Alteration assemblages and geochemical signatures associated with the Phoenix unconformity-related uranium deposit, Athabasca Basin, Saskatchewan

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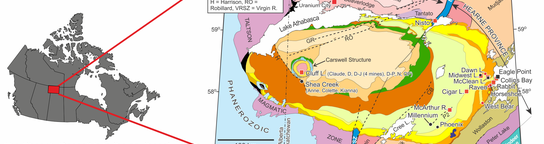
Introduction

The Athabasca Basin is home to the world's highest grade Proterozoic unconformity-related uranium deposits and accounts for about 18% of uranium production globally (OECD, 2012). In 2008, Denison Mines Corporation discovered the significant "Phoenix Deposit" on the Wheeler River property. It is one of the region's premier uranium deposits with indicated resources of 52.3 million lbs U_3O_8 at an average grade of 15.6%. To date, two subhorizontal lenses have been defined, termed the A and B zones, along a 1 km southwest-northeast corridor (Arseneau and Revering, 2010; Roscoe, 2012). Geographically the deposit is located in the southeast corner of the Athabasca Basin, 35 km southwest of McArthur River mine and 25 km southeast of Key Lake mill. It is within a regional corridor of anomalous illite, chlorite and tourmaline (Earle and Sopuck, 1989).

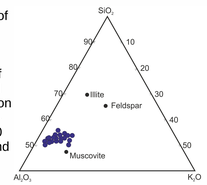
Geologically, the Phoenix deposit is made up of lenses at the interface between basement graphitic metapelite and the unconformably overlying, unmetamorphosed Athabasca Group siliciclastic strata. Monomineralic pitchblende replaces sandstone and conglomerate and extends both along strike and dip of the WS shear zone and splays. The reactivated WS shear zone is a reverse fault that offsets the unconformity, continues upward into the sandstone, and has been proposed as a major conduit for hydrothermal fluid flow that generated the Phoenix deposit and surrounding alteration (Roscoe, 2012, with reference to other unconformity-related deposits of the Athabasca Basin (Jefferson et al, 2007)). The role of the reactivated WS shear structures in fluid movement and thus hydrothermal alteration surrounding Phoenix was examined by this study and is herein compared to areas away from the Phoenix deposit.



The Phoenix Deposit is in the southeast corner of the Athabasca Basin, 400 km north from the city of Saskatoon. Geological map from Jefferson et al. (2007).

Alteration in the vicinity of Phoenix Zone A

Mineralogical expressions of alteration surrounding Phoenix are of classic unconformity-related style, consisting predominantly of illite with minor chlorite and tourmaline. Intense alteration extends up into the conglomerate and sandstone 200 m from the unconformity and less intense alteration extends to the surface.

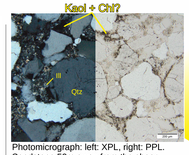


Ternary plot of illite compositions at 190 m down-hole on the WS Shear is similar to that of Athabasca Basin muscovite (cf. Wilson and Kyser, 1987; Alexandre et al., 2005).

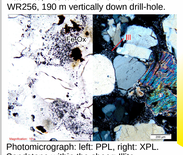
Samples of the WS shear structure are significantly different in mineralogy. Samples from 190 and 225 m depths in the shear zone contain chlorite, wereas those from similar depths away from the shear do not. Thin section observations suggest that alteration along the shear is more intense than elsewhere, with quartz dissolution common.

Illite grains in the WS shear zone and splays are more magnesium rich than those noted from other deposits in the eastern Athabasca basin (cf. Alexandre et al., 2005) and feature compositional and textural differences that suggest multiple generations. Chlorite in the lower sandstone beds has a composition resembling sudoite and elevated values of potassium and aluminium, possibly indicating illite/muscovite intergrowths and/or partial replacement.

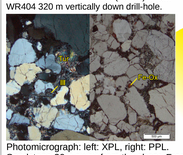
Tourmaline is widespread in sandstone and its composition appears to be closer to that of magnesiofoitite than dravite, although with elevated Mg and Fe substitution. Calcium rich early (pre-ore) tourmaline is present in one sample in the basement part of the WS shear zone.



