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PRINCIPAL COMPONENT ANALYSIS AND Mg/Fe RATIOS OF SANDSTONES OVERLYING THE PHOENIX DEPOSITS: IMPLICATIONS FOR URANIUM EXPLORATION IN ATHABASCA BASIN, SASKATCHEWAN

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Introduction

The Athabasca Basin in northern Saskatchewan and Alberta is comprised of fluviatile sandstones of Paleo to Mesoproterozoic age. The Phoenix uranium (U) deposits have typical unconformity- style mineralization in the southeastern margin of the basin (Fig. 1), with indicated resources of 70.2 million lbs U_3O_8 (Roscoe, 2014). The ore occurs along the unconformity between the Athabasca Group sandstones and Paleoproterozoic metasedimentary rocks and also along the WS Shear Zone in the basement (Fig. 2). The deposits occur ca. 450 m below the surface, with no apparent evidence of the mineralization at the surface.
Recent discoveries of deeply seated U deposits, such as Millennium and Centennial at 650–750 m and 800-830 m depth (Roy et al., 2005; Jiricka, 2010), expand the potential for discoveries of more high-grade U deposits concealed beneath thick sandstones. Our study examines the geochemical data of sandstones in the Wheeler River property of Denison Mines, which includes the Phoenix deposits and the U-poor but REE-rich Maw Zone, to determine if geochemical data from shallow sandstones reflect the mineralization at depth.

Objectives

1. To characterize the elemental assemblages associated with the U mineralization of the Phoenix deposits and the REE mineralization in the Maw Zone.
2. To provide geostatistical tools for targeting potential areas of concealed U mineralization.

Methodology

Principal Component Analysis (PCA) is a multivariate procedure to reduce the dimensionality of a dataset with a large number of variables, while retaining the variation in the variables. The raw data was transformed to centered log-ratios and elemental assemblages were evaluated using simultaneous RQ-mode PCA. This study applied methods developed by Grunsky (2001) in the R statistical environment (R Development Core Team, 2008). Detailed methodology is described by Chen et al. (2014a).This study used 4630 sandstone samples with composition data of 39 elements, obtained by near-total three acid digestion. The detailed results can be found in Chen et al (2014b). Mg/Fe atomic ratios are calculated from MgO wt. % and Fe_2O_3 wt. % before interpolation. Inverse distance weighted (IDW) and Kriging interpolations were carried out with Geostatistical Analyst at ArcGIS.

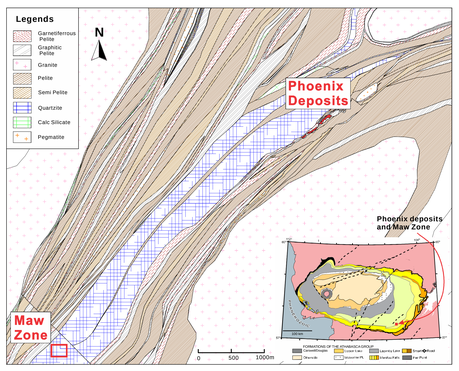

Fig. 1: Basement geological map of the Wheeler River Property. The Maw Zone is 4 km SW from Phoenix Deposit B (modified after Denison Mines, 2014). Inset: Location within the Athabasca Basin, northern Saskatchewan, Canada (after Jefferson et al., 2007).

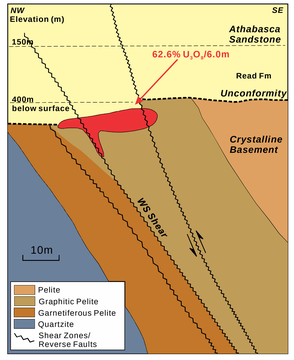

Fig. 2: Schematic vertical section showing the geology of the Phoenix Deposits. (after Gamelin et al., 2010)

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Principal Component Analysis

Eigenvalues are shown in Chen et al. (2014b). Samples and variable scores derived from PCA are projected on to the PC1-PC2 axes of Fig. 3. The two principal components (PC) explain 40.2% of the total variation in the data. Sandstones show relative enrichment of U-HREE-Y-Pb along the positive PC1 axis in RD, MFc and MFd units (Fig.3). Relative enrichment of LREE occurs exclusively in the RD, along the positive PC1 and PC2 axes. The enrichments of U and REE are inversely associated with Fe-Mn-Th-Ti-Al-K, which likely represent oxide minerals (Fe, Mn,Th,Ti) and illite (Al,K).

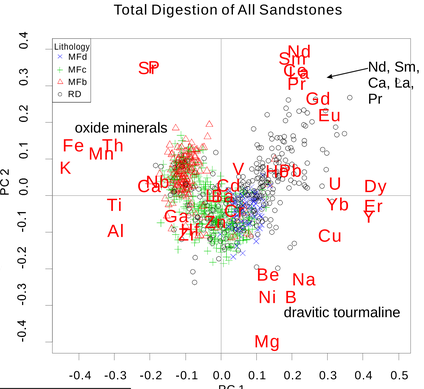

Fig. 3: Biplot of PC1-PC2, Phoenix sandstone dataset. PC1 and PC2 account for 40.2% of the total variability in the data. MFd =, Dunlop member of the Manitou Falls Fm; MFc =, Collins member of the Manitou Falls Fm; MFb =, Bird member of the Manitou Falls Fm; RD = Read Fm.

