



Preliminary Water Well Sampling to Assess the Uranium Potential in the Whiskey Gap Area of Southern Alberta (NTS 82H/2, 3)

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Preliminary Water Well Sampling to Assess the Uranium Potential in the Whiskey Gap Area of Southern Alberta (NTS 82H/2, 3)

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Abstract

The Milk River Ridge–Whiskey Gap area has seen both historic and recent exploration for sandstone-hosted uranium deposits. Within the past two years, mineral exploration industry reports have stated that selected well waters in the Milk River Ridge–Whiskey Gap region produced water samples with highly elevated concentrations of radon and, to a lesser extent, uranium. For example, Hartley (2005, 2007) reported 26 water well samples from the area produced: (a) radon concentrations averaging 32.6 becquerels per litre (Bq/L), with some samples having radon concentrations up to 185 Bq/L, and (b) uranium concentrations averaging 8.4 ppb, with some samples having uranium concentrations up to 30 ppb.

As a result, the AGS conducted a preliminary program of water well sampling in June 2006 that resulted in the collection of 20 water samples from 19 sites distributed about the Milk River Ridge–Whiskey Gap area. The water samples collected by the AGS were analyzed at the Saskatchewan Research Council for radon, uranium and a suite of 24 other elements. Results from these 20 water samples include the following: (a) radon contents ranging from 7 up to 222 Bq/L (189–5994 picocuries/L), (b) uranium contents ranging from 0.2 up to 160 ppb, and (c) some other elements having, in places, elevated concentrations, including arsenic (up to 140 ppb), iron (up to 2.1 ppm), manganese (up to 0.5 ppm), molybdenum (up to 420 ppb), selenium (up to 7.1 ppb), sulphate (up to 670 ppm), vanadium (up to 14 ppb) and zinc (up to 56 ppb).

Prior hydrogeological mapping by Tokarsky (1974b) indicated there is a down-dip west-flowing ‘tongue’ of meteoric water that occurs in the Blood Reserve Formation and immediately adjacent strata east of and beneath the Milk River Ridge–Whiskey Gap area. As well, AGS field examinations during June 2006 found outcrops of Blood Reserve sandstone farther east along the Milk River ridge that exhibit both oxidization and reduction alteration colours. The author suggests these are important observations with respect to possible uranium genesis in this region. That is, the geological and hydrogeological settings existing at the Milk River Ridge–Whiskey Gap area are positive for the formation of sandstone-type uranium deposits because they are similar to in Wyoming, the Colorado Plateau, New Mexico and south Texas.

Future exploration in the Milk River Ridge–Whiskey Gap region should consider an exploratory drilling methodology or pattern similar to that used successfully in several sandstone-type uranium districts in the U.S.A. This methodology comprises (1) an initial wide-spaced drill pattern (holes from 2 to 10 km apart), (2) followed by more closed spaced drilling (holes from a few hundred m to 1–2 km apart) and (3) finally, closed-spaced drilling (holes tens of m to a few hundred m apart) in selected areas intended to find and define uraniferous zones.

Finally, regardless whether important concentrations of uranium exist at surface, in the subcrop or in the subsurface at the Milk River Ridge–Whiskey Gap area in southern Alberta, the hydrogeological setting, consisting of a westerly, downward-flowing tongue of groundwater beneath the Milk River Ridge, may explain the locally anomalous uranium, radon and other elements in groundwater along the flanks of the Milk River Ridge, and the reason that the Blood Reserve Formation is oxidized in this area.

1 Introduction

Starting in late 2004 and through 2005, there was extensive staking by a number of individuals and public mineral exploration companies for uranium in southern Alberta. In total, several million hectares (ha) were staked. The current disposition of mineral claims is shown on the Alberta Department of Energy (ADOE) website at www.energy.gov.ab.ca/2741.asp. The primary uranium exploration target sought is sediment-hosted deposits similar to those that occur in sandstone and related sedimentary strata, which range from early Mesozoic to early Tertiary in the U.S.A., such as those that exist in the Colorado Plateau (Fischer, 1968; Wood, 1968; Malan, 1968; Motica, 1968; Hewitt, 1968), New Mexico (Kelley et al., 1968), Wyoming (Harshman, 1968a, b; Mrak, 1968), South Dakota (Hart, 1968) and south Texas (Galloway and Groat, 1976), and elsewhere in the world such as in Kazakstan (Finch, 1985).

This staking, coupled with some early positive press releases by exploration companies and a few newspaper articles, heightened public as well as government interest in the potential for sediment-hosted uranium deposits in southern Alberta. As a result, the AGS initiated a potential multi-year project in early 2006 to evaluate the prospectivity of various stratigraphic units to be either potential source rocks or potential host rocks for sediment-hosted uranium deposits in this region. A report on the first year of this AGS study is under preparation for publication (i.e., Sandstone-Hosted Uranium Potential of Southern Alberta—Preliminary Assessment by T. Matveeva and S. Anderson, work in progress, 2007). The study reported on herein is a subset of this more comprehensive AGS regional study, and is focused on a specific area where recent exploration results indicated there are or may be anomalous concentrations of radionuclides (i.e., radon and uranium) in some well waters.

The study area is located north and northeast of Whiskey Gap, which is about 30 km southeast of Cardston, Alberta, within Cardston County. It encompasses portions of six townships (i.e., Tp 1 & 2, Ranges 22–24), within the southeastern-most corner of 1:50 000 NTS map area 82H3 (Cardston) and southwestern-most corner of 1:50 000 NTS map area 82H2 (Shanks Lake) (Figure 1). The area is accessed via paved highway from either Cardston or Del Bonita, and there are good gravel secondary and tertiary roads within and around the area.

Within the study area, which forms a rectangle about 13 km long (east-west) by 10 km wide (north-south), 20 water samples were collected from 19 sites from June 9–11, 2006 (Figure 1).

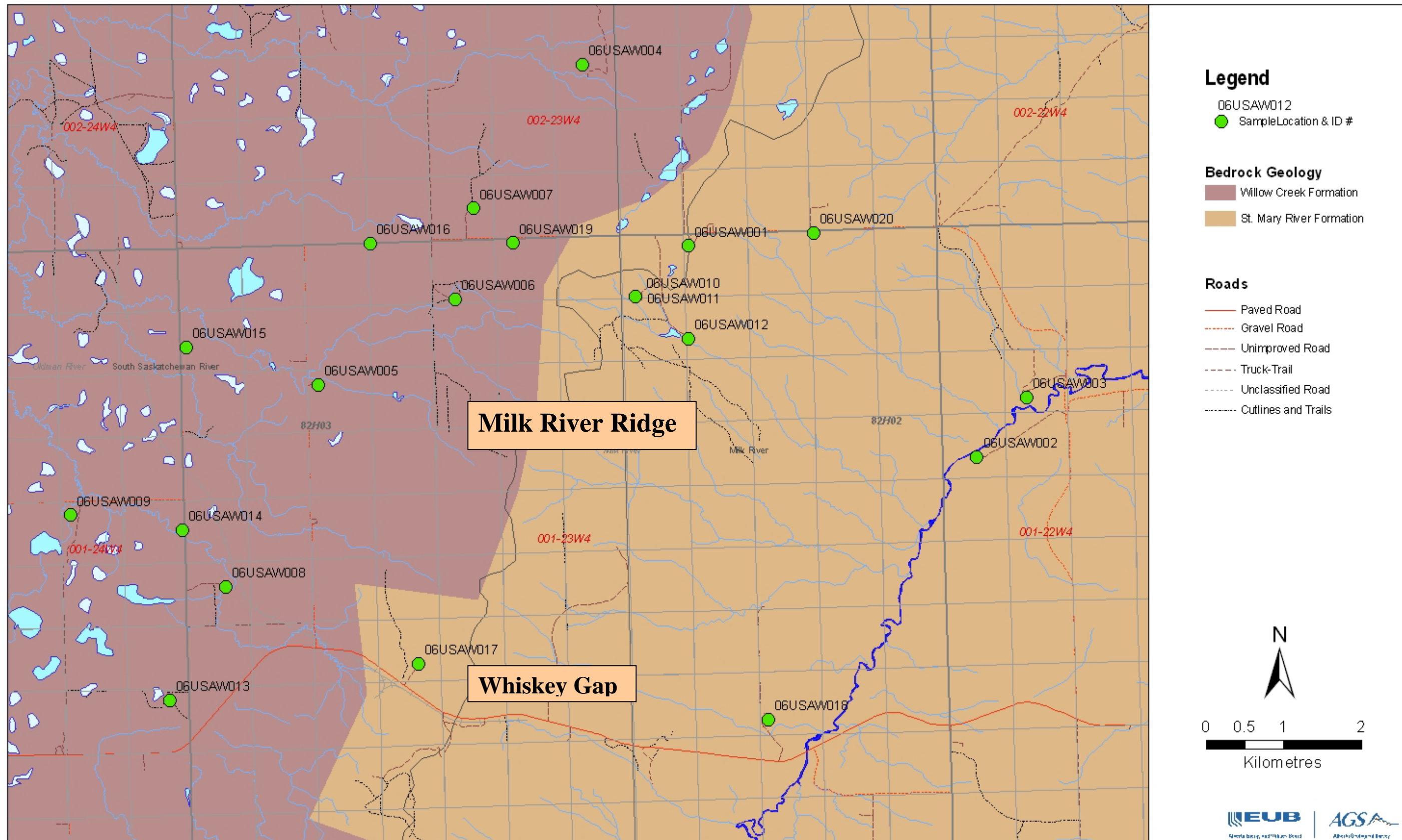


Figure 1. AGS 2006 water well sample locations and local geology

1.1 Brief Overview of Radioactive Decay and the Common Terms Used to Describe and Measure Radioactive Decay

There are some 30 radioactive elements in the Periodic Table, but perhaps the more common are uranium (U), thorium (Th) and potassium (K). In each case, these elements decay by nuclear disintegration through a series of daughter products. Information about radioactive decay, and particularly as it pertains to uranium, can be found on several informative websites including www.cameco.com/uranium_101/,

Uranium has two naturally occurring isotopes: uranium-238 (^{238}U , about 99.28% of all naturally occurring uranium) and uranium-235 (^{235}U , about 0.72% of all uranium). These two uranium isotopes, along with thorium, decay through emission of alpha (α) or beta (β) particles, plus emission of gamma (γ) radiation. In uranium decay, the process occurs in one of two ways: (a) ^{238}U and ends with lead (specifically ^{206}Pb , commonly referred to as the ‘uranium’ decay series) or (b) with ^{235}U and ends with ^{207}Pb (referred to as the ‘actinium series,’ which was named for its first-discovered member, actinium-227). The thorium series begins with thorium-232 (^{232}Th) and ends with the stable nuclide ^{208}Pb . Potassium (K) exists in three isotopes: ^{39}K (93.2581% of all potassium), ^{40}K (0.0117%) and ^{41}K (6.7302%). However, only the ^{40}K isotope is radioactive and decays to ^{40}Ar and ^{40}Ca by electron capture and positron decay.

Each isotope in a decay series has a ‘half-life,’ which for a given radioisotope is a measure of the tendency of the nucleus to ‘decay’ and, as such, is based purely upon probability. In essence, the radioactive half-life for a radioisotope is the time for half the radioactive nuclei in a mass of the radioisotope to undergo radioactive decay. For example, after 1 half-life there will be 1/2 of the original mass present, after 2 half-lives there will be 1/4 of the original mass, after 3 half-lives, 1/8 of the original sample, and so on.

The most common uranium isotope, ^{238}U , decays through a series of daughter product isotopes as summarized in Table 1; this table has radionuclides colour-coded as follows: (a) green for isotopes with very long half-lives ranging from thousands to millions of years; (b) yellow for half-lives ranging from tens to hundreds of years; (b) orange for half-lives that range from a few to tens of days, and (d) pink for those isotopes with very short half-lives ranging from minutes to seconds or fractions of seconds. The end product of ^{238}U decay is the stable end product ^{206}Pb .

Table 1 also shows some interesting aspects of uranium-238 decay, including: (a) ^{238}U has a very long half-life (i.e., ~4.47 billion years) and its intermediary, ^{234}U , has a half-life of 244,500 years; hence, the radioactivity of these two uranium isotopes actually is very low; (b) in contrast, some isotopes in the decay series, such as ^{234}Th , ^{234}Pr , those from ^{222}Rn to ^{214}Po , ^{210}Bi and ^{210}Po , have short half-lives ranging from fractions of a second up to about 138.4 days for ^{210}Po ; hence, they are important sources of radioactivity. In fact, it is the gamma radioactivity and particles emitted by these elements (especially ^{214}Pb and ^{214}Bi) with short half-lives that are detected by radiation detection instruments such as Geiger counters or scintillometers.