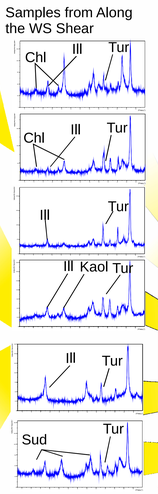
Photomicrograph: left: XPL, right: PPL. Sandstone 50m away from the shear. Kaolinite, illite and minor chlorite. From WR256, 190 m vertically down drill-hole.

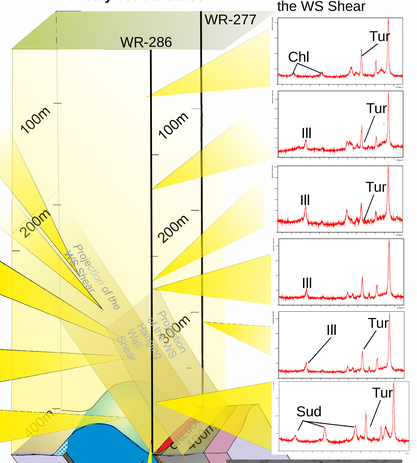


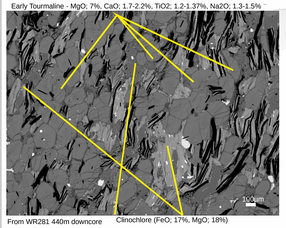
Photomicrograph: left: PPL, right: XPL. Sandstone within the shear: Illite, Tourmaline and iron oxides (Fe-Ox). From WR404 320 m vertically down drill-hole.

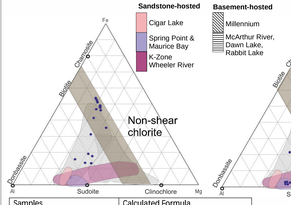


Photomicrograph: left: XPL, right: PPL. Sandstone 30m away from the shear. From WR315, 320 m vertically down drill-hole.









Ternary plots of chlorite compositions from: sandstone (non shear; above), basement non-shear (below far left) and shear (below left). Compositional fields from Alexandre et al. (2005; 2009) and Cloutier et al. (2009).

Samples	Calculated Formula
Sandstone Chlorites	$(Mg_{2.72}Fe_{1.47}Al_{0.83})Al(Si_3Al)O_{10}(OH)_8$.
Basement Chlorites	$(Mg_{3.7}Fe_{1.47}Al_{1.37})Al(Si_3Al)O_{10}(OH)_8$.
Basement Shear Chlorites	$(Mg_{3.1}Fe_{3.1/5}Al_{1.2})Al(Si_3Al)O_{10}(OH)_8$

Calculated average structural formula for sandstone, basement and basement shear hosted chlorite grains.

Sandstone-hosted chlorite grains are comparable in composition to published values from basement hosted deposits.

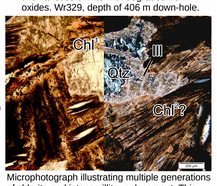
Chlorite from basement non-shear samples generally plot within published ranges in basement-hosted ore from Millennium deposit. Chlorite samples from the WS shear have significantly different compositions, with a wide range of iron concentrations. Collectively, the samples have more SiO_2 than counterparts in the Millennium Deposit (Cloutier et al, 2009) and less than at Eagle Point (Alexandre, 2009).

Samples from along the Basement WS Shear are similar to samples from the rest of the basement; however, a secondary population of chlorite has a sudoite like composition identical to that of Spring Point and Maurice Bay sandstone-hosted deposits.

Samples from the WS Shear also feature increased values of K_2O which may reflect muscovite intergrowths and/or replacement.

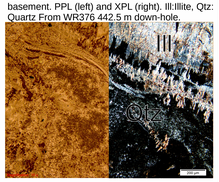
Tourmaline minerals are also present in the basement. Along the WS Shear tourmaline grains are similar in composition to feruvite, although with less magnesium and more titanium. Alteration of all basement samples is intense, with feldspar totally replaced by illite and garnet replaced by a mixture of iron-oxides/illite. Quartz is commonly corroded and altered mainly to illite and sudoite. Chlorite compositions compare to those published by Alexandre et al. (2005, 2009) and Cloutier (2009).

BSE image from a sandstone immediately above the Basement / WS Shear containing two varieties of illite with degraded iron-oxides. Wr329, depth of 406 m down-hole.



