

## Introduction

The Athabasca Basin, Saskatchewan, hosts many world-class high-grade uranium deposits. In the past, the Athabasca Basin was explored with geophysical techniques and surficial geochemistry. These methods are excellent for detecting anomalies associated with uranium deposits, however there is a need for additional methods in order to more accurately identify the mineralization.

Cameco's Millennium deposit is a high grade, basement hosted uranium deposit located 600 km north of Saskatoon near the Key Lake mine in Saskatchewan. This deposit has 68.2 M lbs (indicated) and 22.3 M lbs (inferred) U<sub>3</sub>O<sub>8</sub> at a depth of approximately 750m. To date, water samples have been collected throughout the Millennium deposit and surrounding area to determine to what extent <sup>222</sup>Rn and other radionuclides disperse from the deposit to near surface.

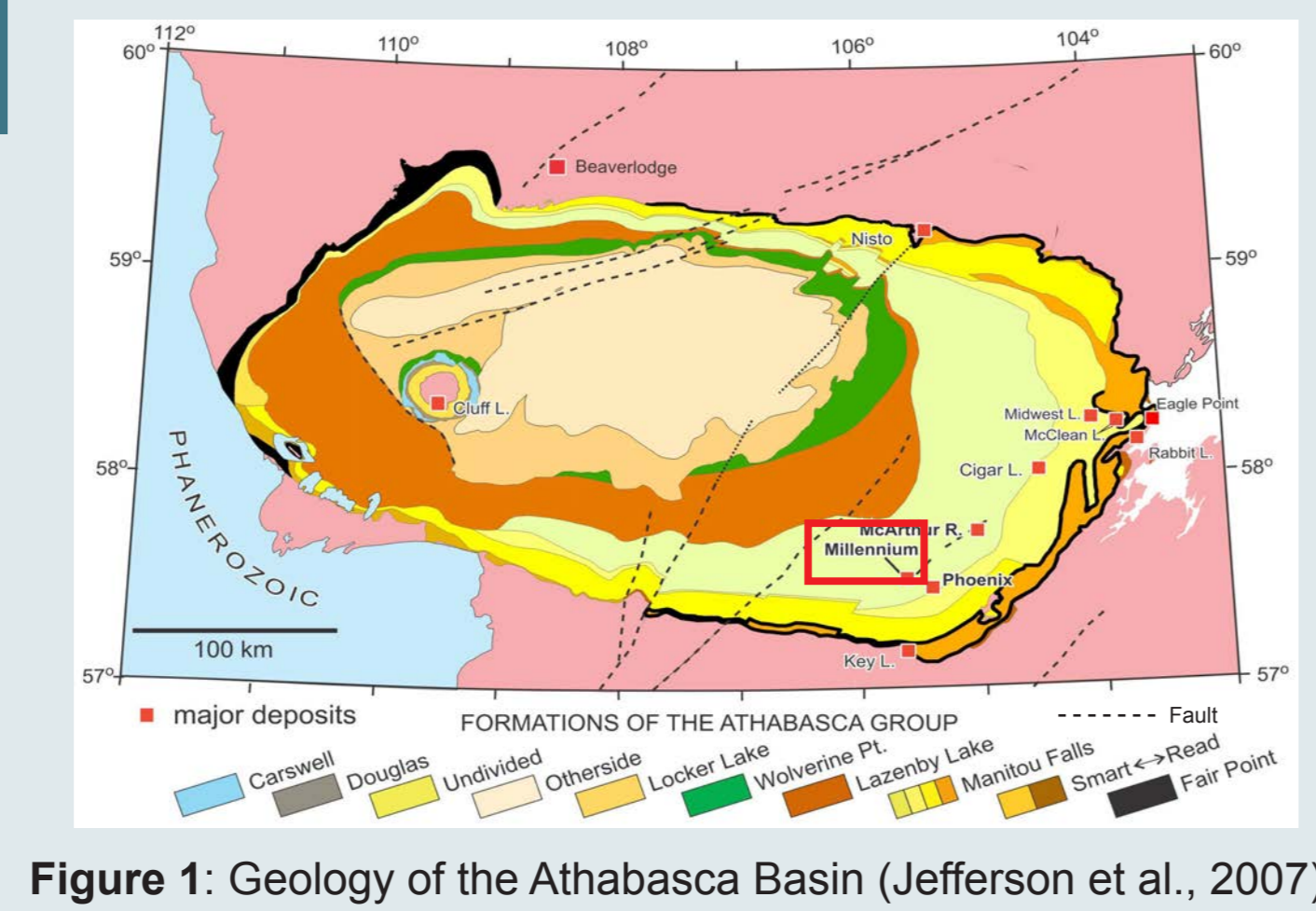


Figure 1: Geology of the Athabasca Basin (Jefferson et al., 2007)

## Objectives

- Does <sup>222</sup>Rn accumulate to detectable concentrations above a known uranium deposit?
- How widespread are the anomalous values?
- What are the most effective sampling and analyzing techniques?
- Do the physical properties of sample waters affect the analysis?
- What is the optimal depth of sampling for Rn measurement?