With specific reference to radon (Rn), it is a naturally occurring, colourless, odourless, gas produced by the radioactive decay of the element radium as shown in Table 1. The radon-222 isotope (^{222}Rn) has a half-life of about 3.82 days, and its parent radium-226 (^{226}Ra) has a half-life of approximately 1600 years. In general, all uranium-bearing zones undergo radioactive decay and, in this process, radon is produced during the radioactive decay process, with the radon gas commonly being either dissolved and transported in groundwater or rising as a gas to the ground surface where it may be detected by various methods (e.g., Track Etch). As a result, a common exploration technique for uranium is sampling untreated well waters, and measuring the amount of dissolved radon gas in a fixed volume of water. Because radon has a very short half-life of 3.82 days, high radon content in groundwaters does indicate that a radium source probably exists in the vicinity. However, because the parent precursor uranium is much farther up the

decay chain, the presence of anomalous radon may or may not indicate that a uraniferous zone is in close proximity.

Table 1. Uranium-238 daughter products, half-life and primary decay method

Isotope	Half-life	Primary Decay by
Uranium-238	4.468 x 10 ⁹ yrs	Alpha + minor γ
Thorium-234	24.1 days	Beta + minor γ
Protactinium-234	1.17 min	Beta + minor γ
Uranium-234	2445 x 10 ⁵ yrs	Alpha + minor γ
Thorium-230	7.7 x 10 ⁴ yrs	Alpha + minor γ
Radium-226	1600 yrs	Alpha + mod. γ
Radon-222	3.8235 days	Alpha
Polonium-218	3.05 min	Alpha
Lead-214	26.8 min	Beta + high γ
Bismuth-214	19.9 min	Beta + high γ
Polonium-214	1.64*10 ⁻⁴ seconds	Alpha
Lead-210	22.26 yrs	Beta
Bismuth-210	5.013 days	Beta
Polonium-210	138.378 days	Alpha
Lead-206	Nil	Stable end product

In short, the direct parent-daughter relationship between ²²⁶Ra and Rn²²², coupled with the variations in the geochemical mobility of various radionuclides, affect the use of radon as an indicator of the proximity to the original parent uranium source. For example, uranium is mobile under oxidizing conditions and immobile under reducing conditions, whereas the reverse is true for the daughter product radium. As a result, if a uranium deposit forms at a site within a favourable sedimentary rock because of oxidizing fluids that have moved through the rock until they interact with a reductant (e.g., organic carbon or some sulphide minerals such as pyrite) then uranium can accumulate and remain immobile if the reducing conditions persist. However, over time as the ²³⁸U decays to its daughter product ²²⁶Ra, and if the radium subsequently is transported away from the parent uranium via reducing fluids, then if these reducing fluids interact with an oxidizing environment, the radium can precipitate from solution. If such occurs, then as the radium decays it produces radon (in this case ²²²Rn); in some cases the parent radium isotope may be sufficiently accumulated to produce 'anomalous' concentrations of radon. As a result, a radon

anomaly (e.g., in soil or water) indicates the proximity of radium due to the short half-life of radon, but it may or may not reflect proximal uranium. That is, it only indicates proximal radium and uranium if the radium produced by ^{238}U decay remains with or very close to its parent uranium source.

Uranium in groundwater is usually present only in very small amounts, and thus normally it is reported by analytical laboratories in parts per billion (ppb). With respect to radon, in the past it normally was reported in picoCuries per litre (pCi/L) where a 'Curie' is defined as the quantity of any radionuclide in which the number of disintegrations per second is 3.7×10^{10} . A 'pico' is 1 trillionth (i.e., 10^{-12}) of the unit to which it is joined, hence a picoCurie essentially is 0.037 disintegrations per second. More recently, radioactive decay is reported in Becquerels, with 1 becquerel (Bq) being equal to 1 nuclear decay or other nuclear transformation per second. The following conversions can be used for consistency between Bq/L and pCi/L:

1 Ci/L = 3.7×10^{10} Bq/L, and

1 pCi/L = 0.037 Bq/L, and

1 Bq/L = ~ 27 pCi/L (i.e., $1/0.037$, which, more precisely, equals 27.027027 pCi/L).

1.2 Synopsis of Prior Exploration for Uranium in Southern Alberta

Olson et al. (1994) summarized prior exploration for uranium in the Phanerozoic strata of Alberta between the late 1960s to the early 1980s, based on information in publicly available assessment reports on file with the AGS and on information in selected proprietary reports on file with R.A. Olson Consulting Ltd. With respect to the uranium content of surface waters in southern Alberta, Olson et al. (1994) reported "up to 240 ppb U [parts per billion uranium] in well waters in the vicinity of a 'faulted zone' at the Eagle Butte Structure in the Bullshead Creek area of the Cypress Hills [and] up to 144 ppb U in well waters from Upper Cretaceous argillaceous sandstone of the Milk River Formation [near Foremost, southwest of the Cypress Hills]." There was no data reported for other radionuclides, such as radon or radium, in surface waters. With respect to the uranium content of surficial sediments and bedrock, Olson et al. (1994) reported "up to 0.01% U_3O_8 across 2.44 m from drill core of carbonaceous claystone within the Ravenscrag Formation," that (Grant, 1981) reported the "average uranium content for 325 stream sediment samples... was 0.6 ppm," with anomalous samples containing from 4 to 6 ppm uranium existing northeast of Claresholm, and that Grant (1982), reported prospecting of Willow Creek Formation along the Waterton River about 30 km south of Fort MacLeod, "discovered a silty limestone with anomalous radioactivity... up to 2,000 cps (SRAT SPP2N), and a rock sample [that produced] assays greater than 2,000 ppm U, 13 ppm Mo, 78 ppm V and 4 ppm Se." It is known that there was exploration for sediment-hosted uranium in southern Alberta by other companies during the period from the 1960s to the early 1980s, but the results of this work are not publicly documented or readily available.

Due to the uranium market downturn from the early 1980s until the early 2000s, there was little or no exploration for uranium in southern Alberta during this period. However, as a result of the rapidly increasing spot price of uranium from less than \$10US/lb. U_3O_8 in early 2003 to \$120US/lb. as of mid-May 2007, there has again been renewed interest in the potential for sediment-hosted uranium deposits in southern Alberta. Beginning in late 2004, and in large part started due to the Metallogenic Study completed in the early 1990s by the AGS (Olson et. al., 1994), several million hectares (ha) were staked in a belt of mineral permits that stretches from immediately south of Calgary, south to Pincher Creek, then east to Whiskey Gap, Del Bonito and to the Cypress Hills in southeastern-most Alberta (see ADOE website www.energy.gov.ab.ca/2741.asp). Summaries of company activities and exploration highlights for recent uranium exploration in Alberta can be found in Olson et al. (2005, 2006).

Of particular relevance to the current study was a report done for International Ranger Corporation that reported on radon sampling of selected water wells in the Whiskey Gap area (Hartley, 2005). Hartley (2005) stated (a) that prior to their water well sampling he had examined well information for 118 water wells previously drilled on the International Ranger Mineral Permits and he found that in some water well logs there is “strong alteration present in bore holes drilled in the Willow Creek Formation”; and (b) he collected a total of 26 “widely distributed” samples in “a ‘door to door’ campaign, [and] as much well data was [sic] collected as available from the individual residents, specifically information relating to the time of collection, depth of the well and general condition of the well. No water samples were collected from wells that had a water softener, unless the sample could be collected by bypassing the softener system.” Regarding sample collection procedures, Hartley (2005) stated (c) that the samples were collected between August 9 and 11, 2005; (d) that four individual samples were collected from each water well sampling site, including (i) two glass 10 mL samples for radon analysis, (ii) one 50 mL plastic bottle preloaded with 5 mL of 17% nitric acid, which was analyzed for uranium, and (iii) one 50 mL plastic bottle, which was not acidified, that was analyzed for sulphate; and (e) that for the radon samples the time between collection and analysis for radon did not exceed one half-life of 3.8 days. In Hartley’s (2005) report, his Table 1 provides the radon results in both Bq/L and pCi/L with the conversion between the two measurements given as 1 Bq equals 27.03 pCi/L, plus the results for uranium in water in ppb and sulphate in water in ppm. Hartley’s (2005) water well results are tabulated in Table 2.

Although the paper by Hartley (2005) provided the analytical results, it did not provide specific sample sites or a location; hence, the exact location of each sample was unknown, except to the extent they are all from the Whiskey Gap area, during the AGS water well sampling program conducted in June 2006. In May 2007, however, International Ranger provided an update on the results from their Whiskey Gap project (Hartley, 2007); in this report (Hartley, 2007, his Maps 1 and 2) provides the location of the 26 water well samples he had previously collected at Whiskey Gap area.

In summary, Hartley’s (2005) radon, uranium and sulphate in water reported results comprise

- (a) for radon, from 1 Bq/L up to 185 Bq/L (27.03 up to 5000 pCi/L) with the arithmetic average or mean being 32.6 Bq/L (880.8 pCi/L);
- (b) for uranium, from less than 0.1 ppb up to 30 ppb, with the arithmetic average being about 8.4 ppb (Hartley, 2005, reported a mean of 11.5 ppb uranium, but based on the data given, the arithmetic average should be 8.4 ppb or, possibly 9.1 ppb, if the two samples having a uranium content below detection of 0.1 ppb are excluded); and
- (c) for sulphate, from 17 ppm up to 270 ppm sulphate in well water, with the arithmetic average being 101.6 ppm.

Hartley (2005) compared his Whiskey Gap water well results to results for 25 water wells in the South Texas Uranium District (as reported in Beaman and Tissot, 2004) and in waters from the uranium producing areas of Wyoming that were published in 1996/1997 (no reference provided by Hartley, 2005). Hartley (2005) noted (a) for the 25 water samples from South Texas, the radon concentrations ranged from 42 up to 4,813 pCi/L, with the arithmetic, average radon concentration being 687 pCi/L; and (b) for Wyoming, radon concentrations exceeding 3000 pCi/L exist in three counties where past uranium production has occurred.

Table 2. Radon, uranium and sulphate results from Hartley (2005) Table 1 entitled “Whiskey Gap Well Sample Data”

Hartley (2005) Water Well Sample #	Radon		Uranium (ppb)	Sulphate (ppm)
	Bq/L	pCi/L (calculated) ¹		
85	8.6	232.46	9.0	20
86	88.0	2378.64 ³	17.0	48
87	24.0	648.72	1.5	49
88	30.0	810.90	6.8	38
89	14.0	378.42	4.7	210
90	1.0	27.03	2.3	270
91	42.0	1135.26	7.1	100
92	20.0	540.60	2.2	100
93	4.4	118.93	<0.1 ²	570
94	16.0	432.48	10.0	32
95	13.0	351.39	3.1	70
96	44.0	1189.32	4.7	28
97	2.6	70.28	<0.1	45
98	5.6	151.37	1.9	190
99	30.0	810.90	27.0	40
100	25.0	675.75	7.1	84
101	25.0	675.75	4.9	20
102	47.0	1270.41	5.4	17
103	23.0	621.69	16.0	23
104	16.0	432.48	24.0	73
105	67.0	1811.01	30.0	250
106	12.0	324.36	15.0	150
107	185.0	5000.55	3.4	56
108	40.0	1081.20	5.1	79
109	22.0	594.66	3.3	44
110	42.0	1135.26	6.9	36
Arithmetic Average	32.6	880.8	8.4	101.6
Arithmetic Average for U, excluding 2 samples below detection			9.1	

¹Note: Radon in pCi/L is calculated from the Bq/L results using a factor of 27.03 pCi/L = 1 Bq/L (Hartley, 2005).

²Note: <0.1 denotes less than 0.1 ppb detection

³Note: Beige and pink colours identify those samples that exceed the recommended levels in potable drinking water as discussed below.

Hartley (2005) concluded, from a mineral exploration perspective, that the elevated radon in water results for some of his samples from the Whiskey Gap area, which are comparable in concentration to water wells from the South Texas and Wyoming uranium areas, “must be regarded as extremely positive.” Furthermore, “uranium values in waters exceeding 4 ppb are considered to be of exploration interest, in American sandstone hosted uranium deposits,” and finally, that sample locations (e.g., his site 105) with elevated sulphate (250 ppm), high uranium (30 ppb) and elevated radon (1811 pCi/L) “must be considered extremely prospective and should be further investigated.”

In Table 2, the beige and pink highlights identify those samples that exceed the recommended levels in potable drinking water as discussed in greater detail below in Section 2.3. As a result of these analyses reported by Hartley (2005), and because there were no sample locations available in mid 2006, the AGS undertook a small program of water well sampling in the Whiskey Gap area during June 2006 as part of a preliminary reconnaissance evaluation for sandstone-hosted uranium deposits in southern Alberta.

1.3 Synopsis of Prior Water Well Sampling in Southern Alberta and Adjacent Southwestern Saskatchewan and Northern United States of America

During the 1970s, the Geological Survey of Canada (GSC) completed a federal-provincial groundwater uranium orientation survey in the Cypress Hills area of southwestern Saskatchewan (Dyck and Campbell, 1976). In this survey, about 1000 well and spring water samples were collected from a 17 900 km² region within map areas NTS 72F, 72K/1 and 72K/2 in southwestern Saskatchewan. The samples were analyzed for uranium (U), radon (Rn), fluorine (F), oxygen (O₂), standard reduction potential (also termed redox potential or Eh), acidity (pH) and alkalinity. Dyck and Campbell (1976) stated, “the U and Rn ranges were 0–240 ppb and 0–4100 pCi/L, respectively... a regional coincidence between U and Rn highs is present where relief is low. Where relief is moderate, a displacement of U highs towards the lowlands, relative to Rn, is evident. In each of the main exposed formations, the deepest wells have lower U and Rn contents on average than the shallower wells. This fact, plus a strong positive correlation between U and alkalinity, suggests near-surface leaching of rocks and radioactive lignites, solution transport downward, and loss of Rn by decay and U by precipitation or later dilution.”