Microphotograph illustrating multiple generations of chlorite and intense illite replacement. This sample is located below the deposits in the graphitic pelite. PPL (left) and XPL (right).Ill:Illite, Chl: chlorite, Qtz: Quartz. From Wr383 at a down-hole depth of 407 m.

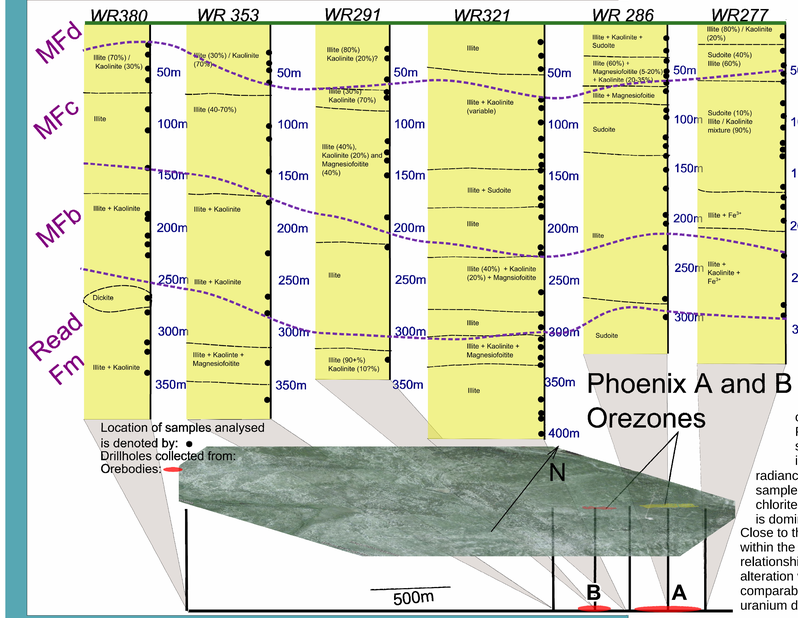
Microphotograph illustrating the intense alteration associated with fractures and veins in the basement. PPL (left) and XPL (right). Ill:Illite, Qtz: Quartz From WR376 442.5 m down-hole.



