SURFICIAL EXPRESSION OF DEEPLY BURIED PHOENIX AND MILLENNIUM URANIUM DEPOSITS IN THE ATHABASCA BASIN, SASKATCHEWAN, CANADA

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Introduction

The eastern margin of the Athabasca Basin hosts world-class U deposits along the unconformity between metamorphosed basement rocks and the Athabasca sandstones (Jefferson et al., 2007). Recent discoveries of U deposits in the centre of the basin, such as the Centennial deposit (Jiricka, 2010), indicate the potential for discoveries in this area; however, the sandstones are thicker towards the centre of the basin. Since deep drilling through thick sandstones is expensive, innovative techniques are necessary to help detect deeply-buried U ore. We initiated a project in the summer of 2011 to evaluate the best methods and most reliable surface media to use in detecting concealed U deposits. Two sites were selected for the study (Figure 1); the Phoenix deposits with indicated resource of 70.2 million lb U_3O_8 (Roscoe, 2014) and the Millennium deposit with indicated resource of 75.9 million lbs U_3O_8 (Cameco Corporation, 2013). The Phoenix deposits lie at a depth of 450 m below the surface along the unconformity and also along a steeply dipping shear zone, the WS Shear, in graphitic pelitic gneisses of Paleoproterozoic basement (Kerr, 2010; Figure 2a). The Millennium deposit is ca 750 m below the surface along a major shear zone, the Marker Fault, hosted by graphitic metasedimentary rocks of the basement (Figure 2b). There is no apparent evidence on the surface for the U deposits at depth.

The region has a sub-arctic climate with cold winters and short, mild summers with precipitation of 480 mm/year (Dimitrov et al., 2014), and is covered by glacial deposits 20-30 m thick in most places except for the top of eskers.

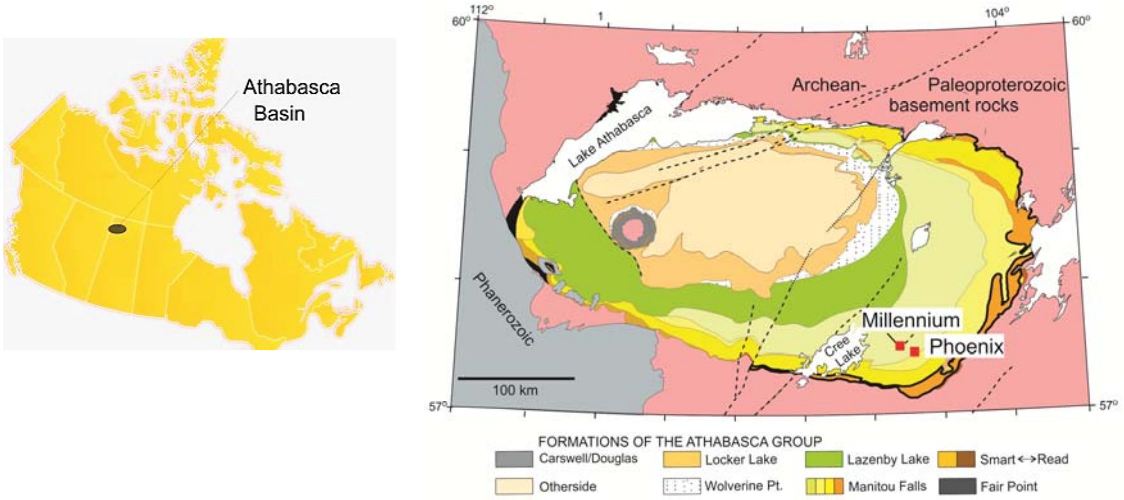

Figure 1a. Location of the Athabasca Basin. 1b. The location of Phoenix and Millennium U deposits in the Athabasca Basin. Modified after Jefferson et al. (2007).