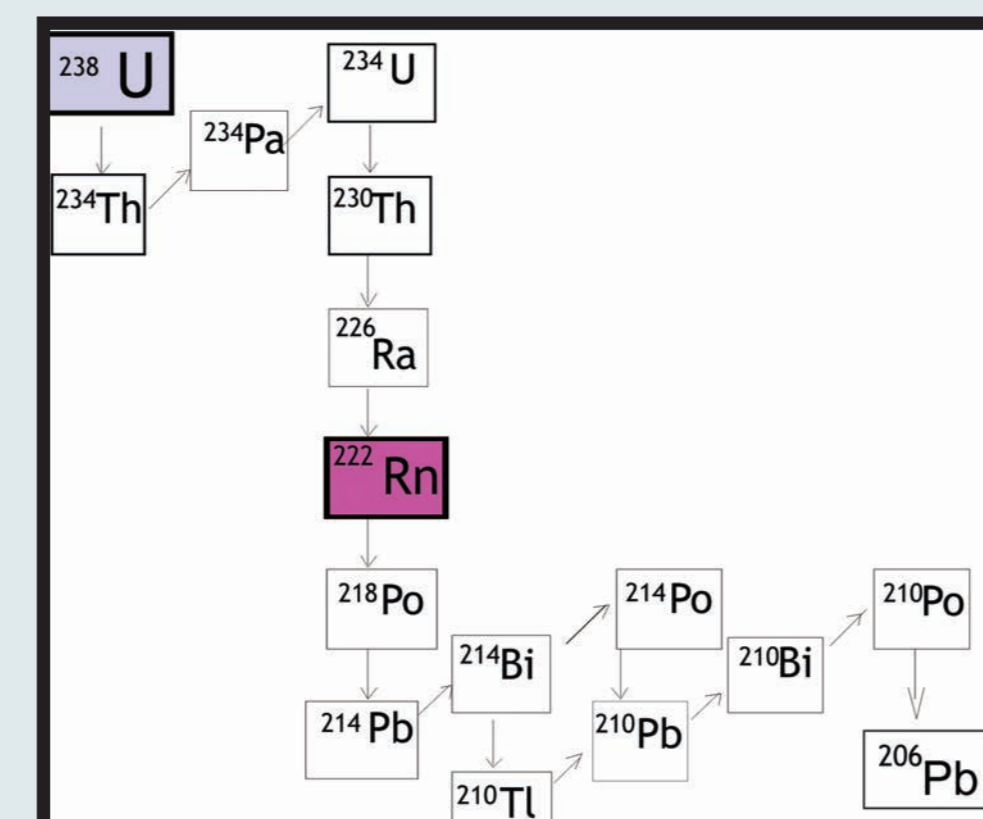


Figure 2: <sup>238</sup>U decay series

## Sampling Methods

- Sample locations were chosen based on varying proximity to the surface projection of the buried high-grade uranium. At each drill hole, water was collected close to the water level using copper bailers.

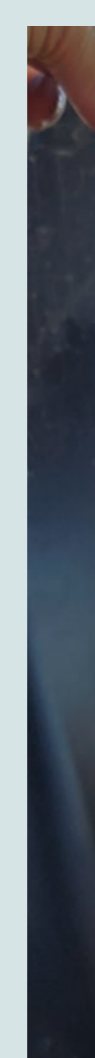
### Water Extraction Method (EM)

- Water is poured directly from copper bailer to 220 mL transparent glass bottles
- Analysis completed at Universite du Quebec a Montreal
- Extraction and calibration procedures are described in Lefebvre et al. (2013)



### Diffusion Sampler Method

- This new technique was applied to the analysis of CX-52.
- A silicon tube is connected to copper tubes on both ends and filled with ~12 mL of mineral oil and submerged to 10 meters below the surface.
- The tube was submerged for 30 hours, allowing Rn in the ground water to diffuse into the silicon tube and to be incorporated into the mineral oil.
- The diffusion sampler was then quickly retrieved from the drill hole and the mineral oil was transferred to a translucent 22 mL glass bottle.
- This sample was analyzed at the University of Ottawa on the scintillation counter.
- Similar results were found from the diffusion sampler method and the mineral oil method (Figure 3.2).



### Mineral Oil Extraction Method

- This is a modified method described by Leaney et al (2006).
- Water is poured into a 250 mL polyethylene terephthalate (PET) bottle.
- 30 mL of scintillation mineral oil is added to 250 mL bottle, headspace free.
- Sample is shaken for 4 minutes, and then left to stand until water and mineral oil separate.
- Mineral oil is extracted from top of bottle using pipettes, and transferred to transparent 22 mL glass bottle.
- Radon contents in oil were measured at the University of Ottawa on a liquid scintillation counter.