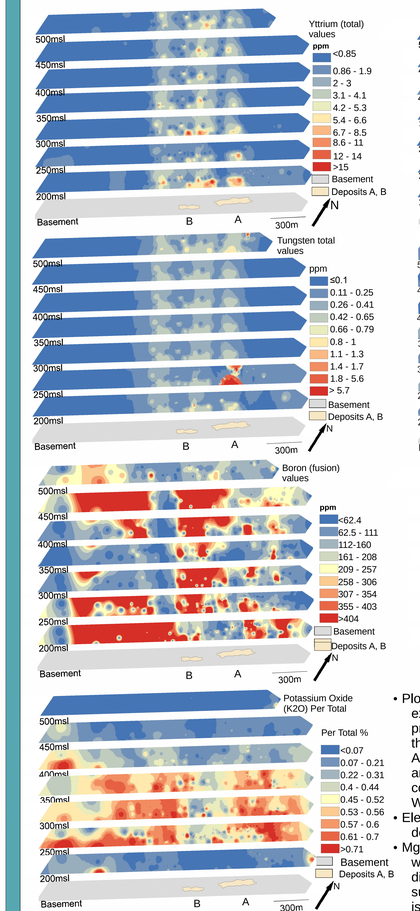
Alteration along the WS Shear

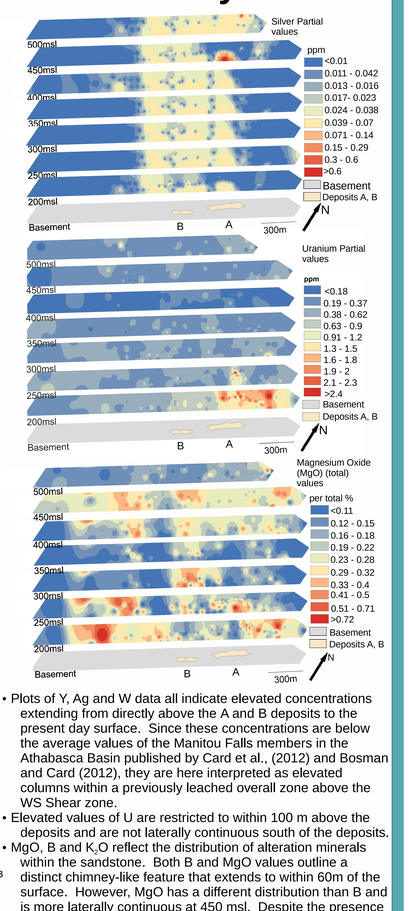
Clay concentrations in the sandstone range from complete replacement in veinlets, to minor interstitial abundances in heavily silicified sandstone with 'welded grains'. Iron oxide minerals are widespread throughout the sandstone, both as a major component in 'red beds' and as a minor component associated with illite. Silicified and desilified zones are documented throughout the sandstone.

Drillholes have been sampled up to 2 km south of the deposit along strike of the WS Shear, where the structure intersects the unconformity. The samples were taken to determine whether alteration observed in samples taken close to Phoenix deposit extends along the shear beyond the deposit. As indicated by short-wave infrared radiance (SWIR), the mineralogy of samples taken away from the deposit lack chlorite (either sudoite or clinochlore) and is dominated by a mixture of illite/kaolinite. Close to the deposit, sudoite and tourmaline within the sandstone suggest a spatial relationship to pitchblende. Overall, alteration within the sandstone appears to be comparable to other Athabascа unconformity uranium deposits.



Whole Rock Geochemistry





All geochemical data were provided by Denison Mines Corp. For this study, 696 geochemical analyses from 124 DDH were used to generate the interpolations. Elements Y, Ag, W, Ho and U have detection limits of 0.01ppm, while K_2O: 0.002%, MgO; 0.001%, B; 2ppm. Values of W, Y, MgO and K_2O were obtained by digestion to dryness in a Teflon tube using a hot mixture of concentrated HF-HNO_3-$HClO_4$. The residue was then dissolved in dilute HNO_3 and analyzed by ICP-MS and ICP-OES. The values of Ag and U were determined by digestion in a mixture of HNO_3-HCl, in a hot water bath. The solutions were then diluted using de-ionized water and analyzed by ICP-MS and ICP-OES. Boron fusion values were obtained by fusing an aliquot of pulp in a mixture of NaO_2/$NaCO_3$ in a muffler oven. The fused melt was dissolved in de-ionized water. Interpolation (IDW method) was performed using ArcMap 10.0 software equipped with the Spatial Analysis toolbox. MSL = meters above mean sea level.

- Plots of Y, Ag and W data all indicate elevated concentrations extending from directly above the A and B deposits to the present day surface. Since these concentrations are below the average values of the Manitou Falls members in the Athabasca Basin published by Card et al., (2012) and Bosman and Card (2012), they are here interpreted as elevated columns within a previously leached overall zone above the WS Shear zone.
- Elevated values of U are restricted to within 100 m above the deposits and are not laterally continuous south of the deposits.
- MgO, B and K_2O reflect the distribution of alteration minerals within the sandstone. Both B and MgO values outline a distinct chimney-like feature that extends to within 60m of the surface. However, MgO has a different distribution than B and is more laterally continuous at 450 msl. Despite the presence of sudoite in core, elevated values of MgO do not appear to be spatially related to the orebodies.
- K_2O, interpreted to be due to sericite-illite alteration within the sandstones, is present between 250msl to 350msl and features two major areas of elevated values which do not correlate with high values of B and MgO.

Acknowledgments and References

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Procedure for clay mineral concentrates

Due to the low proportions of clay minerals within the sandstone and the nature of X-Ray Diffraction (XRD) in the detection of minor phases, clay concentrates were produced for more effective analysis. Ground samples were centrifuged in tubes for 20 minutes at 2500 rpm. The clay-sized fraction that settled at the top was removed, dried and re-ground. Quartz was retained in samples in order to calibrate the spectra. Recovery rates for clay within the sandstones ranged from 5% to 60%. Samples were analysed under a continuous $CuK\alpha$ scan with a step size of 0.02°, 1 s per step with a scan speed of 0.02°and are presented as square root of intensity spectra to emphasize smaller peaks.