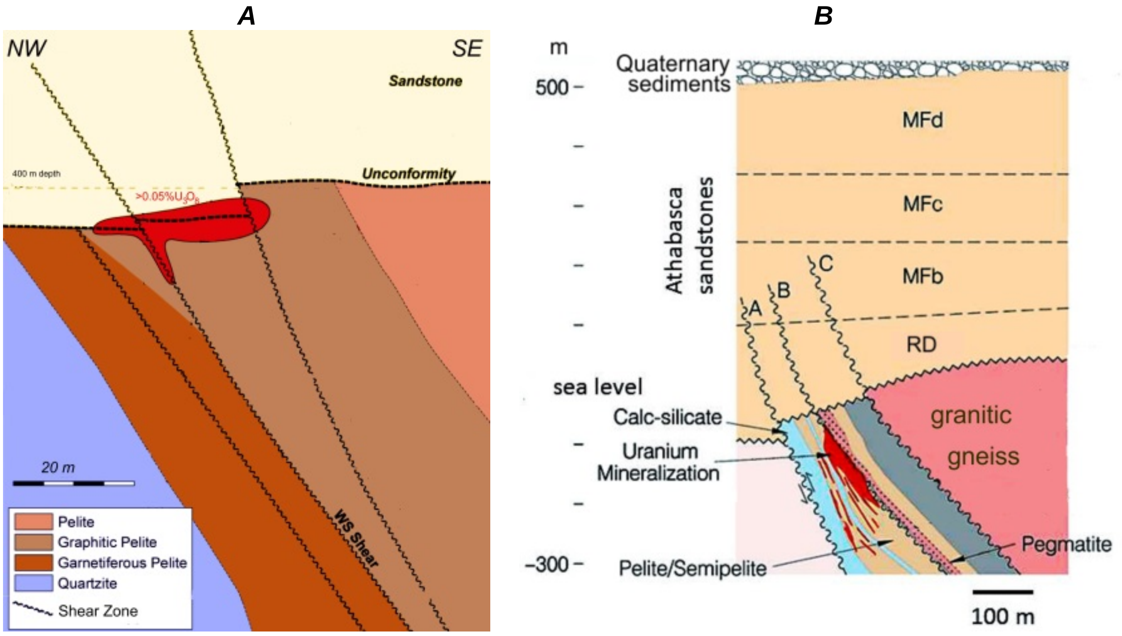

Figure 2. Vertical sections of (A) the Denison Mines' Phoenix deposit, modified after Kerr (2010) and (B) the Cameco's Millennium deposit, modified after Wood et al. (2012).

Methodology

Soil samples: The area became ice-free only ca 8000 years ago, but soil horizons are well developed, up to 60 cm thick in most places (Figure 3), partly due to well-drained sandy glacial sediments on the surface, except for bogs immediately around a small swamp and close to Slush Lake in the western part of the Millennium property. Soil horizons vary in thickness from 2 to 5 cm for humus, from 5 to 15 cm for E-horizon soil, and up to 100 cm for B-horizon soil. Most samples (1-2 kg each) were collected using a hand-held Dutch auger or a shovel (Figure 3). Humus samples were digested with *aqua regia* and B-horizon soil with ammonia acetate leach after drying at ~ 60°C and sieving at – 80 mesh (0.177 mm) at Acme Labs Ltd., Vancouver.

Laboratory testing: For selected humus samples, a laboratory test was conducted at the University of Ottawa to evaluate the sites of metals after agitating samples in Milli-Q water, 0.02 N HBr, 1 N HNO_3, and a hot mixture of concentrated HF-HBr.

Lead isotope analysis: Solutions used for the test above were analysed for Pb isotopes. After separation and purification of Pb using Dowex AG1-8X anion resin and HBr solution, the isotope compositions were determined using Agilent HP-7700 IPC-MS and also a Thermo-Finnigan Triton thermal ionization mass spectrometer. After mass fractionation correction, the two instruments provided similar results, ± 1 % of the quoted values.

Noble gases: Radon gas dissolved in groundwater in monitoring wells and exploration drill holes was extracted using mineral oil in the field, and the contents were measured using a liquid scintillation counter at the University of Ottawa. Gases dissolved in water were collected using a Cu diffusion gas sampler and noble gas abundance was measured at the University of Ottawa and at the University of Quebec at Montreal.