### Radon Concentrations of Groundwater

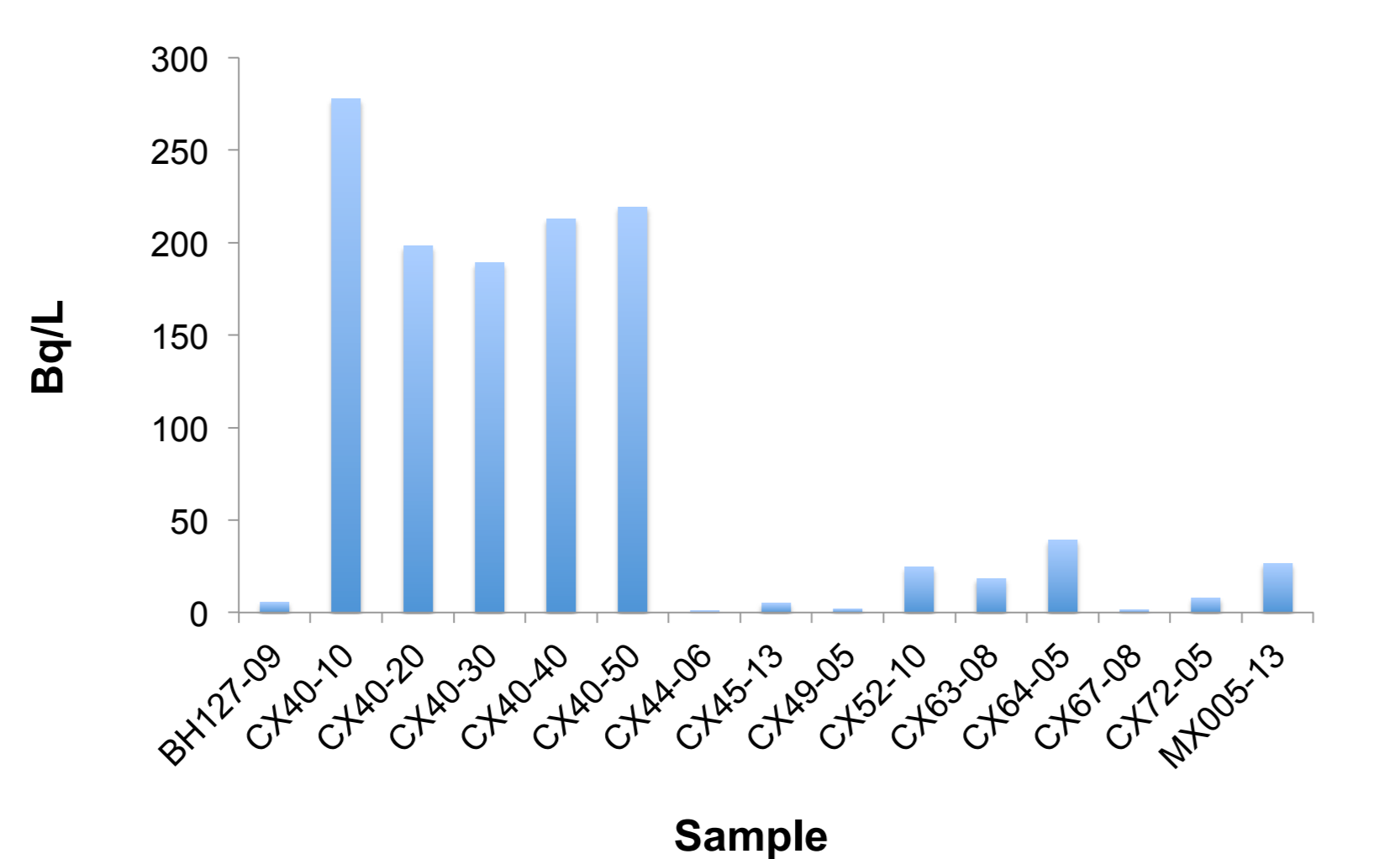


Figure 3.1 (Above)  
Concentration of Rn in groundwater in Bq/L of 11 drill holes at Millennium. Sample names are labeled as the hole ID followed by the sampling depth. CX-40 was measured in 10 m intervals from 10-50 m. CX-40-10 has the highest concentration of 277.6 Bq/L.

Figure 3.2 (Left)  
A comparison of the diffusion sampler method and the mineral oil method for samples at CX-52. Error bars represent 1 standard deviation between analyses (n=2).

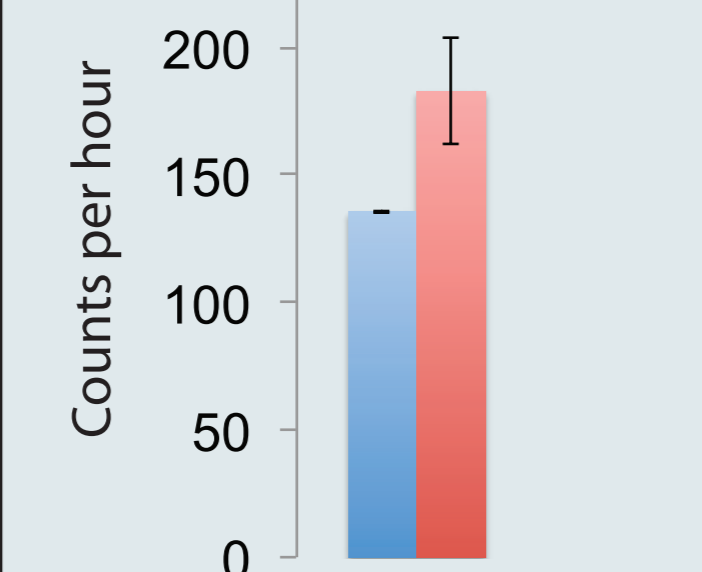


Figure 3.3 (Below)  
Concentration of Rn in groundwater (counts/hour) of 13 drill holes at the Millennium site. Sample names are labeled as the hole ID followed by the sampling depth. CX-40-10 has the highest counts measured at 5026 counts/hour. Error bars represent 1 standard deviation between analyses (n=2).

