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RADON AND HELIUM DISTRIBUTION AND CONCENTRATIONS ABOVE BURIED URANIUM ORE: THE PHOENIX DEPOSITS, SASKATCHEWAN

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Introduction

The Athabasca Basin is located in northern Saskatchewan and Alberta, and hosts one of the largest reserves of uranium in the world. The Wheeler River property is located on the south-eastern margin of the basin (Fig.1) and hosts the Phoenix deposits, with currently defined resources of 70.2 M lb U_3O_8 (Roscoe, 2014). The deposits are situated along the unconformity between the Athabasca Group sandstones and metasedimentary basement rocks approximately 400 meters below the surface (Denison Mines, 2014a). Sampling locations were selected based on whether or not drill holes intersected mineralization. Water was collected mostly from the top of the water column in each drill hole using copper and plastic-laminated steel bailers. In addition, four samples were collected at various depths below the water table at drill holes WR-314 and WR-380 (Fig. 3).

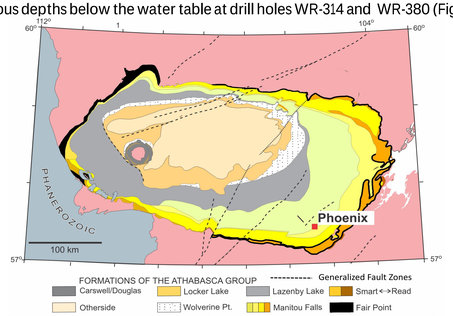

Figure 1: Location of the Phoenix deposits in the southeastern corner of the Athabasca Basin. Geologic map after Jefferson et al. (2007)

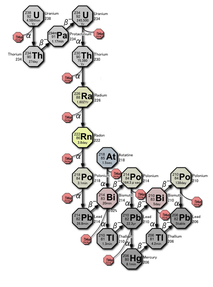

Figure 2: Uranium decay chain (modified from Tosaka, 2012; Wikimedia Commons, CC-BY-SA.3.0)

Why Radon and Helium?

Radon and helium are decay products of uranium and both occur in a gas phase, allowing for easy transportation and dispersion from the ore body. Because of this intimate relationship with uranium, radon and helium are both used extensively in the search for uranium ore bodies (e.g. Dyck, 1980). This study has shown elevated radon in groundwaters overlying the Phoenix deposits. Thus understanding their sources, how they are transported, and how radon and helium distribute is crucial to the use of these gases in the future exploration of concealed uranium deposits. Five possible sources and/or transportation methods are considered: contamination, diffusion, bubbling, water flow, and lastly a local source.

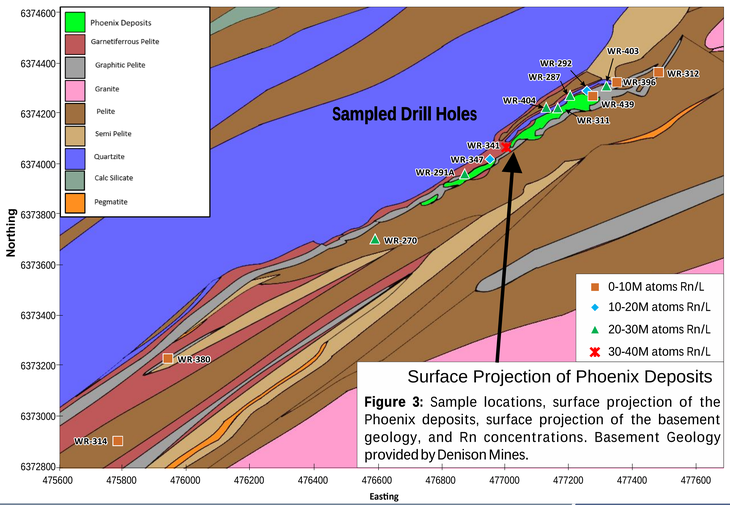

Figure 3: Sample locations, surface projection of the Phoenix deposits, surface projection of the basement geology, and Rn concentrations. Basement Geology provided by Denison Mines.

Contamination?

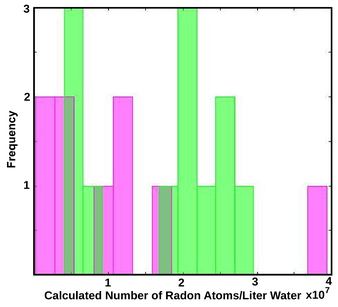

Figure 4: Oil-extracted radon histogram illustrating that drill holes that did not intersect mineralization contained the highest Rn concentrations.

If contamination from drilling the ore zone is the source of radon, water sampled from drill holes that did not intersect mineralization would have less radon than water in holes that did intersect mineralization. No significant difference exists between the two. Thus contamination is not a relevant source of radon.

Transport by Diffusion?

Two diffusion models are considered: vertical and spherical diffusion in water. Diffusion represents an unlikely transportation model for radon with a half-life of 3.8 days and the depth to ore. Helium-4 is stable, diffuses more quickly and thus can diffuse great distances.