Dyck and Campbell (1976) concluded that “while the U values [in southwestern Saskatchewan] are appreciably higher and the Rn values lower than those encountered in the Carboniferous basin of Eastern Canada... they are still much lower than the 18,000 ppb U high observed in the U ore-bearing Morrison Formation of the Colorado Plateau (Phenix, 1960), or the 200,000 pCi/L Rn observed by Harshman in the U-bearing district of Wyoming (Harshman, 1968).”

With respect to information about uranium and radon in groundwater in northern Montana, the Montana Geological Survey website www.mbmgt.mtech.edu/radon.htm#radongeology states, “Many water wells in Montana contain high levels of radon. Data from the Ground-Water Information Center (housed at MBMG), indicate that out of a total of 386 water analyses, 103 wells (27%) contain radon in concentrations under 300 pCi/L, 271 wells (70%) showed radon between 300 and 3,000 pCi/L, and 12 wells (3%) contained radon in excess of 3,000 pCi/L.” In short, some 70% of wells tested in Montana have radon concentrations between 300 and 3000 pCi/L. The website also suggests that the glaciated northern Great Plains in Montana “has a high geologic radon potential at a moderate confidence level.” Regarding aquifers, this website states “none of the wells in Cretaceous sediments contained water with radon concentration greater than 3,000 pCi/L. But wells in the Quaternary sediments and in the Tertiary rocks showed concentrations ranging from 10 to 14,000 pCi/L. [Further,] there are large variations in ground-water radon levels, even in the same aquifers and adjacent locations.”

Turning to southern Alberta, and specifically NTS map area 84H, in the past there have been several regional studies of groundwater; these include, for example, the reports by Geiger et al. (1965), Tokarsky (1974a, b), Meyboom (1960) and Toth et al. (1977, see especially the chapter by Wallick, p. 19–30, entitled “*Sampling of Groundwater for Chemical Analysis*”). However, all of these reports are now quite old, and none has data or information on uranium or radon in groundwater. Fabryka-Martin et al. (1991) did provide some information with respect to the radon content in the Milk River aquifer; this unit exists at depth (at least about 1200 m below ground surface) in the Whiskey Gap area (Tokarsky, 1974b). More recently, the groundwater in southern Alberta has been summarized (a) for the County of Warner No. 5 (immediately to the east of the Whiskey Gap area) by Stantec Consulting Ltd. (2002) and (b) for Cardston County (which encompasses Whiskey Gap area) by Hydrogeological Consultants Ltd. (HGCL, 2003).

The HGCL (2003) report describes the hydrogeology in Cardston County, including Tp 001 to 007, R 19 to 29, W4M and stated the following generalizations:

- (a) There are 2,671 water wells in Cardston County, with 2,264 water wells being completed for domestic/stock purposes, and the remainder being completed for other purposes.
- (b) For 2,134 of the water wells there is a completion depth given, and, for these, about 81% (~1728 wells) have a completion depth of <50 m.
- (c) There are 886 water wells with both completion intervals and lithologic information such that the aquifer can be determined; for these wells 427 (~48%) were completed in surficial aquifers.
- (d) There are 146 springs in the groundwater database for Cardston County.
- (e) Figure 2 in the HGCL (2003) report indicates that in the Whiskey Gap area there are water wells producing from both bedrock and surficial aquifers, and there are a few springs present.
- (f) Figure 4 in the HGCL (2003) report indicates that the Base of Groundwater Protection, which, they state, AENV defines as the elevation below which groundwater will have more than 4000 milligrams per litre (mg/L or ~1 mg/L = 1 ppm) of total dissolved solids, reaches depths of up to several hundred metres in the Whiskey Gap region.
- (g) Regionally, the bedrock surface varies between 820 and 1460 m above mean sea level (amsl) across the country, but some of the highest bedrock topography (above 1300 m amsl) occurs along the northeasterly-trending Milk River Ridge.
- (h) In most of the region, the surficial deposits are less than 45 m thick; however, they tend to be thickest in buried valleys such as the Buried Whiskey Valley, which lies southeast of and subparallel to the Milk River Ridge.
- (i) The chemical quality of groundwater from surficial deposits are generally chemically hard and high in dissolved iron; with specific respect to sulphate (HGCL, 2003, Table 4), the range is from zero up to 3500 mg/L, with the median being 250 mg/L.
- (j) The chemical quality of groundwater in 'upper bedrock' aquifers comprises from <500 mg/L up to more than 2000 mg/L total dissolved solids (TDS), and with respect to sulphate, when TDS exceeds 1200 mg/L, the sulphate concentrations typically exceed 400 mg/L.
- (k) With respect to the lower Willow Creek and upper and lower St. Mary River Formations, which underlie and comprise much of the bedrock along the Milk River Ridge, (1) for Willow Creek Formation TDS is mainly <1500 mg/L and the sulphate concentrations generally are <1000 mg/L with more than 73% of the groundwater samples from Willow Creek Formation having <500 mg/L, and (2) for St. Mary River, TDS ranges from <500 up to >3000 mg/L and the sulphate concentrations range from <150 mg/L up to > 1500 mg/L, with more than about 50% of the samples having <500 mg/L sulphate.
- (l) Finally, the HGCL (2003) report does not discuss uranium or radon in groundwater in Cardston County; hence, one assumes there are no or very little data for these radionuclides.

1.4 2006 AGS Water Well Sampling Methodology

In 2002, the AGS published a series of Geo-Notes that provide current ‘standard hydrogeological’ protocols for sampling (a) surface and spring waters (Lemay 2002a), (b) groundwater from wells (Lemay, 2002b) and (c) formation water from wells (Lemay, 2002c). These protocols were not developed by the AGS, but, instead, are a compilation of published water sampling protocols that were largely taken from those prescribed by the United States Geological Survey (USGS), supplemented by comments and recommendations obtained from hydrogeologists and other specialists employed by the University of Alberta, University of Calgary, University of Saskatchewan in Saskatoon and GSC in Calgary.

Regarding water wells, Lemay (2002b) recommended “standard purge procedures involve removal of at least three well volumes of standing water. Field measurements, water level, pumping rate and the volume of water removed are recorded as a function of time.” Further, “a sufficient volume has been purged from the well when the variability in sequentially monitored field measurements is within the prescribed criteria for stability.” The field measurements being referred to by Lemay (2002b) are given in his Table 1 and include the following: pH (acidity, ± 0.1 standard pH units), temperature (± 0.2 to 0.5°C depending on whether a thermistor or liquid in glass thermometer is being used), specific electrical conductance ($\pm 3\%$ to 5% for $\text{SC} > 100$ and ≤ 100 $\mu\text{S}/\text{cm}$), and dissolved oxygen (± 0.3 mg/L). In essence, the purging of wells is intended to stabilize these field measurements prior to collection of any samples.

With respect to surface stream and spring waters Lemay (2002a) describes protocols for ‘isokinetic’ vs. ‘non-isokinetic’ sampling; in general, and in the simplest of terms, non-isokinetic sampling refers to taking a ‘grab’ water sample (which hopefully is representative, but may not be) from a specific stream or springwater source. Lemay (2002a) describes four separate non-isokinetic sampling methods, termed ‘Dip Sampling,’ ‘Discrete Sampling,’ ‘Pump Sampling’ and ‘Still Water Sampling’ methods. Because, in most cases, the stream or spring is flowing, there is no purging process as is the case for a water well sample.

Turning to the sampling methodology done by the AGS during June 2006, methods and results were as follows:

- 1) The intent was to sample water wells in a semi-regional reconnaissance fashion along both the northwestern and southeastern sides of the Milk River Ridge northeasterly from Whisky Gap along Highway 501;
- 2) A map that illustrated possible water well sample sites had previously been obtained from AENV; this was used to visit selected landowners on June 9 to request their permission to sample their well;
- 3) Sampling was done on June 10 and 11, 2006, and 20 water samples (06USAW001 to 06USAW020) were collected from 19 sites, with two samples (06USAW010 and 06USAW011) being duplicate samples collected from the same well (Figure 1). Of the 19 sites,
 - a) 17 are definite wells;
 - b) 1 of the wells is flowing (at sample site 06USAW016);
 - c) 1 site (06USAW004) was taken from a water trough believed to be derived from a spring; another site (06USAW005) was believed to be from a well, but the AENV database indicates the source is from a spring.
- 4) In general, the AGS 2006 sampling protocols were
 - a) The water well was allowed to run for about 10–20 minutes to purge somewhat, but, in general, this period was prescribed by what the well owner would permit and the AGS time restraints to complete the sampling over two days. In short, it is improbable that each well

- was purged to three well volumes, nor were any field measurements taken to assess well stabilization as prescribed by Lemay (2002b);
- b) Four individual samples were collected from each water well sampling site, including (i) two glass 10 mL samples for radon analysis, (ii) one 50 mL plastic bottle preloaded with 5 mL of 17% nitric acid which was analyzed for uranium and a suite of other elements and (iii) one 50 mL plastic bottle that was not acidified and was analyzed for sulphate;
- 5) The samples were packaged for safe transport, driven to Calgary on June 12, and sent via surface courier to SRC Geoanalytical Laboratories in Saskatoon. The SRC lab reports indicate the water samples were received by them on June 13, 2007 and all radon analyses were completed during the a.m. period on June 15 (Chorney, pers. comm., 2007). Thus, the maximum and minimum times from collection to radon analyses (for samples 06USAW001 and 06USAW020, respectively) ranged between approx. 4.8 and 3.8 days. SRC uses the exact date and time of sample collection, vs. the exact date and time of their analyses, to back-calculate the radon content at time of sampling using a radon half-life of 3.82 days (Chorney, pers. comm., 2007).

2 Regional Geology

2.1 Synopsis of Stratigraphic Units in the Whiskey Gap Area, Southern Alberta

The geology of the Milk River Ridge–Whiskey Gap area is shown at 1:253 440 (1 inch = 4 miles) scale on GSC Map 20-1967 (Irish, 1968). In general, in subcrop the area is underlain by the Willow Creek and St. Mary River Formations.

In summary, the following stratigraphic units, from top to subsurface, exist in outcrop, subcrop and in the shallow subsurface in the Milk River Ridge–Whiskey Gap area.

Quaternary Surficial materials and Overburden

In general, the Milk River Ridge–Whiskey Gap area is extensively mantled with glacial and glaciofluvial deposits of clay, silt, sand, gravel and till so that bedrock exposures are rare, except along parts of the major river or stream valleys, or in a few places in road cuts, such as those that exist at Whiskey Gap (Irish, 1968). The thickness of the surficial material is variable, ranging from metres or less, to, in a few places, a few tens of metres or more thick.

Paleocene and Late Cretaceous (late Maastrichtian) Willow Creek Formation

Willow Creek Formation consists of soft, medium-grained, grey argillaceous sandstone interbedded with clayey, brightly multi-coloured grey, green and pink shale, plus some calcareous shale, fossiliferous limestone and massive, crossbedded, buff-weathering grey sandstone in the upper part. The unit is continental (i.e., non-marine) and is about 300–400 m thick along the Oldman River.

Late Cretaceous (Maastrichtian) St. Mary River Formation

Typically, the St. Mary River Formation is a hard, buff-weathering, green-grey when fresh, fine-grained sandstone interbedded with friable green and grey silty shale. Fissile grey shale, coal and coquinoid limestone occurs in the basal part of the unit. In general, the unit is much drabber than the overlying Willow Creek Formation, is about 150 m thick along the Oldman River and is continental (i.e., non-marine). Tokarsky (1974a) stated the sandstone beds in the St. Mary River Formation constitute aquifers, albeit of generally low yield.

To the north, in the vicinity of Red Deer, the Willow Creek and St. Mary River Formations are separated by the Kneehills tuff zone. This unit comprises a light green to grey, white-weathering, clayey sandstone (Whitemud equivalent) that is overlain by mauve-weathering, dark purplish-grey bentonitic shale. This

unit is about 6 m thick along the Oldman River near Lethbridge. To the south, it appears to be absent (Irish, 1968); hence, in the south, the St. Mary River–Willow Creek Formations contact may be either a disconformity or an unconformity.

Late Cretaceous (early Maastrichtian) Blood Reserve Formation

The Blood Reserve Formation typically is a massive, buff- to yellow-weathering, grey or greenish grey sandstone that was deposited in a partly marine and partly non-marine environment. The Blood Reserve Formation is about 30 m thick near the Canada-U.S.A. border, but thins to the north and is absent north of Lethbridge (Irish, 1968). Tokarsky (1974a) noted that the Blood Reserve Formation “constitutes a good aquifer near Del Bonita.”