### Alpha emission counts from Rn in Oil

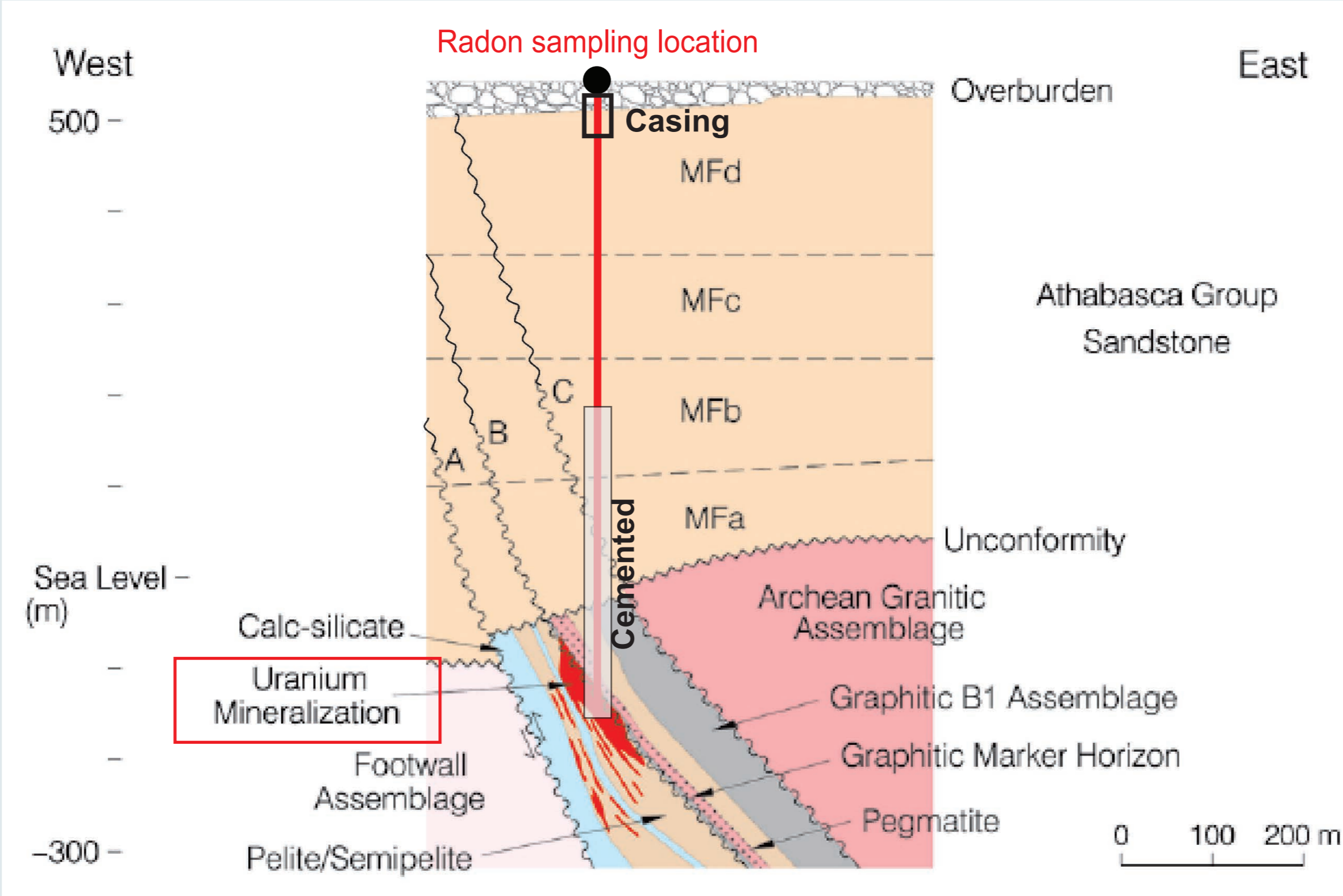
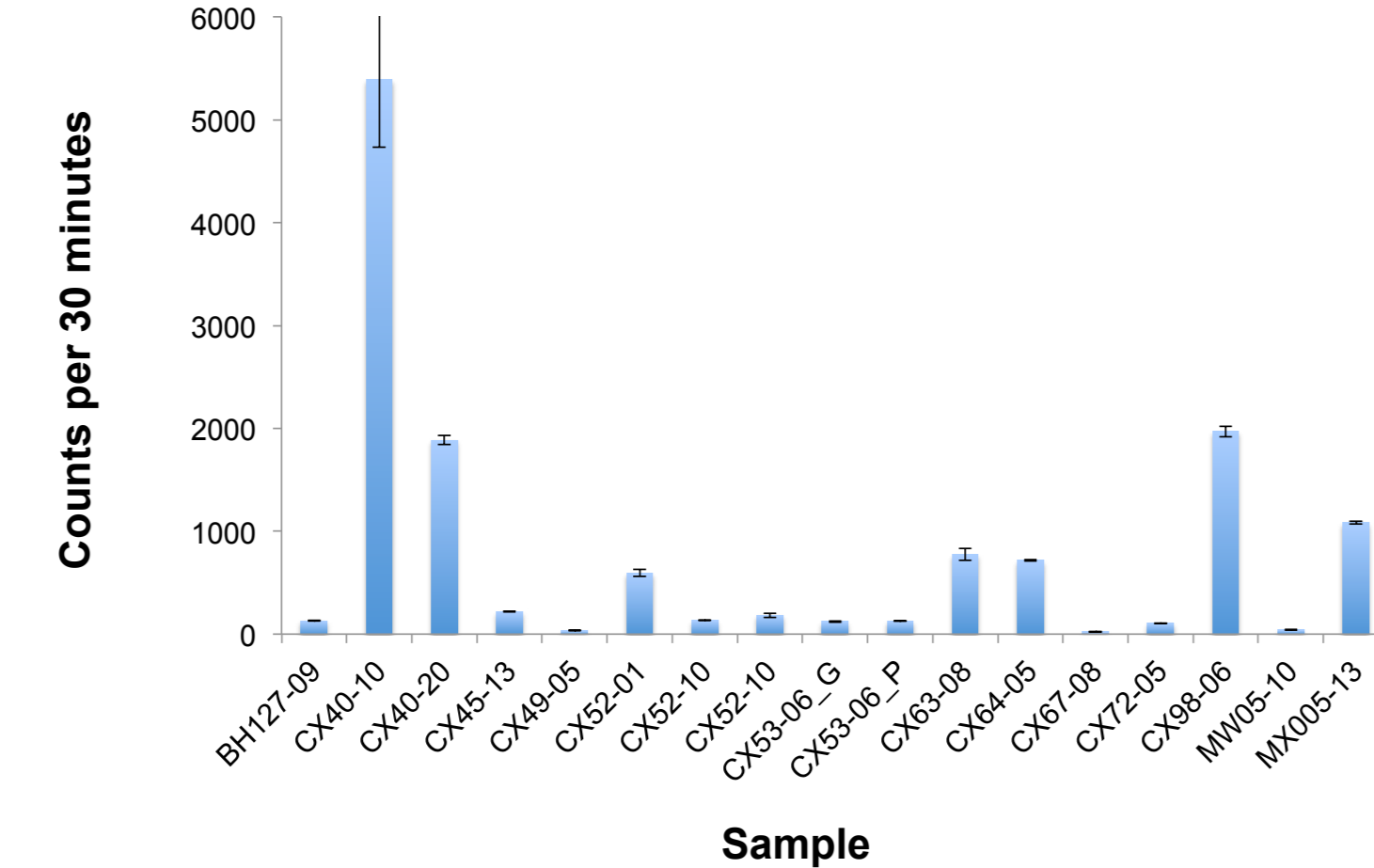