Figure 3. Typical soil profile in the area, showing the black humus, buff-coloured E-horizon and brown B-horizon soil in the Millennium property.

Results

Humus and B-horizon soil samples contain high metal contents, including U, directly above the ore bodies and WS Shear Zone of Phoenix deposit (Figure 4), and in broad areas over the surface projection of shear zones at the Millennium property (Figures. 5, 6). The anomalies in the soil samples were reproduced at the sites in subsequent years of sampling at both properties. A laboratory test of humus samples shows that water and weak HBr in an ultrasonic bath for more than 1 hr did not leach metals from humus. Strong acids, 1 N HNO3 and concentrated HBr-HF, were required to leach metals from humus. Uranium, in particular, was strongly held by organic material. The release of U from humus required the digestion of the sample with hot concentrated HBr-HF. The results suggest that metals are tightly held in organic material, not adsorbed on the surface of clays or organics.

Lead isotope compositions of leach fractions (water, 0.02N HBr leach, 1 N HNO3 leach, concentrated HF-HBr digestion) of humus from the Phoenix site show 206Pb/204Pb values ranging from 17.3 to 1.6 and 207Pb/204Pb from 15.4 to 15.6. The values are similar to those of the mid-Proterozoic crust, and much lower than those expected from the U ore.

The concentrations of He dissolved in groundwater are extremely high in water close to the surface projection of the Millennium ore body (Figure 7), particularly in the western part of the property, but He contents are low above the Phoenix deposits.

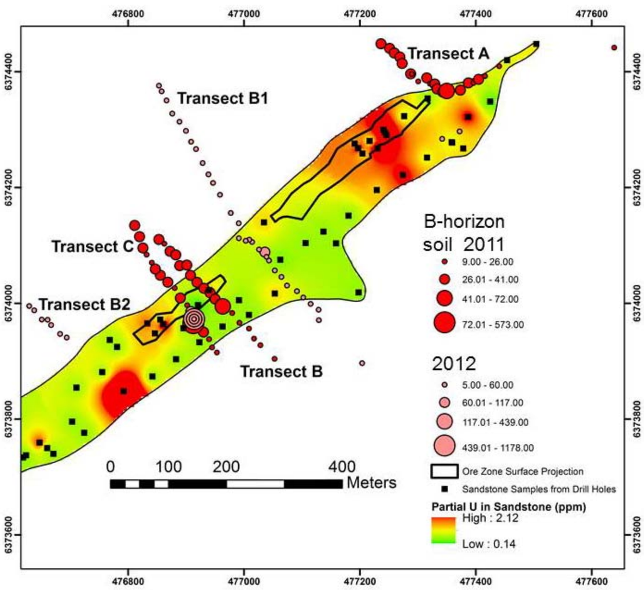

Figure 4. Uranium concentrations in ammonia acetate leach of B-horizon soil (circles) and in aqua regia of the uppermost sandstones above the Phoenix deposits.

The site (PHX 28) for soil in multiple years is show with brown triple circle. Modified after Power et al. (2012). Note sampling traverses are selected to be right angles to SW-trending glacial dispersion trail, which is parallel to the orientation of deposits.