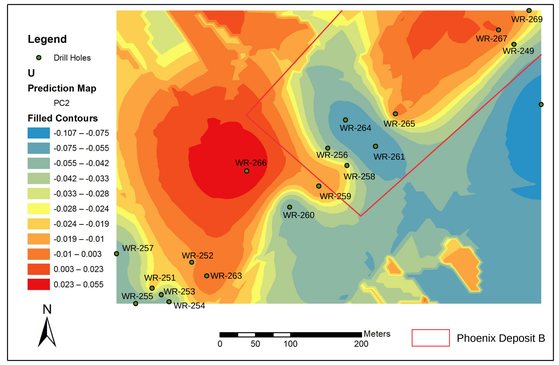

Fig. 4: Kriging interpolation map for PC2 scores of the uppermost sandstone (<40m depth). High PC2 values occur in sandstones from drill holes WR-266, WR-259, WR-263, WR-249, WR-269 and WR-267. Low values occur in sandstones from WR-257, WR-255, WR-251, WR-260, WR-261and WR-264.

By calculating relative contributions of the elements (results not shown), U is the largest contributor to PC2. Therefore, PC2 can represent geological process related to U and its associated elements (REEs-Y-Pb).

PC2 scores of the uppermost sandstone is plotted using Universal Kriging interpolation in Fig. 4.

Hole Number	From (m)	Grade (% U3O8)	Thickness (m)
WR-266	413.5	1.152	3.5
WR-259	397	13.381	6
WR-263	NA	0	0
WR-249	406.4	0.999	2.6
WR-269	408.25	9.094	1.5
WR-267	405	19.963	3.5
WR-265	NA	0	0
WR-257	NA	0	0
WR-255	NA	0	0
WR-251	393.2	0.061	1
WR-260	399.7	0.065	1
WR-261	405	0.05	1
WR-264	399.4	0.481	2.7

Table 1: Phoenix Deposits drill hole intersections (Roscoe, 2012). Drill holes with high PC2 values in the upper sandstones are in red. Drill holes with low PC2 values in the upper sandstones are in blue. NA = Not Applicable (no mineralized intersection).

Table 1 shows drill hole intersections of the Phoenix deposits. Most drill holes located in areas with high PC2 values of the uppermost sandstone intersected significant U mineralization at depth. Most drill holes located in areas with low PC2 values of the uppermost sandstone did not intersect high grade U mineralization at depth .

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Mg/Fe Ratios

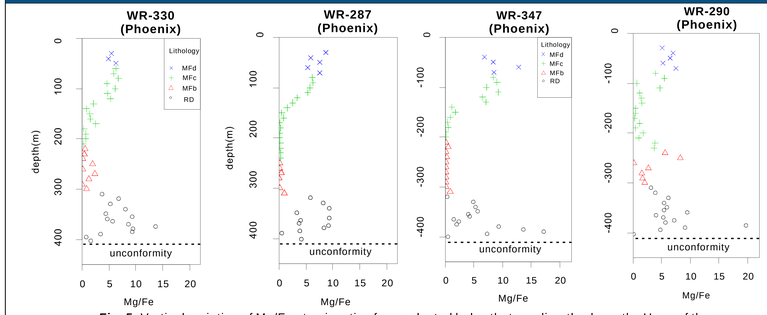

Fig. 5: Vertical variation of Mg/Fe atomic ratios from selected holes that are directly above the U ore of the Phoenix Deposits

Fig. 5 shows the Mg/Fe atomic ratios of sandstone samples from selected drill holes directly above the Phoenix Deposits. The Mg/Fe ratios are high in the uppermost sandstone unit (MFd), which corresponds to regional chlorite trend noted by Earle & Sopuck (1989) and Gamelin et al. (2010). The values decrease sharply in MFc and MFb and increase in RD. High Mg/Fe ratios are not observed in sandstones in U-poor, but REE-rich Maw Zone (Fig. 6) which is 4 km SW to southern end of Phoenix Deposits (Fig. 1).

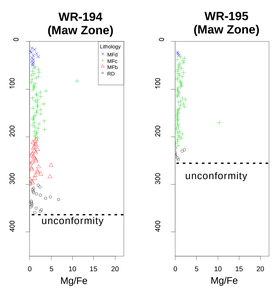

Fig. 6: Vertical variation of Mg/Fe atomic ratios from selected holes in the REE-rich Maw Zone (no U mineralization). The Mg/Fe atomic ratios do not vary much in sandstones.

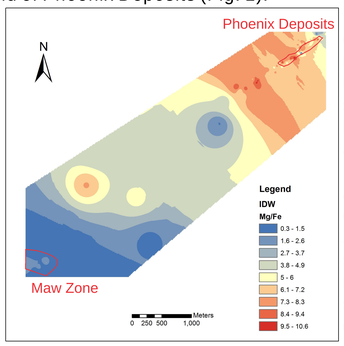

Fig. 7: IDW interpolation map for Mg/Fe atomic ratios of the uppermost (<40m depth) sandstones

The spatial variation of Mg/Fe atomic ratios in the uppermost sandstone shows high values in the area overlying the Phoenix Deposits and low in the area of the U-poor Maw Zone. This may suggest that Mg/Fe ratios of shallow sandstones reflect deep-seated U mineralization at district scale.

Summary

1. **PCA results show that U is strongly associated with HREE-Y-Pb and intermediately with LREEs-Cu-Na-B, but inversely correlated with K-Al-Fe-Ti-Th. Na and B likely represents magnesio-foitite, alkali-deficient Mg tourmaline.**
2. **Areas with high PC2 values of the uppermost sandstones correspond to locations of drill holes that intersect significant U mineralization at depth. Since each PC represents a group of elements, mapping suitable PC scores of shallow sandstone samples by interpolation may be useful for targeting potential areas of U mineralization.**
3. **Mg/Fe ratios of the uppermost sandstones overlying the Phoenix Deposits are high, whereas the values are low in the U-poor Maw Zone. The high Mg/Fe ratios correspond to the regional chlorite trend. This study suggests the composition of upper sandstones may be useful in detecting uraniferous hydrothermal activity at district scale.**

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