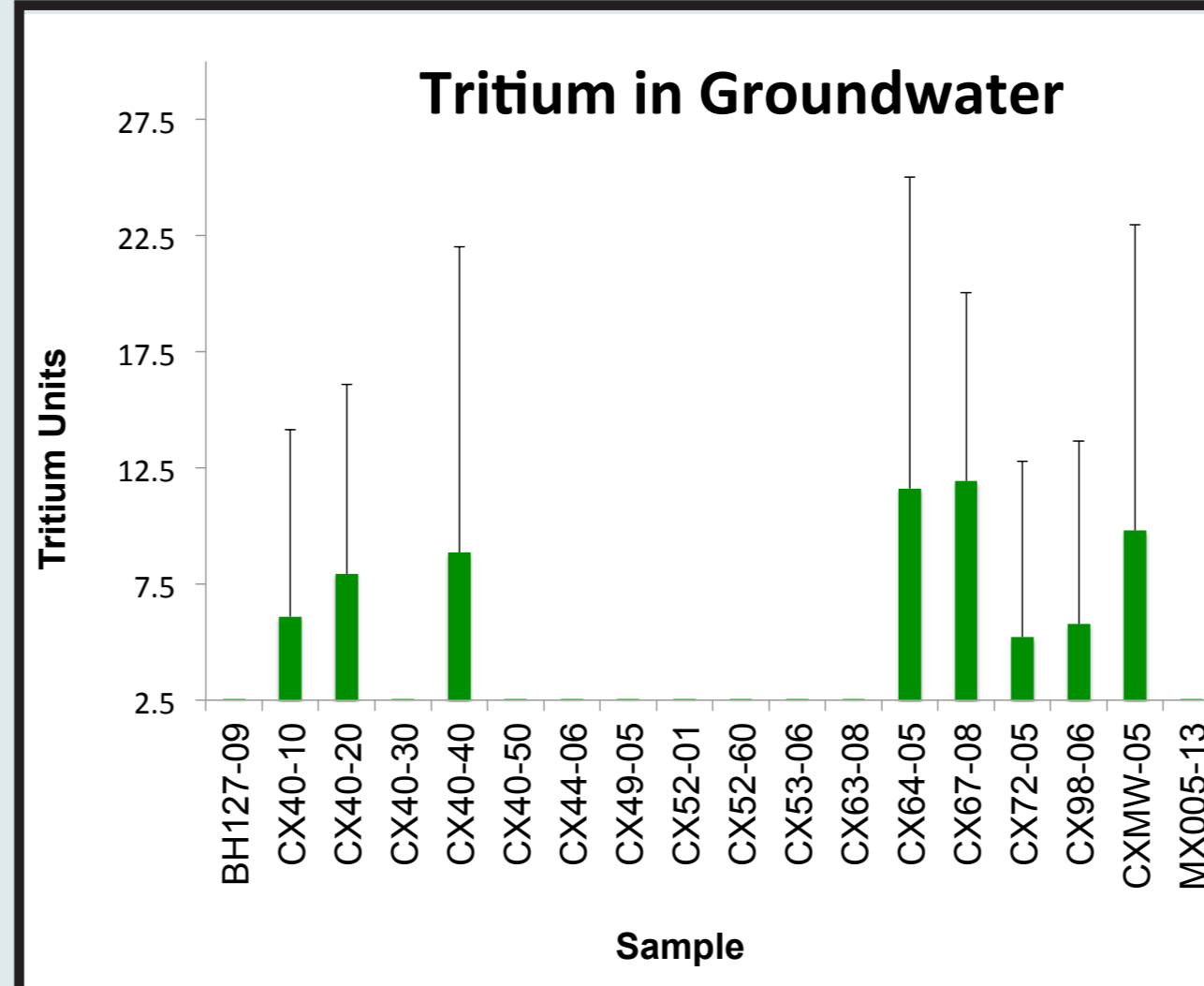
Figure 4: Geological cross section of the Millennium deposit showing sample location relative to ore mineralization. Modified from Wood et al. (2012).

Groundwater gas samples were taken from cased and cemented drill holes and monitoring wells roughly 700 m above mineralization. For this reason, it is considered that radon is dispersing from the uranium ore to shallow depths via groundwater and fractures within the basement and sandstones.

## Groundwater Recharge

- To estimate the residence time of the groundwater sampled at the Millennium deposit, tritium (<sup>3</sup>H) was measured.
- <sup>3</sup>H levels of most samples are below the detection limit, 2.5 Tritium Units (TU)
- The remaining samples show values between 5-11 TU, however reproducibility is very poor as represented by large error bars.
- This may suggest that the recharge took place after 1970. Before 1970 surface waters contained high tritium due to atomic bomb testing.
- CX-40 was measured at 10 m depth intervals from 10 m - 50 m below the water level. There is an increase in <sup>3</sup>H from 10 m to 20 m and again to 40 m, however at 30 m and 50 m <sup>3</sup>H levels were below detection. The data suggests different groundwater reservoirs at different depths.

Figure 6 (right):  
<sup>3</sup>H measured in 18 groundwater samples are reported in Tritium Units (TU). Sample names are labeled as the hole ID followed by the sampling depth. Error bars represent 1 standard deviation between replicate analyses (n=6).



## Depth Profiles

- Samples collected at 10 m depth intervals within one exploration drill hole (CX-40) show how pH, conductivity, chlorine and <sup>222</sup>Rn vary with depth.