Late Cretaceous (late Campanian to early Maastrichtian) Bearpaw Formation

The Bearpaw Formation consists of dark grey and brownish grey, rubbly and flaky shale, silty shale and grey, argillaceous sandstone. In places, there are ironstone concretionary beds and bentonitic layers. The unit is marine and up to about 220 m thick along the St. Mary River. Tokarsky (1974a) stated the unit is an aquitard.

Although there are other units both to the east and west, and at depth, the above formations are the main units at surface and within a few hundred m depth at the Milk River Ridge–Whiskey Gap area.

For a more complete summary description of the stratigraphy in southern Alberta, see “Sandstone-Hosted Uranium Potential of Southern Alberta—Preliminary Assessment” (T. Matveeva and S. Anderson, work in progress, 2007).

2.2 Synopsis of Structure in Southern Alberta

A few km west of the Milk River Ridge–Whiskey Gap area is the eastern limit of Foothills deformation (Irish, 1968). However, structural deformation may occur farther east than this ‘limit’ because to the north, near Lethbridge, there is the Monarch Fault Zone, which presumably trends south-southeasterly towards the Del Bonita area. Near Lethbridge and some 60 km northeasterly of the eastern limit of the Foothills, the enigmatic Monarch Fault Zone comprises strata from the Bearpaw, Blood Reserve and St. Mary River formations that are extensively upturned and faulted. This locale is interestingly structurally because the strata to the west and east are relatively flat lying, whereas the strata at the Monarch Faulted Zone clearly are faulted and upturned.

At the Milk River Ridge–Whiskey Gap area, the Phanerozoic strata to the west generally dip gently easterly, whereas east of the axis of the Alberta Syncline they dip gently westerly (Irish, 1968). Farther east, near Del Bonita, there are a few other anticline and syncline axes, but, in general, the strata to the east dip gently westerly and there are few structures present other than jointing.

3 Summary of Results

SRC analyzed the 20 water samples for uranium, radon, sulphate and a suite of 23 other elements, as tabulated in Table 3. A detailed list of the analytical results for each sample is in the Excel spreadsheet that accompanies this report (Appendix I). Table 3 also provides the minimum and maximum concentrations found for each element, and the arithmetic mean and median for the 20 water samples. For those sample results below detection, they have been converted to one-half of the detection limit (e.g., a result of <0.0002 ppm for thallium is tabulated as 0.0001 ppm) to allow the calculation of the arithmetic mean and median.

Results from these 20 water samples include (a) radon contents ranging from 7 up to 222 Bq/L (189 to 5,994 pCi/L), (b) uranium contents ranging from 0.2 up to 160 ppb, (c) and some other elements having, in places, elevated concentrations, including arsenic (up to 140 ppb), iron (up to 2.1 ppm), manganese (up to 0.5 ppm), molybdenum (up to 420 ppb), selenium (up to 7.1 ppb), sulphate (up to 670 ppm), vanadium (up to 14 ppb) and zinc (up to 56 ppb). Those samples with elevated to anomalously high concentration of these and some other elements are highlighted by colour in the table in Appendix I.

Table 3. Radon, uranium and sulphate and other analytical results for the 20 water samples collected in 2006 by AGS at the Milk River Ridge–Whiskey Gap area

Element	Units	Minimum	Maximum	Arithmetic Average	Median Result
Radon	Bq/L (pCi/L)	7 (189)	222 (5994)	59.9 (1617)	42.0 (1134)
Uranium	ppb ¹	0.2	160	20.2	9.0
Sulphate	ppm ²	13	670	153.9	68.5
Aluminum	ppm	0.0010	0.0750	0.0086	0.00385
Antimony	ppm	0.0002	0.0023	0.0002	0.0001
Arsenic	ppm	0.1	140.0	20.8625	5.3
Barium	ppm	0.0094	0.54	0.0886	0.0465
Beryllium	ppm	<0.0001	<0.0001	All <detection	
Boron	ppm	0.02	0.30	0.0905	0.10
Cadmium	ppm	<0.0001	0.0002	0.0001	0.00005
Chromium	ppm	<0.0005	0.016	0.0010	0.00025
Cobalt	ppm	<0.0001	0.0009	0.0002	0.0001
Copper	ppm	<0.0002	0.05	0.0051	0.0013
Iron	ppm	0.0018	2.10	0.1871	0.0295
Lead	ppm	<0.0001	0.0026	0.0005	0.0002
Manganese	ppm	<0.0005	0.50	0.0640	0.0037
Molybdenum	ppm	0.0003	0.420	0.0291	0.0064
Nickel	ppm	<0.0001	0.0071	0.0012	0.0002
Selenium	ppm	<0.0001	0.0071	0.0018	0.0006
Silver	ppm	<0.0001	0.0001	0.0001	0.0001
Strontium	ppm	0.034	1.4	0.5883	0.495
Thallium	ppm	<0.0002	<0.0002	All <detection	
Tin	ppm	<0.0001	0.0002	0.0001	0.0001
Titanium	ppm	0.0004	0.0016	0.0007	0.0006
Vanadium	ppm	<0.0001	0.0140	0.0009	0.0001
Zinc	ppm	0.0007	0.0560	0.0121	0.0060

¹Note: SRC reported the results in µg/L (micrograms per litre) which equals ppb (parts per billion)

²Note: SRC reported the results in mg/L (milligrams per litre) which equals ppm (parts per million)

Although the primary purpose of the preliminary water sampling conducted in the Whiskey Gap area was to evaluate background vs. ‘anomalous’ levels of selected elements of potential interest for uranium exploration in this region, of secondary consideration was whether any of the waters might contain elevated concentrations of any elements that exceed the recommended maximum concentrations suggested by Canadian and International drinking water standards. As a result, in the Excel spreadsheet that accompanies this report, the recommended maximum concentration levels for selected elements in drinking water are provided. The source of these recommended maximum concentrations in potable drinking water is from

- (a) The Recommended Levels for Drinking Water Guidelines issued by Health Canada are provided on website http://www.hc-sc.gc.ca/ewh-semt/pubs/water-eau/doc_sup-appui/sum_guide-res_recom/index_e.html, and specifically the parameters with guidelines at http://www.hc-sc.gc.ca/ewh-semt/pubs/water-eau/doc_sup-appui/sum_guide-res_recom/chemical-chimiques_e.html#t4.
- (b) The Recommended Levels for Drinking Water Guidelines issued by the USA Environmental Protection Agency are provided on their website at <http://www.epa.gov/safewater/standards.html>, and more specifically at <http://www.epa.gov/safewater/contaminants/index.html#inorganic>.
- (c) The Recommended Levels for Drinking Water Guidelines issued by the World Health Organization are provided at www.who.int, and more specifically at www.who.int/water_sanitation_health/dwq/gdwq3rev/en/index.html and especially the levels for Radon (their section 9.5) and “*Chemical Fact Sheets*” (their section 12) are found in the document at www.who.int/water_sanitation_health/dwq/gdwq0506.pdf.

Finally, highlighted in **bold red** in the Excel file included with this report, are the maximum levels recommended for drinking water for each element. Normally these are the ones recommended by Health Canada, but where Health Canada does not provide specific recommended levels (e.g., for beryllium, cobalt, molybdenum, nickel, silver, strontium, thallium, tin, titanium, vanadium and radon), then either the USA EPA or World Health Organization recommendations are highlighted. As well, in the table those sample results that exceed the recommended maximum concentration limit (MCL) in drinking water are highlighted in red (denotes a water sample with an element concentration that is at least 2.0 times recommended MCL), orange (denotes a water sample that is from >1.0 to <2.0 above the recommended MCL), and in yellow for those samples where there is no recommended MCL, but the element concentration is equal to or greater than three times the median for that element. This information is provided for general interest and information, but the water quality data are not discussed further because they were not the primary focus or intent of the sampling described in this report. Furthermore, the concentrations reported herein should be considered as ‘approximators’ of the actual element concentrations at each well because the sampling procedures herein were more akin to ‘standard exploration industry’ practices, rather than being rigorously done from a hydrogeological perspective as suggested by Lemay (2002b) and as discussed above in section 1.4.

4 Discussion

The statistical analysis program S-Plus-7 was used to (a) evaluate the underlying geochemical distribution for selected elements (Figures 2–12), and (b) prepare a few simple X-Y plots that illustrate the geochemical relationship (either positive or negative) between selected elements (Figures 13–20). In general, the elements shown on figures 2–20 (i.e., U, radon, sulphate, Mo, V, Cu and Zn) were chosen because they commonly are associated with sandstone-hosted uranium deposits.

Figures 2, 5, 8 and 12 are Quantile-Quantile (Q-Q) probability plots that compare the underlying distribution to that of a ‘normal’ (Gaussian) distribution. In brief, with respect to the Q-Q plots, if on these plots the geochemical distribution follows a straight line, then either it is or it approximates a normal distribution. In some cases, a portion of the distribution may follow a straight-line segment, and thus, this part of the distribution may approximate normality. A more extensive discussion of the use of probability graphs to interpret underlying geochemical distributions is provided by Lepetier (1969) and Sinclair (1976), which, although they may be ‘old’ references, are in the author’s opinion still two of the best papers that summarily describe the use of probability plots for interpreting geochemical distributions.

With respect to the underlying geochemical distributions for the AGS 2006 water well samples, the small size of the data set (i.e., 20 sample results from 19 sampling sites) is perhaps too small to make definitive comments. Having said this, the following generalizations are derived from Figures 2–12.

- (a) For uranium, the geochemical distribution (i) is positively skewed; (ii) is truncated at the lower end; (iii) between about zero and 40 ppb uranium may approximate a part of a normal distribution (Figure 2); and (iv) there is a single outlier of 160 ppb U at the high end (Figures 3 and 4).

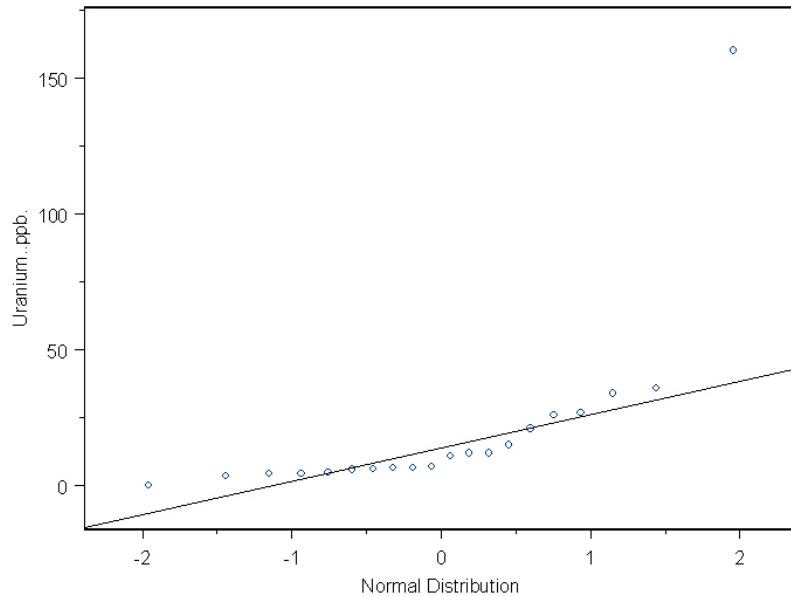


Figure 2. Q-Q plot for uranium in comparison to that of a normal (Gaussian) distribution. In general, this plot indicates that there may be one, and possibly two, underlying distributions in the range from 0 to about 50 ppb uranium.

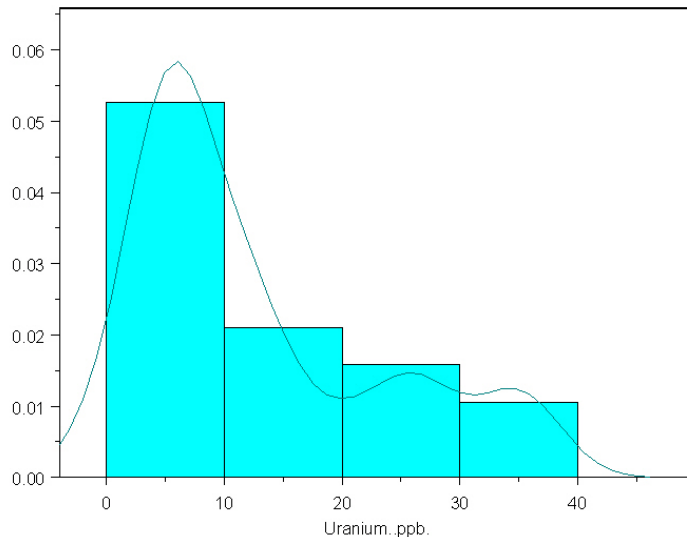


Figure 3. Illustration of the geochemical distribution for uranium excluding the single high outlier (i.e., 160 ppb U).