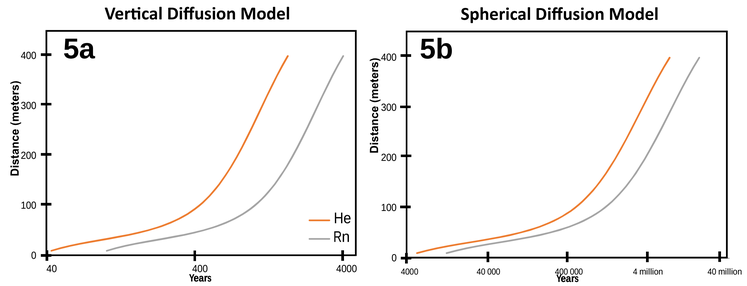

Figure 5. Diffusion modelling illustrating distance and time relationships for: **(a)** Vertical diffusion with diffusivity directed in a single direction. **(b)** Spherical diffusion with radial expansion. Diffusion Coefficients taken from Yaws (2009).

Gas Bubbling?

Bubbling was not observed from ground water, or in samples. Thus bubbling as a means of transportation for observed radon can be rejected.

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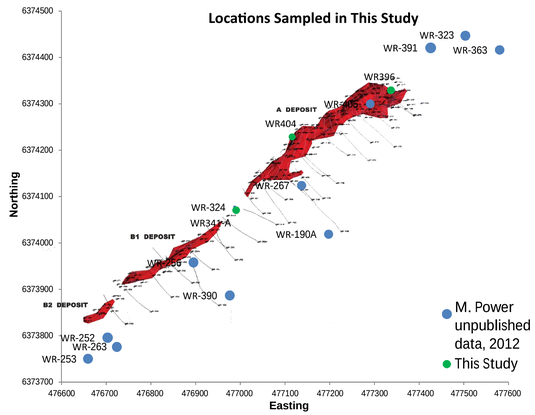
Transport in Ground Water Flow?



Ground water samples surrounding the Phoenix deposits have helium/argon and helium/neon values indicative of ground water in equilibrium with atmosphere. If ground water was flowing upwards from the Phoenix deposits, one would expect high helium/argon ratios. Low helium values suggest a lack of upward flow of water from the deposits to the surface.

Figure 6: Locations sampled in this study. ($^4He/^{36}Ar$) normalized to ($^4He/^{36}Ar$) ASW (air saturated water) values average 0.92 ± 0.03 and $^4He/^{22}Ne$ values average 1.12 ± 0.05. These ratios are considered the values expected given equilibrium with the atmosphere under slightly elevated pressure. Data collected by M. Power, unpublished data 2012, and this study.

Local Sources?

Radon concentrations range from 5–2035 Bq/L. Assuming secular equilibrium and a minimal distance for transportation, a local source of radon requires between 0.035–6.6 ppm of uranium. Sandstones and soils above the Phoenix deposits have uranium concentrations within this range (Power et al., 2012a; Dann et al., 2014) .

Pore fluids in soil in the vicinity of holes WR-314 and WR-380 contain radon below the detection limit of 3 Bq/L. The ground water in holes of WR-314 and WR-380 showed high radon contents of 105 and 20 Bq/L respectively. The data suggests that soil is unlikely to be a major contributor of radon in groundwater observed in this study.

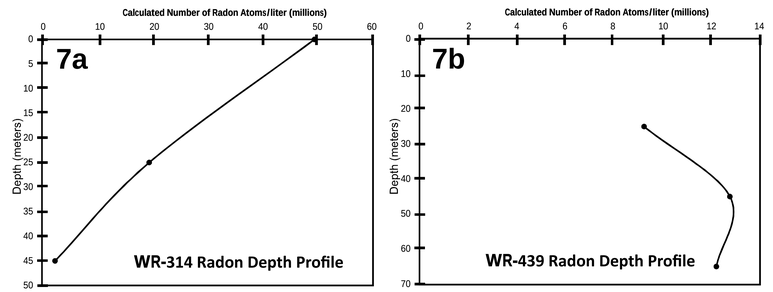


Figure 7: Radon Depth Profiles; The water table at WR-314 (7a) is at ground level, where the highest concentration of radon is found, potentially indicating soil as the source of radon. The water table for WR-439 (7b) is 25 meters down, with a peak at 45 meters down. WR-314 from water dissolved radon. WR-439 from oil extracted radon.

Summary

Diffusion is an extremely slow process, and thus cannot be responsible for transporting radon, but may be a mechanism transporting helium. Helium/argon and helium/neon ratios are in equilibrium with the atmosphere, indicating ground water is not transporting radon upwards from the Phoenix deposits.
Eliminating the possibilities of contamination, bubbling, ground water upwelling, vertical diffusion from the ore body, and soil, the only remaining possible source of radon is uranium and/or radium in upper sandstones or till.

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