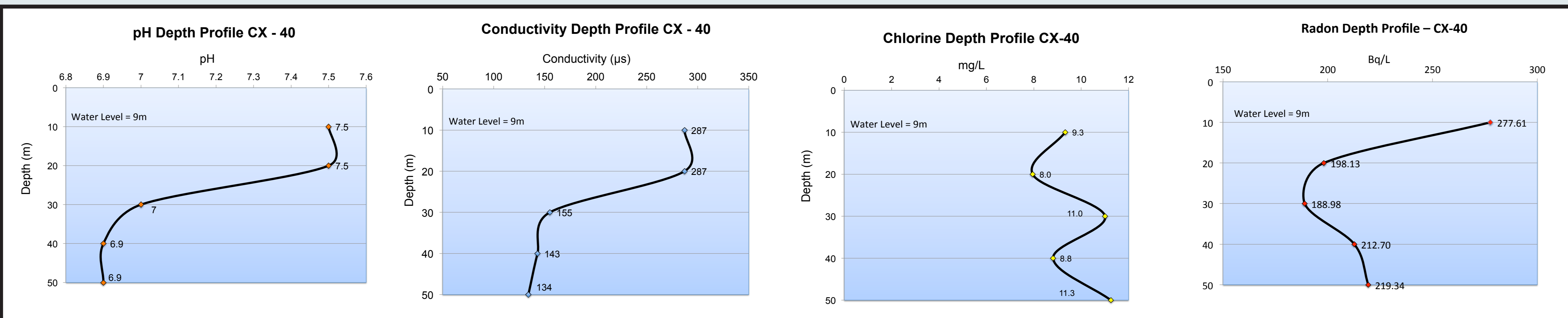


Figure 7:

- pH generally decreases with depth. Overall the pH ranges from neutral to slightly more alkaline conditions at shallower depths.
- Conductivity ranges from 134 us to 287 us and generally decreases with depth.
- Chlorine concentrations range from about 8 mg/L to 11.3 mg/L with no direct trend with respect to depth.
- The down-hole profile of CX-40 shows no direct trend of Rn concentration with depth. Anomalous values occur throughout the water column with the highest values at roughly 10 m below the surface.

## Analytical Methods

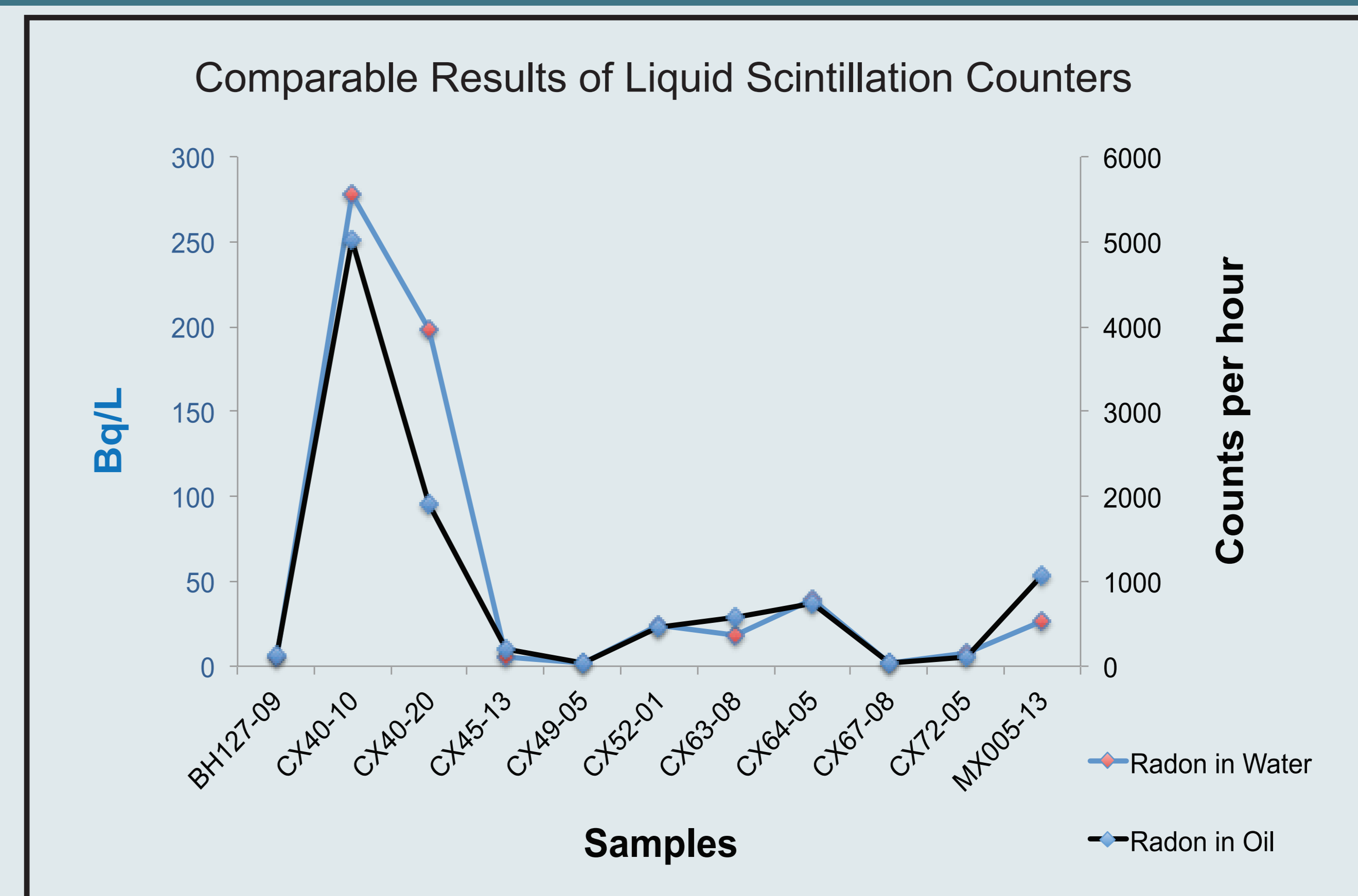


Figure 8:  
Analytical results from the "radon in water" and "radon in oil" show a very similar trend. Radon concentrations in oil samples were not calibrated, so results are not quantitative, but show relative concentrations of samples. By comparing them to quantitative Bq/L results, we see that scintillation counting of extracted oil from water is an effective sampling technique.