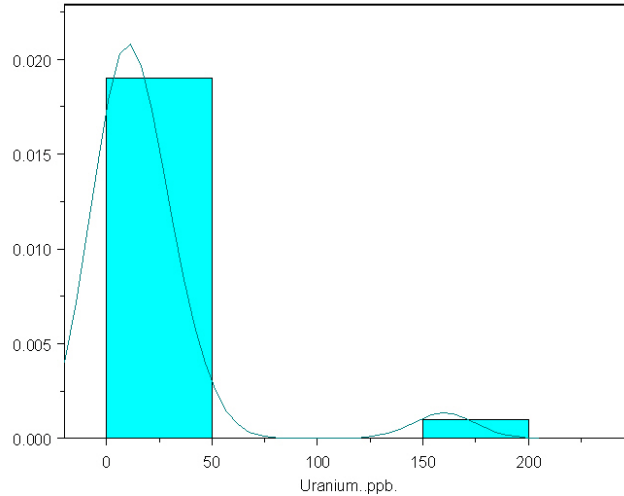


Figure 4. Illustration of the geochemical distribution for uranium including the single high outlier (i.e., 160 ppb U).

- (b) For radon, the geochemical distribution (i) is also positively skewed, (ii) may be truncated at the lower end; (iii) between about zero and 100 Bq/L radon may approximate a portion of a normal distribution (Figure 5); and (iv) there is a single outlier averaging 215 Bq/L at the high end (the outlier is treated as single because the two samples high in radon are duplicate samples from the same water well) (Figures 6 and 7).

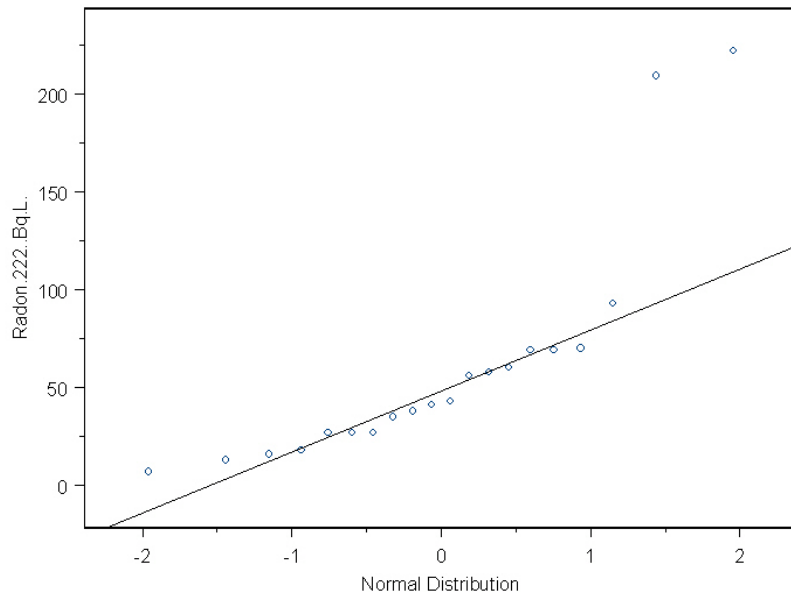


Figure 5. Q-Q plot for radon in comparison to that of a normal (Gaussian) distribution. In general, this plot indicates that there may be one, and possibly two, underlying distributions in the range from 0 to about 100 Bq/L radon.

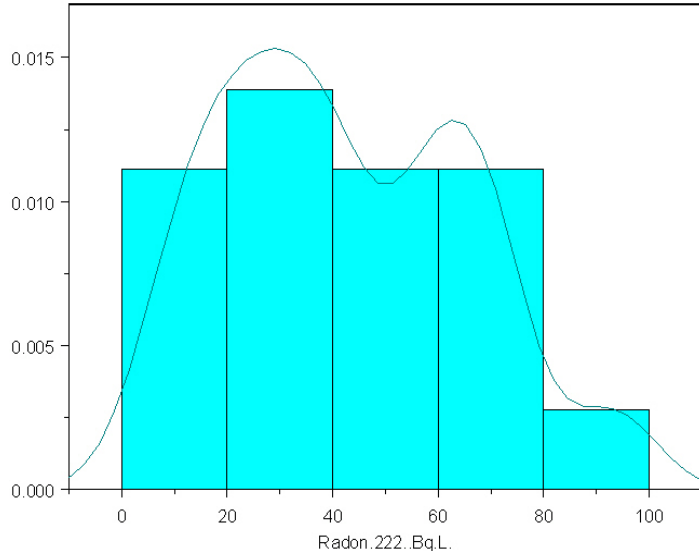


Figure 6. Illustration of the geochemical distribution for radon excluding two high outliers (i.e., 209 and 222 Bq/L).

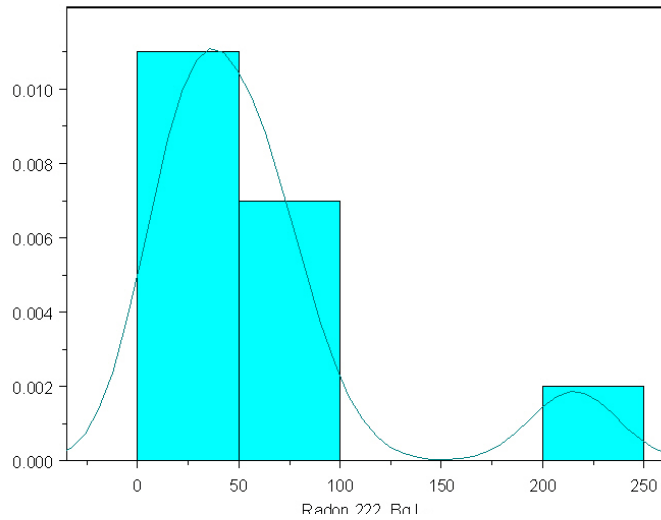


Figure 7. Illustration of the geochemical distribution for radon including two high outliers (i.e., 209 and 222 Bq/L).

- (c) With respect to sulphate, the geochemical distribution (i) is positively skewed; (ii) may be truncated at the lower end; (iii) between about zero and 200 ppm does not approximate a portion of a normal distribution (Figure 8), although at the low end from zero to perhaps about 150 ppm sulphate, the distribution may approximate a straight line and thus, may follow a 'normal' distribution and (iv) there are a few outliers at the high end (i.e., 460, 580 and 670 ppm sulphate) (Figures 9 and 10).

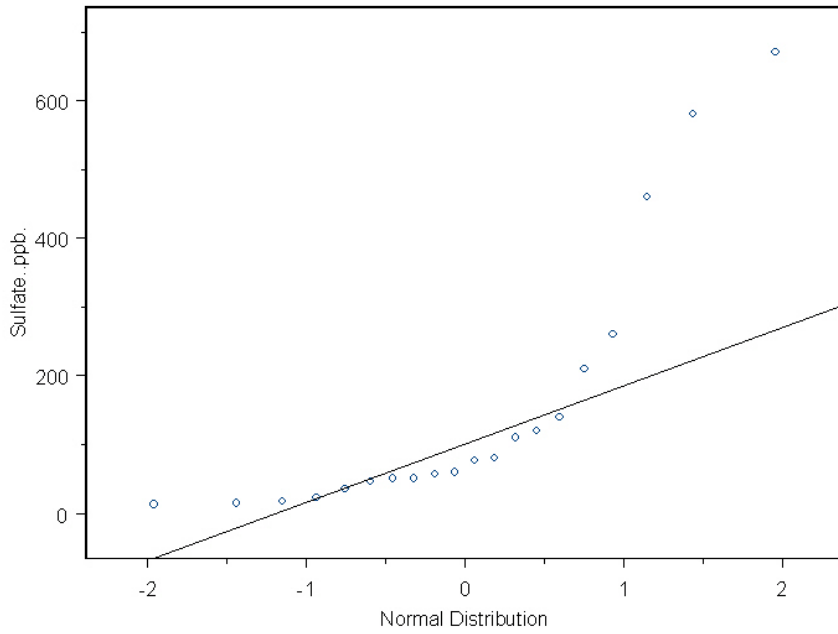


Figure 8. Q-Q plot for sulphate in comparison to that of a normal (Gaussian) distribution.

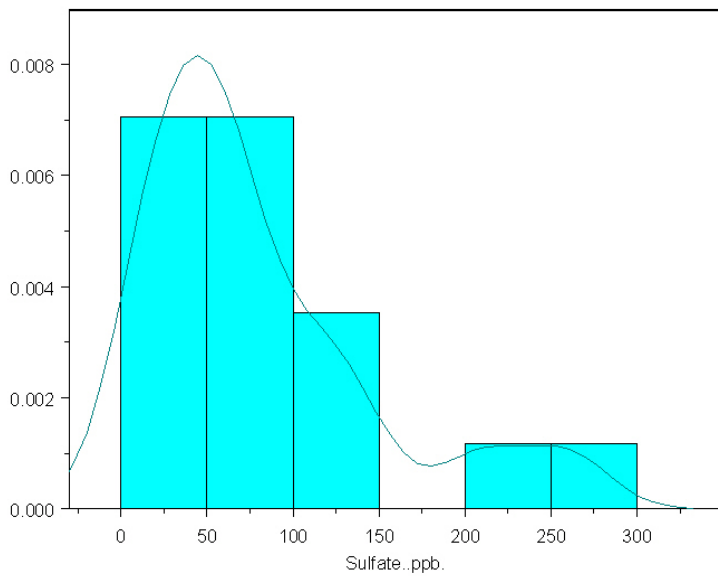


Figure 9. Illustration of the geochemical distribution for sulphate including three high outliers (i.e., 460, 580 and 670 ppm).

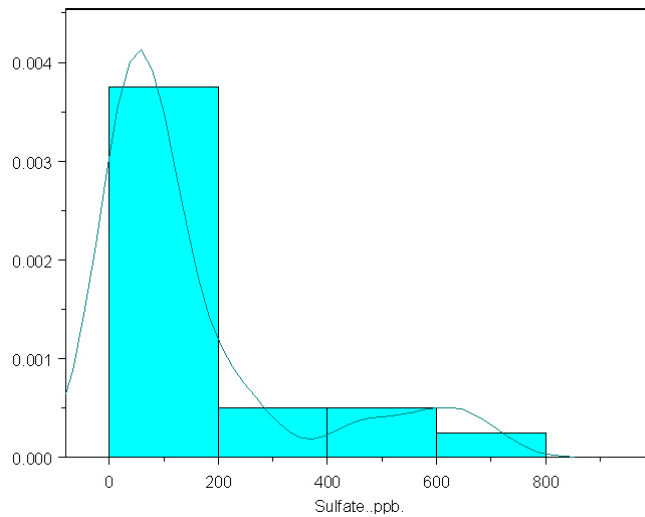


Figure 10. Illustration of the geochemical distribution for sulphate excluding three high outliers (i.e., 460, 580 and 670 ppm).

- (d) Finally, with respect to the geochemical distribution for molybdenum (i) it is positively skewed; (ii) it may be truncated at the lower end; (iii) between about zero and 30 ppm does approximate a portion of a normal distribution (Figure 11); and (iv) there is a single outlier at the high end (i.e., 420 ppb molybdenum) (Figure 12). Molybdenum is perhaps one of the few elements whose underlying distribution reasonably approximates a normal distribution, as shown by the Quantile-Quantile (Q-Q) plot in Figure 12. On this figure, and excluding the high outlier, the molybdenum distribution falls quite close to the line that represents a normal (Gaussian) distribution.

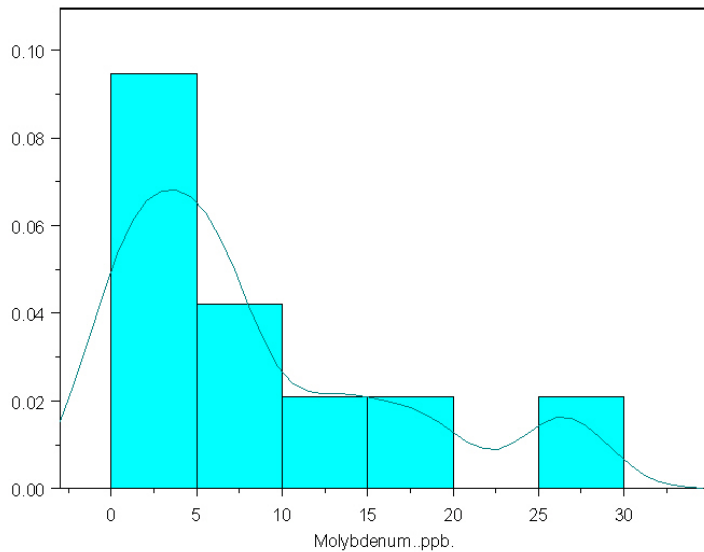


Figure 11. Illustration of the geochemical distribution for molybdenum excluding a single high outlier (i.e., 420 ppb).