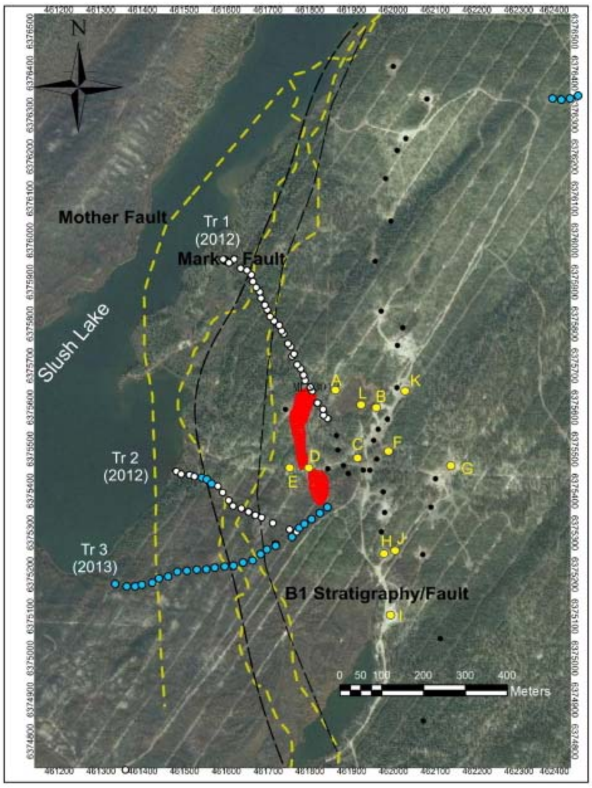

Figure 5. Plan map of the Millennium property showing the soil sampling traverses (Tr1, Tr2, Tr3).
Yellow circles are the locations of gas sampled from wells and exploration drill holes, modified after Krahenbil et al. (2014).

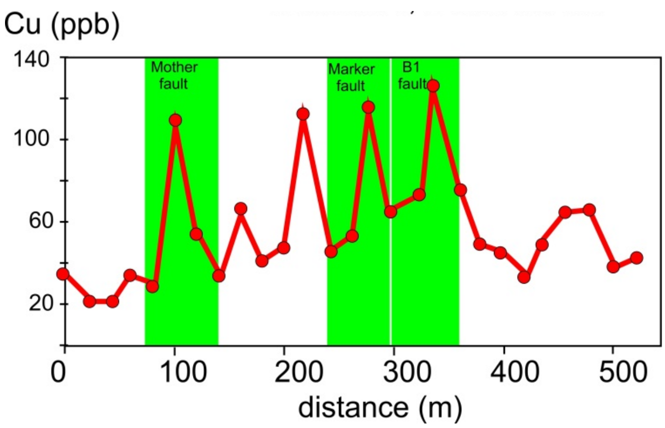

Figure 6. Copper concentrations in ammonia acetate leach of B-horizon soil along transect 3 (Figure 5) at the Millennium property. Modified after Krahenbil et al. (2014).
Green areas are surface projection of basement faults.

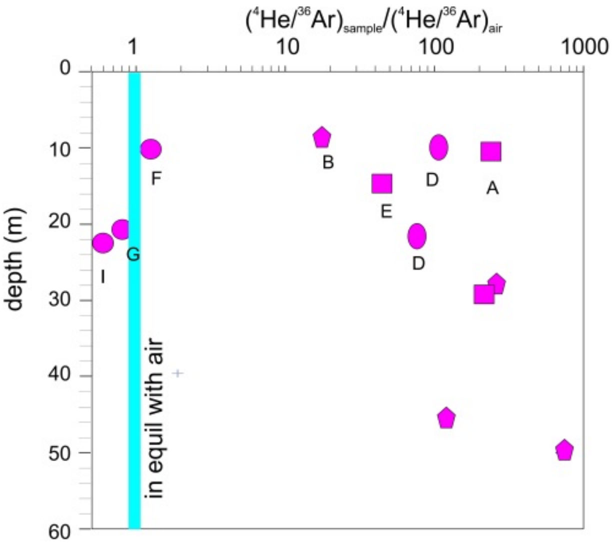

Figure 7. $^{4}He/^{36}Ar$ ratios of noble gas dissolved in water in environmental monitoring wells and exploration drill holes.
The labels correspond to those in Figure 3.

Discussion

High metal contents in soil over the surface projections of the Phoenix deposits and Millennium deposit indicate an upward movement of metals to surface media. Several possible sources for the metals are considered; the deeply seated U ore, sandstones and glacial sediments. The compositions of the uppermost sandstones determined by a 2-acid digestion show elevated metal contents over the Phoenix deposit (Figure 4; Power et al., 2012). Furthermore, metal contents including B, heavy REE and W in the sandstones show a 'chimney-like' distribution; there are high contents of metals directly above the U deposits upward to the uppermost sandstones (Figure 8; Dann et al., 2014).