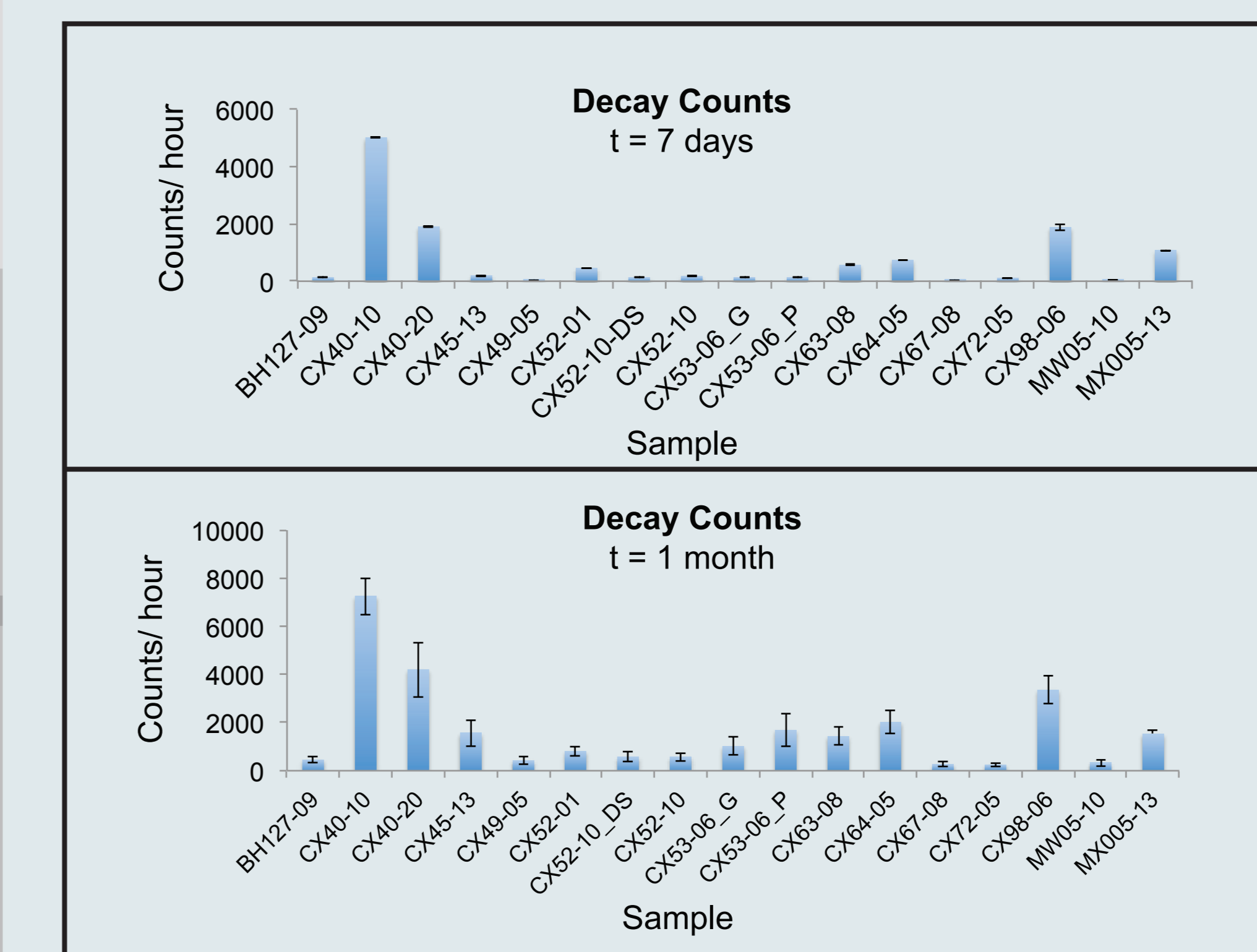


Figure 9:  
Nearly one month after sampling, groundwater with initially anomalous counts of Rn still show higher values. After counting each sample for 420 minutes (7 rounds of 1 hr counting), values were converted to counts per hour and compared to the initial counting results. Error bars represent 1 standard deviation between analyses (n=7).

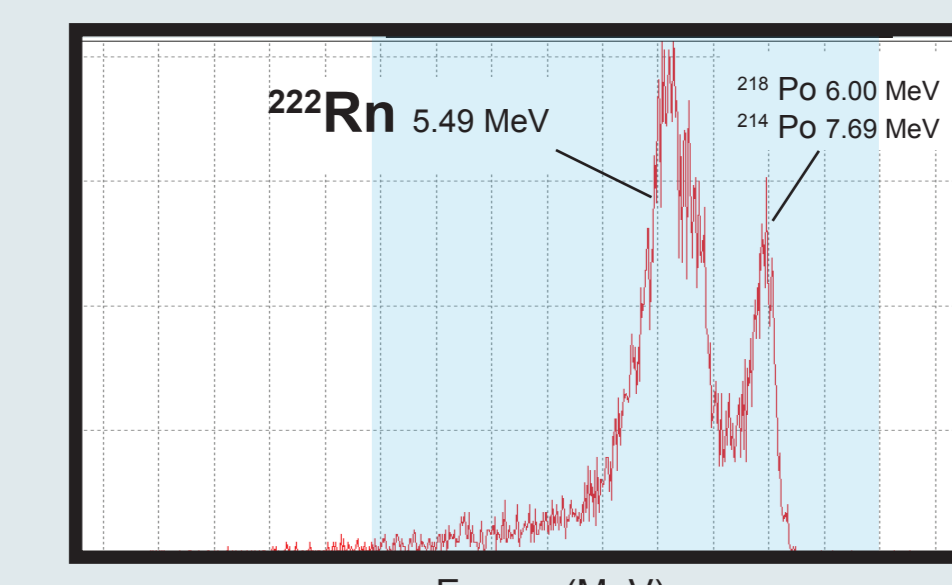


Figure 10: Emission energy spectrum of a sample (CX-40) shows the alpha particle emission from radon and its decay products. The data were collected in the range of 3-9 MeV, shown in blue.