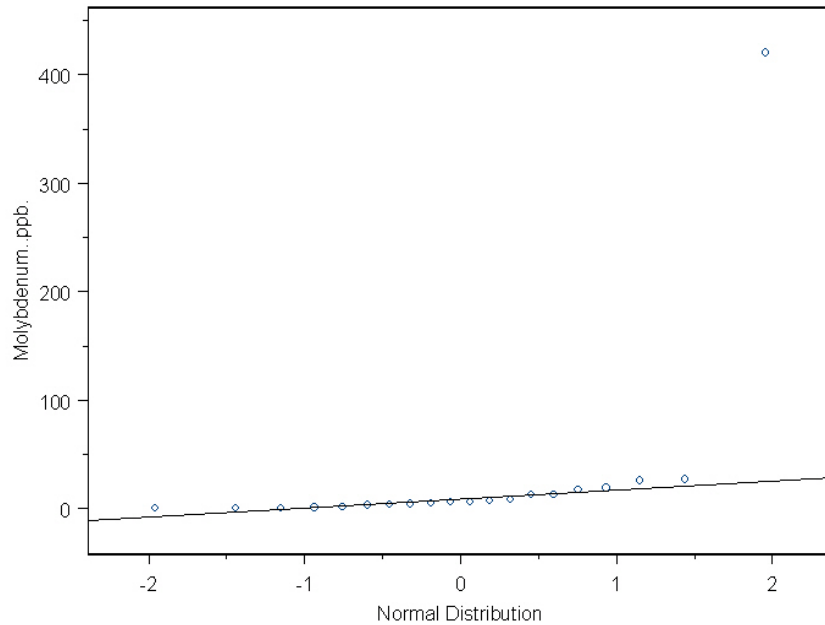
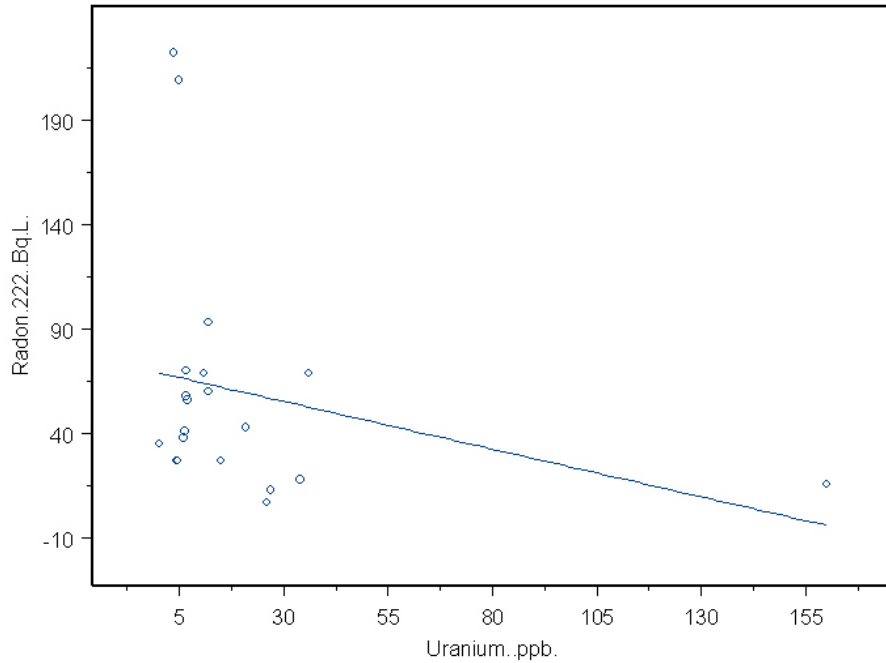


Figure 12. Q-Q plot for molybdenum in comparison to that of a normal (Gaussian) distribution.

In short, the distributions for uranium, radon and sulphate are typical of many trace element distributions (i.e., positively skewed, tendency to be truncated at the low end due to concentrations occurring below the analytical detection limit, and a few outliers existing at the high end). As a result of their poor approximation of a normal distribution, with the possible exception of that for molybdenum, this means that any statistical analysis based on the normal (Gaussian) distribution are liable to be inexact or have little validity statistically (e.g., for calculation of the standard Gaussian correlation coefficients between sets of elements). As a result, following are a few simple X-Y plots that represent the ‘correlations’ between various elements (Figures 13–20). Also shown on each X-Y plot is a regression line constructed by the S-Plus program using the linear least-squares method.

Figure 13 illustrates the relation between uranium and radon. In general, this X-Y plot indicates there may be a poor negative correlation between the two radionuclides. This is perhaps explained by the fact that radon is the direct daughter product of ^{222}Ra , and is several daughter products down the decay chain from uranium as shown in Table 1 and discussed above. In this particular case, therefore, there would seem to be little direct relationship between high radon content in ground well water and anomalous uranium in the water.

With respect to the relation between uranium and sulphate, Figure 14 indicates there may be a tenuous to poor positive correlation. This is also indicated by the data in the table in Appendix I, where for the six samples with higher uranium concentrations (i.e., 06USA005, 06USA008, 06USA009, 06USA013, 06USA014 and 06USA017; all of which contain from 21 to 160 ppb uranium), five of these samples correspond to elevated sulphate concentrations ranging from 210 to 670 ppm sulphate. It should be noted that the position of the regression line in Figure 14 is biased by the one sample that contains the highest uranium concentration (i.e., 160 ppb U) and marginally higher sulphate.



With respect to uranium and vanadium, Figure 15 indicates there is a positive correlation, but this presumed positive correlation is biased by one sample (6USAW017) which has very high uranium (160 ppb) and the highest vanadium (14 ppb) content.

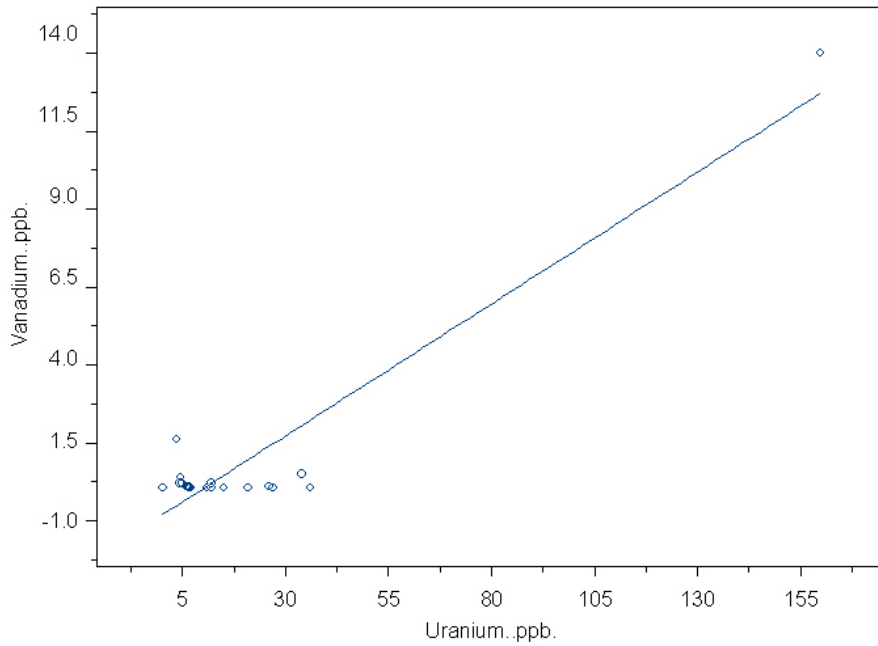


Figure 15. Uranium (ppb) vs. Vanadium (ppb) X-Y plot.

With respect to uranium and arsenic, there is perhaps a more convincing positive correlation (Figure 16). Having said this, there remains a very high scatter about the linear regression line.

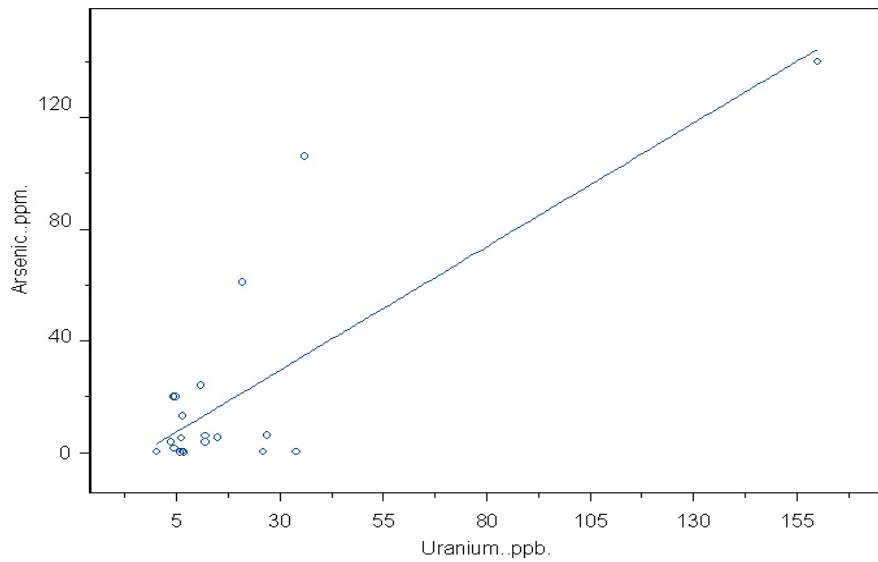


Figure 16. Uranium (ppb) vs. Arsenic (ppb) X-Y plot.

With respect to uranium and copper, Figure 17 indicates there may be a weak negative correlation, but this inferred negative correlation is biased by two samples: 6USAW017, which contains 160 ppb U and 3.1 ppb Cu, and 6USAW003, which contains 50 ppb Cu but only 4.5 ppb U.

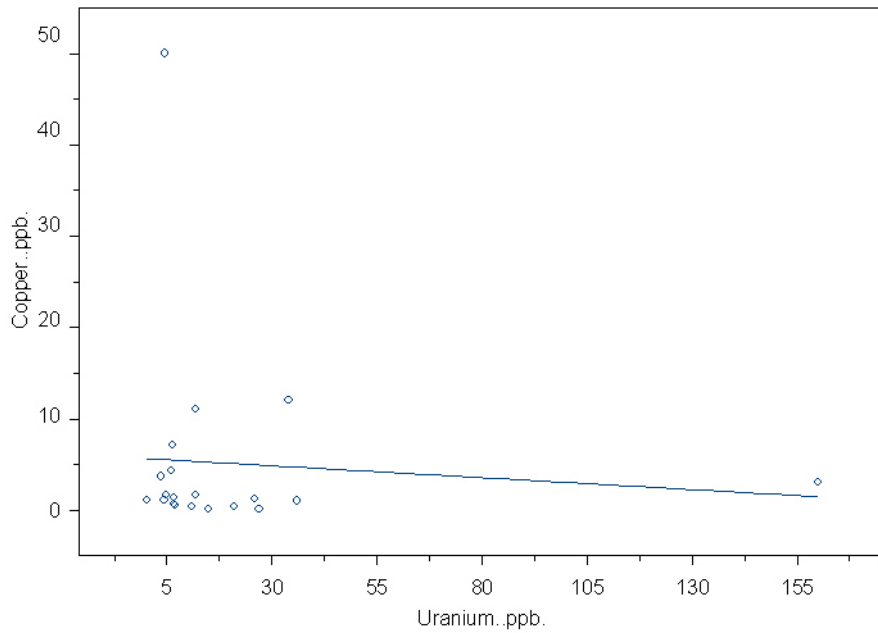


Figure 17. Uranium (ppb) vs. Copper (ppb) X-Y plot.

With respect to uranium and zinc (Figure 18), there may be a weak positive correlation, but there is a very high scatter about the linear regression line.