Elevated metal contents directly above U ore suggests that metals were dispersed in sandstones, probably during uraniferous hydrothermal activity, and that these metals were subsequently transported to surface media. The proposed interpretation is consistent with low ^{206}Pb and ^{207}Pb in humus samples because Pb in the ore should have very high ^{206}Pb and ^{207}Pb. Furthermore, our interpretation is also supported by high contents of Rn dissolved in ground waters (Figure 9; Dudek et al., 2015). Because ^{222}Rn (half-life of 3.8 days) cannot diffuse in water from the ore to the surface in several days, it likely originates from U and/or ^{226}Ra (direct parent of ^{222}Rn) in the upper sandstones.

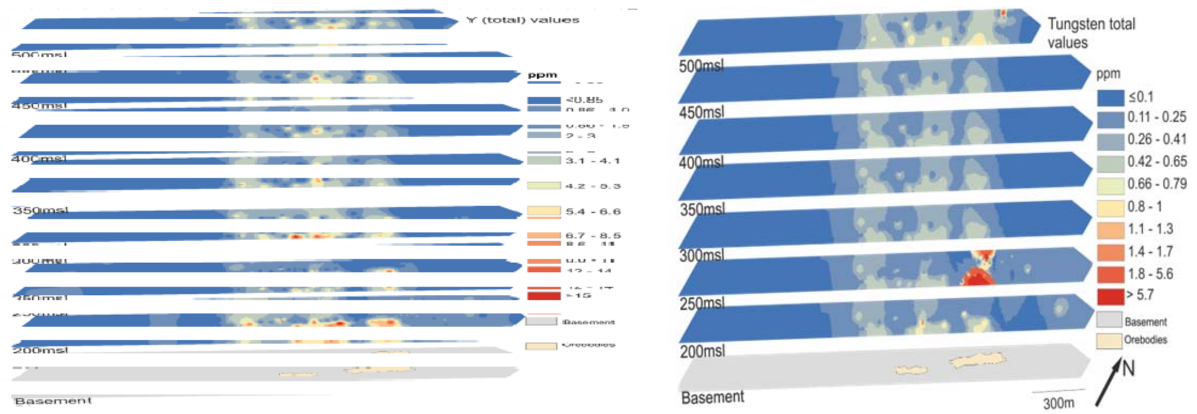

Figure 8. Concentrations of Y (A) and W (B) in sandstones above the Phoenix Deposit A and B, after Dann et al. (2014). MSL = metres above sea level

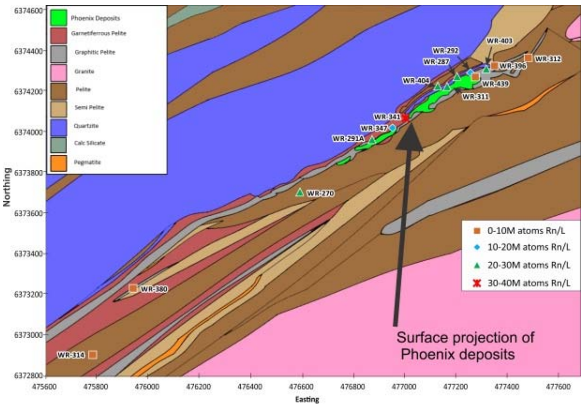

Figure 9. Radon concentrations of groundwater in exploration drill holes above the Phoenix deposits, modified after Dudek et al. (2015)

Conclusions

Geochemical anomalies are detectable in surface media, even from deposits at a depth of ~400 m and ~750 m, but anomalies may not be apparent in a single medium at an individual site due to a variety of factors affecting the composition of surface media. In exploration, use of multiple surface media is recommended.

Sandstones above the U deposits commonly contain elevated concentrations of metals, most likely produced during the uraniferous hydrothermal activity as a distal halo. These results suggest that shallow sandstone data may be used to predict the presence of deeply seated U deposits. Elevated metal concentrations in soil likely reflect those of upper sandstones.

High contents of Rn are dissolved in groundwater at the two properties. Considering its short life, Rn is likely sourced from elevated U or Ra in the upper sandstones, which in turn may reflect deeply seated U ore.

Acknowledgements

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