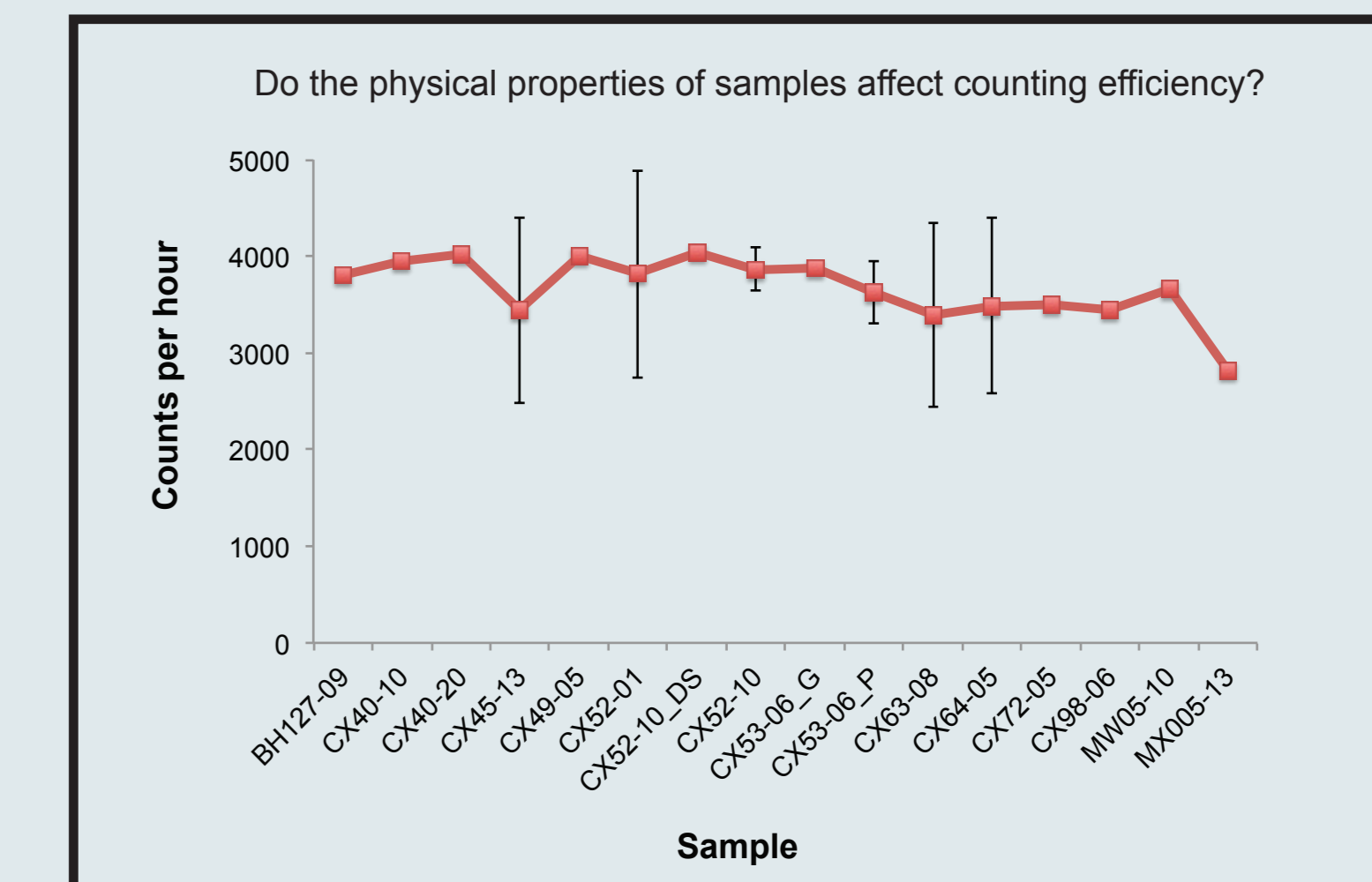


Figure 11:  
To test if suspended sediment and colour affect scintillation counting efficiency, radon from a water sample with high Rn concentrations was extracted using the mineral oil method. 5 mL was then added to fully decayed "mineral oil method" samples. Results show that each sample yielded similar counts, suggesting that physical properties had little effect.

## Future Work

- Gas diffusion sampling will be carried out at other sites in the next field season to evaluate the extent of Rn anomalies and local background values.
- Larger quantities of groundwater will be sampled and concentrated to get more accurate and precise <sup>3</sup>H values.
- Determine U, Pb, Th, I, Br and dissolved organic carbon concentrations in groundwater.
- <sup>129</sup>I and <sup>210</sup>Pb analysis of groundwater.

## Summary

- Similar results were found from the diffusion sampler method and the mineral oil method. The gas diffusion sampler method is the easiest in the field.
- CX-40 is a near vertical borehole almost directly above the mineralization. It gave the highest concentration of Rn in groundwater samples.
- Varying levels of anomalous Rn occur throughout the deposit area, not just directly above mineralization.
- Groundwater tritium values ranged from below detection to 11 TU, which may suggest that groundwater recharge occurred since the 1970s.
- Radon concentration was the highest near the top of water column. The variation in Rn contents is not correlated with those of concentrations of Cl, pH, conductivity and <sup>3</sup>H.
- The efficiency of liquid scintillation counting does not appear to be strongly affected by the physical properties of mineral oil, such as color and suspended sediment.
- Radon has a very short half-life of 3.8 days, but nearly one month after sample collection, groundwater samples with high Rn concentrations yielded anomalously high alpha emission.