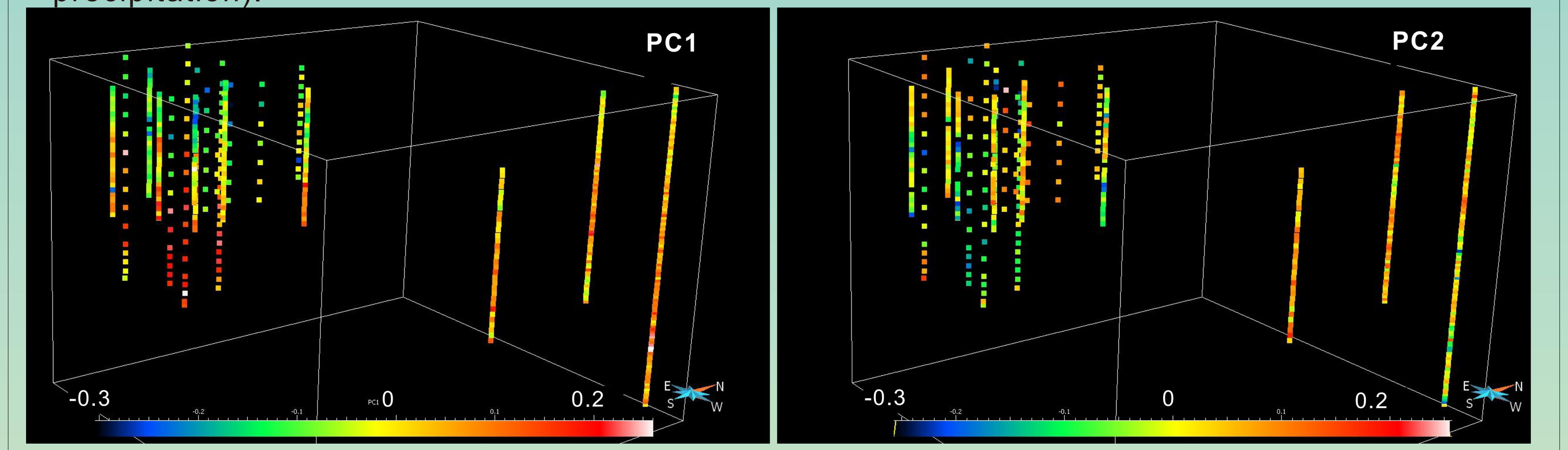


Fig. 17: The 3D diagrams shows the locations of drill holes and scores of PC1 (Left) and PC2 (Right) in the Maw Zone. Strontium, U, Th, LREE (La, Ce, Nd, Sm), Ti, V and Y account for the total variation of PC1 and Y, HREE (Dy, Yb, Er, Gd), Eu, Li, P and Ba for PC2. Negative scores of PC1 and PC2 appear in the upper part. Since HREE show strongly negative scores in PC1 and PC2, this reflects enrichment of xenotime in the upper sandstone unit.

Ongoing work: Linear discriminant analysis of the data and detailed 3D modeling including geological and mineralogical information to predict the areas underlain by buried mineralization.

Acknowledgements

This is a part of the senior author's PhD thesis project. We thank Denison Mines Corp. for supplying the geochemical data and their permission to display the results. We acknowledge a grant to K. Hattori from Natural Resources Canada through the TGI-4 program and a critical review by Eric Potter.

Recommended citation
Chen, S., Hattori, K., Grunsky, E.C., and Liu, Y., 2014. Elemental Assemblages in Sandstones Overlying the Phoenix U Deposits and REE-rich Maw Zone, Athabasca Basin, Saskatchewan; Geological Survey of Canada, Open File 7629, 1 poster. doi:10.4095/295056

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doi:10.4095/295056

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