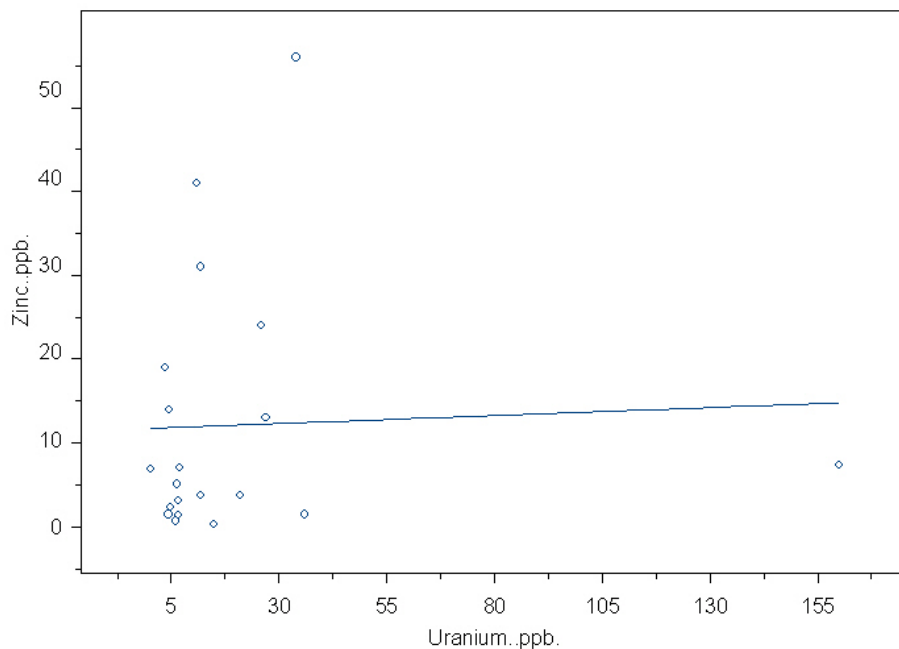
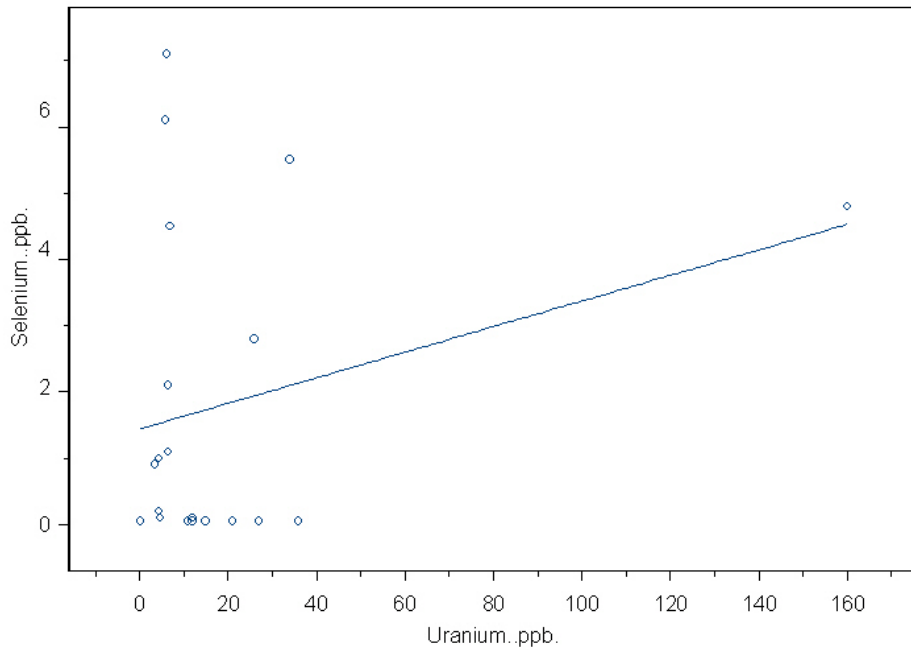


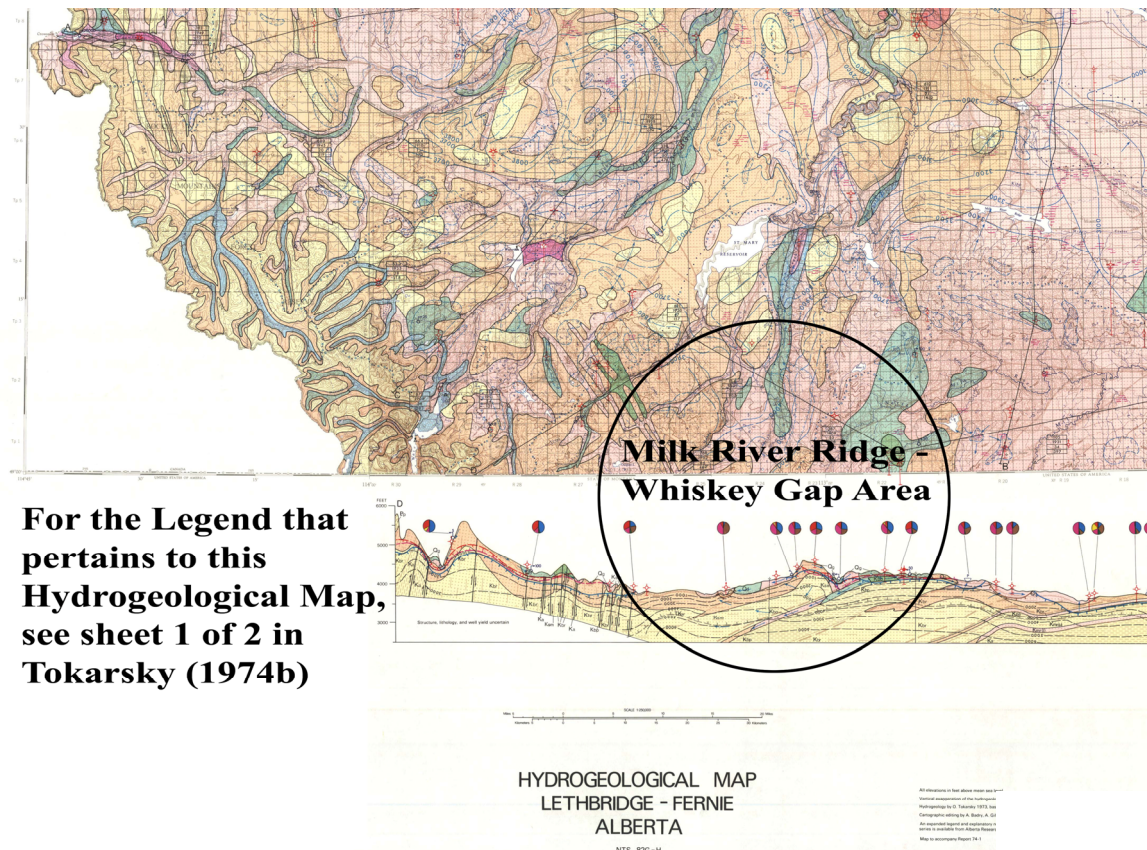
Figure 18. Uranium (ppb) vs. Zinc (ppb) X-Y plot.

With respect to uranium and selenium, Figure 19 indicates there may be a weak positive correlation; however, (a) this presumed correlation is biased by one sample, 6USAW017, which contains 160 ppb U and 4.8 ppb Se, and (b) there is a very large scatter about the linear regression line.



In short, the above data indicate (a) there is either no correlation or perhaps a weak negative correlation between uranium and radon; and (b) there generally is a poor correlation between uranium and those elements that are commonly associated with it in sandstone-type uranium environments. Having said this, the one sample (6USAW017) with the highest uranium content is associated with elevated to high concentrations of arsenic, molybdenum, sulphate and vanadium. Hence, these elements may be useful as a uranium exploration tool for elevated uranium concentrations in southern Alberta.

Perhaps one of the more interesting things about the Milk River Ridge–Whiskey Gap area is the geological and groundwater cross-section shown on Map 105 in Tokarsky (1974b); a portion of the bottom part of this map is produced below as Figure 21 and, in greater detail, in Figure 22.



21. Portion of a hydrogeology map from Tokarsky (1974b). Circle indicates Milk River Ridge–Whisk cross-section that is enlarged in Figure 22.

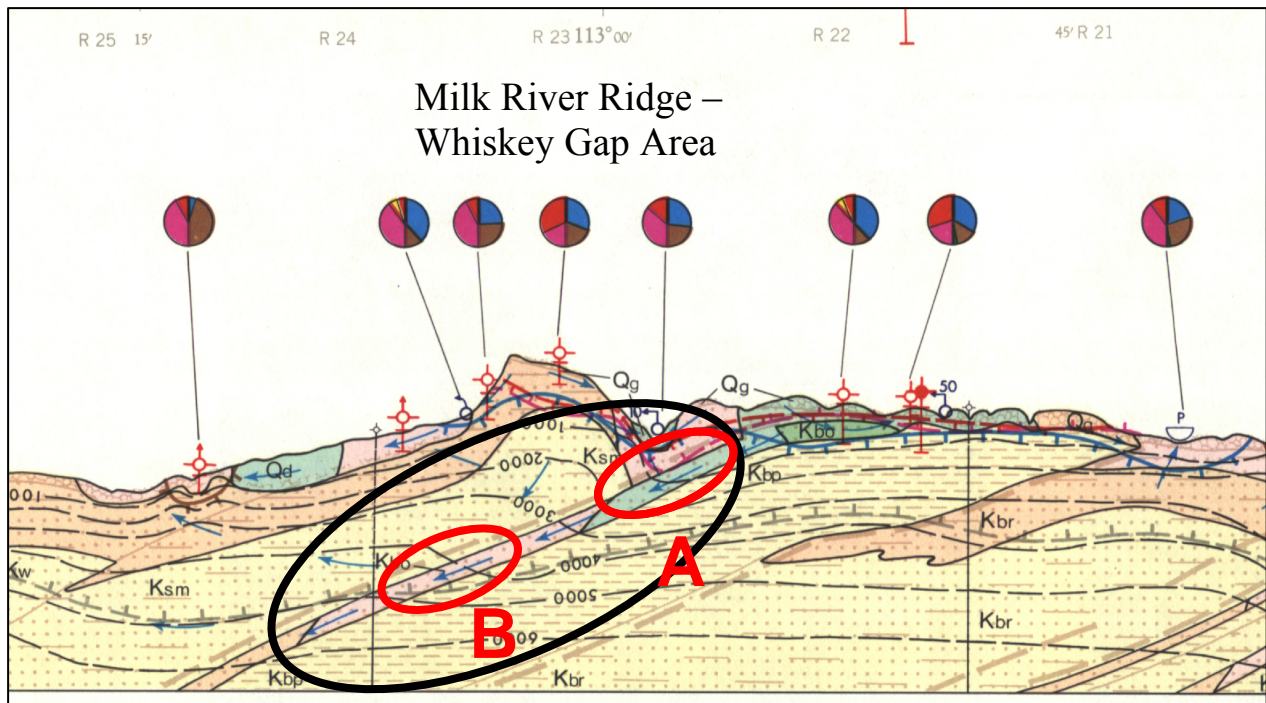


Figure 22. Cross-section from Tokarsky (1974b) that shows a tongue of presumably oxidizing meteoric water (black oval) flowing down-dip within the Blood Reserve Formation (Section is north-looking). Red ovals indicate prospective locales on either side of the Milk River Ridge where drill testing of the Blood Reserve Fm should encounter lesser amounts of overlying strata.

Figure 22 shows that the Milk River Ridge–Whiskey Gap area

- 1) is underlain by gently west-dipping Cretaceous strata, including Bearpaw Formation shale, which is overlain by Late Cretaceous Blood Reserve and St. Mary River Formations, which in turn is overlain, probably unconformably or disconformably, by Late Cretaceous–Tertiary Willow Creek Formation;
- 2) there is a down-dip westerly flowing ‘tongue’ of meteoric groundwater concentrated in the Blood Reserve Formation along its contact with underlying Bearpaw Formation; and
- 3) some of the westerly flowing tongue of groundwater makes its way back towards the surface along the westerly flank of the Milk River Ridge.

This setting is a classical situation for roll-front uranium deposit formation, assuming (a) the westerly flowing tongue of meteoric groundwater is oxidizing and thus, capable of mobilizing uranium; (b) there exists sufficient uranium in the upper Bearpaw Formation, Blood Reserve and lower St. Mary River Formation that is capable of being leached by the groundwater; and (c) down dip, there is a suitable reductant such as organic carbon or sulphides that will reduce and precipitate uranium from solution along an oxidation (up dip)–reduction (down dip) front. This setting, based on a comparison with the hydrogeology shown on other sections along the margins of the hydrogeological map in Tokarsky (1974b), is anomalous, and perhaps explains why uraniumiferous and radioactive waters exist in some parts of the Milk River Ridge–Whiskey Gap region. It is also possible that if a uranium deposit formed (or currently is forming) at depth somewhere along this tongue, then the upward flowing waters may be transporting uranium or its daughter products, or both, up towards the surface and, thus, cause the observed elevated concentrations of uranium, radium or other radionuclides.

Interestingly, especially from a uranium exploration perspective, about 25 km northeast of Whiskey Gap within the McIntyre Ranch (Plate 1), exposures of Blood Reserve Formation on a ridge exhibit both reduced and oxidized alteration patterns (Plates 1–5). The alteration includes small oxidation fronts that resemble classic ‘roll-fronts’; however, at this particular locale, no anomalous radioactivity was associated with this oxidation-reduction front. Nonetheless, the alteration patterns indicate that oxidizing waters have been moving through the Blood Reserve Formation and, thus, a uranium deposit(s) may exist down dip to the west associated with the tongue of west-flowing meteoric water shown on the cross-section in Figure 22).



Plate 1. Entrance to the McIntyre Ranch (Tp 3, Rg 21, W4) in southern Alberta



Plate 2. Blood Reserve Formation outcrops; looking west-northwesterly toward McIntyre Ranch.



Plate 3. Oxidized and reduced zones in the Blood Reserve Formation.



Plate 4. Oxidation front in the Blood Reserve Formation.



Plate 5. Close-up of oxidation front in the Blood Reserve Formation.

Finally, with respect to the uranium exploration potential in the Milk River Ridge–Whiskey Gap area, the most readily accessible locales with regard to drilling depth would be (a) the eastern shallower portions of the west-flowing tongue of meteoric water and (b) the deeper portions of the tongue along the west flank of the Milk River Ridge (red ovals identified by A and B, respectively, on Figure 22).

5 Conclusions and Recommendations for Further Study

The Milk River Ridge–Whiskey Gap area has seen both historic and recent exploration for sandstone-hosted uranium deposits. Most recently, reports from industry (Hartley, 2005) indicated that selected well waters in the region produced water samples with highly elevated concentrations of radon and, to a lesser extent, uranium. As a result, the AGS conducted a preliminary program of water well sampling in June 2006 that resulted in the collection of 20 water samples from 19 sites distributed about the Milk River Ridge–Whiskey Gap area. The water samples collected by the AGS were analyzed at the Saskatchewan Research Council for radon, uranium and a suite of 24 other elements.

The 2006 program of water well sampling, geological fieldwork and office studies resulted in three key observations:

- (1) Several water samples contain elevated to anomalous concentrations of one or more of radon (up to 222 Bq/L or 5,994 pCi/L), uranium (up to 160 ppb), arsenic (up to 140 ppb), iron (up to 2.1

ppm), manganese (up to 0.5 ppm), molybdenum (up to 420 ppb), selenium (up to 7.1 ppb), sulphate (up to 670 ppm), vanadium (up to 14 ppb) and zinc (up to 56 ppb). In general, these suite of elements are associated with sandstone-hosted uranium deposits; hence, where they exist in elevated to anomalous concentrations in groundwater may be favourable for the presence of a uranium concentration in the vicinity.

- (2) The hydrogeologic flow regime in the Whiskey Gap area comprises a westerly, downward flowing tongue of meteoric water in the Blood Reserve Formation.
- (3) Finally, outcrops of the Blood Reserve sandstone farther to the northeast along the Milk River ridge exhibit both oxidized and reduced alteration colours.

These data indicate that the geological setting at the Milk River Ridge–Whiskey Gap area is favourable for the formation of sandstone-type uranium deposits because it is similar to the hydrogeological conditions that favoured uranium deposit formation in the Wyoming, the Colorado Plateau, New Mexico and south Texas uranium districts. Future exploration at the Milk River Ridge–Whiskey Gap region may consider an exploration drilling methodology similar to that used successfully in the past in several sandstone-type uranium districts in the USA. This methodology, in general, comprised the following:

- (a) Initially, drill reconnaissance exploration holes at a wide spacing of a few kilometres or more to search for ‘oxidized’ vs. ‘unoxidized’ (reduced) stratigraphic intervals within the prospective formation(s), which in this case are the Blood Reserve and perhaps the overlying St. Mary River Formations. All holes should be surveyed with a down-hole radiometric probe to evaluate the background radioactivity in the prospective unit(s) of interest and search for any anomalous radiometric patterns. In this reconnaissance drilling phase, the drilling method can either be diamond drilling (which provides core for detailed stratigraphic logging) or some less costly drilling method (e.g., air-core or reverse circulation drilling) that provides cuttings for logging across some systematic interval (e.g., ~3 m to 6 m, or equivalent to a 10 or 20 ft. drill rod).
- (b) If potential oxidation vs. reduced ‘fronts’ are indicated by the preliminary wide-spaced drilling, then conduct closer spaced drilling, with holes at intervals of about 1–5 km, in order to more precisely define the oxidation-reduction front(s) and search for anomalous radioactivity. Again, all holes should be radiometrically probed and, as a minimum, cuttings should be obtained to allow for logging of oxidized vs. unoxidized material.
- (c) If the drill results are positive, then conduct even closer spaced drilling at selected locales, with hole separations being perhaps at 100–500 m intervals, to try and define more precisely the oxidation front and search for anomalously radioactive zones. In this instance, diamond drilling probably is preferred because it will provide core in which the details of stratigraphy, lithology, alteration, trace minerals for uranium deposition (e.g., organic matter, sulphides) and anomalous radioactivity are present.
- (d) Lastly, conduct very closely spaced drilling, with hole intervals being tens to 100 m apart, with the intent being to search along the oxidation-reduction front for those locales with elevated radioactivity and, hopefully, identify anomalous to important concentrations of uranium.

Finally, regardless of whether important concentrations of uranium exist at surface, in the subcrop or in the subsurface at the Milk River Ridge–Whiskey Gap area in southern Alberta, the hydrogeological setting that shows groundwater moving downward to the west, but in places also flowing upwards towards the surface, may explain why there exist locally anomalous uranium, radon and some other elements in groundwater in places along the flanks of the Milk River Ridge and why the Blood Reserve Formation is oxidized in this area.

6 References

- Beaman, M. and Tissot, P. (2004): Radon in ground water of the South Texas uranium district, presentation, ESRI Education User Conference, San Diego, California, URL <http://gis.esri.com/library/userconf/proc04/docs/pap1842.pdf>, [May 2007].
- Boyle, R.W. (1982): Geochemical prospecting for thorium and uranium deposits; *Developments in Economic Geology* No. 16, Elsevier Scientific Publishing Company, 498 p.
- Dyck, W. and Campbell, R.A. (1976): Well water uranium reconnaissance, southwestern Saskatchewan; *in Uranium in Saskatchewan*, C.E. Dunn (ed.), Saskatchewan Geological Society, Special Publication no. 3, p. 157–168.
- Fabryka-Martin, J., Whittemore, D.O., Davis, S.N., Kubik, P.W. and Sharma, P. (1991): Geochemistry of halogens in the Milk River aquifer, Alberta, Canada; *in Dating Very Old Groundwater, Milk River Aquifer, Alberta, Canada*, M. Ivanovich, K. Fröhlich and M.J. Hendry (ed.), *Applied Geochemistry*, v. 6, no. 4, p. 447–464.
- Finch, W.I. and Davis, J.F., ed. (1985): Geological environments of sandstone-type uranium deposits; International Atomic Energy Agency, IAEA-TECDOC-328, 408 p.
- Fischer, R.P. (1968): The uranium and vanadium deposits of the Colorado Plateau Region; *in Ore Deposits of the U.S. 1933–1969*, J.O. Ridge (ed.), v. 1, American Institute of Mining, Metallurgical and Petroleum Engineers, p. 735–746.
- Galloway, W.E. and Groat, C.G. (1976): South Texas uranium province: geology and extraction; Texas Bureau of Economic Geology, Research Note RN0006, 10 p.
- Geiger, K.W., Brown, R.E., Withers, D.W. and de Vries, P.H. (1965): Water-well records, southern Alberta Townships 1–10; Alberta Research Council, Alberta Geological Survey, Earth Sciences Report 1965-04, 131 p.
- Grant, A.H. (1981): Exploration for sandstone-hosted uranium deposits within Upper Cretaceous–Lower Tertiary sediments, Alberta (1980); unpublished report prepared by Trigg, Woollett, Olson Consulting Ltd., 18 p.
- Grant, A.H. (1982): Exploration for sandstone-hosted uranium deposits within Upper Cretaceous–Lower Tertiary sediments, Alberta (1981); unpublished report prepared by Trigg, Woollett, Olson Consulting Ltd., 18 p.
- Harshman, E.N. (1968a): Uranium deposits of Wyoming and South Dakota; *in Ore Deposits of the U.S. 1933–1969*, J.O. Ridge (ed.), v. 1, American Institute of Mining, Metallurgical and Petroleum Engineers, p. 815–831.
- Harshman, E.N. (1968b): Uranium deposits of the Shirley Basin, Wyoming; *in Ore Deposits of the U.S. 1933–1969*, J.O. Ridge (ed.), v. 1, American Institute of Mining, Metallurgical and Petroleum Engineers, p. 849–856.
- Hart, O.M. (1968): Uranium in the Black Hills; *in Ore Deposits of the U.S. 1933–1969*, J.O. Ridge (ed.), v. 1, American Institute of Mining, Metallurgical and Petroleum Engineers, p. 832–837.

Hartley, G.S. (2005): Radon sampling on the Whiskey Gap uranium property, NTS 83H (sic, actually 82H); prepared for International Ranger Corporation, URL <http://www.internationalranger.com/view.php?site_id=property&content_id=126>, [Oct 2005].

Hartley, G.S. (2007): Summary (sic) of exploration and diamond drilling, NTS 83H (sic, actually 82H) for North American Gem Ltd and International Ranger Corp.; prepared for International Ranger Corporation, URL <<http://www.internationalranger.com>>, [May 2007].

Hydrogeological Consultants Ltd. (HGCL) (2003): Cardston County, part of the south Saskatchewan and Missouri River basins, Tp 001 to 007, R 19 to 29, W4M, regional groundwater assessment; prepared for the Government of Canada, Agriculture and Agri-Food Canada, 65 p.

Irish, E.J.W. (1968): Geology, Lethbridge, West of Fourth Meridian, Alberta; Geological Survey of Canada, Map 20-1967, scale 1:253 440.

Kelley, V.C., Kittel, D.F. and Melancon, P.E. (1968): Uranium deposits of the Grants Region; *in* Ore Deposits of the U.S. 1933–1969, J.O. Ridge (ed.), v. 1, American Institute of Mining, Metallurgical and Petroleum Engineers, p. 747–769.

Lemay, T. (2002a): Sampling of surface water and spring water in the Athabasca Oil Sands (in situ) area, Alberta, 1999–2001 – a compilation of protocols and methods; EUB/AGS Geo-Note 2002-09, 43 p.

Lemay, T. (2002b): Sampling of groundwater from wells in the Athabasca Oil Sands (in situ) area, Alberta, 1999–2001 – a compilation of protocols and methods; EUB/AGS Geo-Note 2002-10, 52 p.

Lemay, T. (2002c): Sampling of formation waters from wells in the Athabasca Oil Sands (in situ) area, Alberta, 1999–2001 – a compilation of protocols and methods; EUB/AGS Geo-Note 2002-11, 7 p.

Lepeltier, C. (1969) A simplified statistical treatment of geochemical data by graphical representation; *Economic Geology*, v. 64, p 538–550.

Malan, R.C. (1968): The uranium mining industry and geology of the Monument Valley and White Canyon districts, Arizona and Utah; *in* Ore Deposits of the U.S. 1933–1969, J.O. Ridge (ed.), v. 1, American Institute of Mining, Metallurgical and Petroleum Engineers, p. 790–804.

Meyboom, P. (1960): Geology and groundwater resources of the Milk River sandstone in southern Alberta; Alberta Research Council, Alberta Geological Survey, Memoir 02, 89 p.

Motica, J.E. (1968): Geology and uranium-vanadium deposits in the Uravan Mineral Belt, southwestern Colorado; *in* Ore Deposits of the U.S. 1933–1969, J.O. Ridge (ed.), v. 1, American Institute of Mining, Metallurgical and Petroleum Engineers, p. 805–813.

Mrak, V.A. (1968): Uranium deposits in the Eocene sandstones of the Powder River Basin, Wyoming; *in* Ore Deposits of the U.S. 1933–1969, J.O. Ridge (ed.), v. 1, American Institute of Mining, Metallurgical and Petroleum Engineers, p. 838–848.

- Olson, R.A., Dufresne, M.B., Freeman, M.E., Eccles, D.R. and Richardson, R.J.H. (1994): Regional metallogenic evaluation of Alberta; Alberta Research Council, Alberta Geological Survey, Open File Report 1994-08, 190 p.
- Olson, R.A. (2005): Alberta 2005 exploration overview; unpublished report, URL <http://www.ags.gov.ab.ca/activities/minerals/northern_resource.html>, 12 p., [June 2007].
- Olson, R.A. et al. (2006): Alberta mineral exploration review; unpublished report, URL <http://www.ags.gov.ab.ca/activities/minerals/northern_resource.html>, 31 p., [June 2007].
- Phenix, D.A. (1960): Occurrences and chemical character of ground water in the Morrison Formation; *in* Part 4 of Geochemistry and Mineralogy of the Colorado Plateau Uranium Ores, U.S. Geological Survey, Professional Paper 320, p. 55–64.
- Ridge, J.D. (1968): Ore deposits of the United States, 1933–1967, the Graton-Sales Volume; American Institute of Mining, Metallurgical and Petroleum Engineers, volumes. I and II, 1833 p.
- Sinclair, A.J. (1976): Application of Probability Graphys in Mineral Exploration; The Assoc. of Exploration Geochemists, Special Vol. No. 4, Richmond Printers Ltd., Richmond, B.C., 95 p.
- Stantec Consulting Ltd. (2002): Regional assessment of potable water in County of Warner #5, Nov. 2, 2002, 1-02-15277, URL <<http://www.agr.gc.ca/pfra/water/reports/ReportWarner-04.pdf>>, 16 p. [May 2007].
- Tokarsky, O. (1974a): Hydrogeology of the Lethbridge-Fernie area, Alberta; Alberta Research Council, Alberta Geological Survey, Earth Sciences Report 1974-01, 140 p.
- Tokarsky, O. (1974b): Hydrogeological map of the Lethbridge-Fernie area, Alberta, NTS 82G and NTS 82H; Alberta Research Council, Alberta Geological Survey, Map 105, scale 1:250 000.
- Toth, J., Ozoray, G.F., Wallick, E.I., Bibby, R., Gabert, G.M., Stein, R. and Lytviak, A. (1977): Contributions to the hydrogeology of Alberta; Alberta Research Council, Alberta Geological Survey, Bulletin 35, 92 p.
- Wood, H.B. (1968): Geology and exploitation of uranium deposits in the Lisbon Valley area, Utah; *in* J.D. Ridge (ed.), Graton-Sales Ore Deposits of the United States, 1933-1967, v. I, p. 770–789.

Appendix 1 – Tabulation of Results from AGS 2006 Preliminary Water Well Sampling in Southern Alberta

SEE EXCEL TABLE ON CD.