EUB/AGS Earth Sciences Report 2007-10

Sandstone-Hosted Uranium Potential of Southern Alberta — Preliminary Assessment

Alberta Geological Survey

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Sandstone-Hosted Uranium Potential of Southern Alberta – Preliminary Assessment

T. Matveeva[1], Shar D.A. Anderson[2]

[1]Alberta Energy and Utilities Board
Alberta Geological Survey
[2] Formerly of Alberta Geological Survey

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Alberta Geological Survey
4th Floor, Twin Atria Building
4999 – 98th Avenue
Edmonton, Alberta
T6B 2X3
Canada

Tel: (780) 422-3767 (Information Sales)
Fax: (780) 422-1918
E-mail: EUB.AGS-Infosales@gov.ab.ca
Website: www.ags.gov.ab.ca

Contents

Figures

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Abstract

After a 20-year hiatus, southern Alberta has again become an exploration ground for uranium. The exploration model that has been used in the past and is now applied again is that of sandstone-hosted uranium. According to the database of the International Atomic Agency, 30% of world uranium reserves are hosted by this type of deposit (International Atomic Energy Agency, 2003). Sandstone hosted uranium deposits are known and are being explored for on all continents. The geological setting of southern Alberta has a lot in common with that of Wyoming and Colorado, world-class sandstone-hosted uranium producers, where uranium deposits are hosted in Jurassic, Cretaceous and Eocene sandstone units. Deposits are formed by the process of leaching of uranium from felsic volcanics and/or granites, transport in oxidizing ground waters through confined aquifers, and deposition along regional redox fronts. Location of individual ore bodies is controlled by presence of a reducing agent within productive package. Location of individual ore bodies is controlled by the presence of a reducing agent within the productive package. Deposits are low-grade (0.05%–0.4% U_3O_8) and small in size (often up to 50 000 t U_3O_8) (Dahlkamp, 1993) but economically attractive because they occur in clusters and can be mined using the low-impact, economical In Situ Leach (ISL) method.

A limited amount of exploration conducted in southern Alberta in the 1980s discovered a few anomalies in upper Cretaceous rocks, but no new follow-up was conducted due to the collapse of the uranium market around the world. Since 2004, new interest in uranium exploration resulted in land-staking of over 1 000 000 hectares (ha) in southern Alberta. Prospecting, geophysical log interpretation from oil and gas exploration wells, ground and airborne radiometric surveys, and drilling are reported for several exploration projects in the area.

In 2006, the Alberta Geological Survey initiated a project to assess the regional potential of southern Alberta. Previously reported uranium occurrences were examined in the field; outcrops were studied for presence of favourable lithologies and characterized using thin sections and geochemical assays. Over 200 geophysical logs from oil and gas exploration wells were assessed for their usefulness in locating radiometric anomalies and thick sandstone packages within the formations. Regional geochemical data from Canada and bordering areas in the U.S.A. were then compiled.

Preliminary results of this work show that shallow geological formations of southern Alberta have characteristics similar to formations recognized as hosts of sandstone-hosted uranium deposits.

1 Introduction

Uranium is increasingly being viewed worldwide as a source of a clean, reliable energy by both governments and energy companies. With climate change, pollution, CO_2 emissions and depletion of world oil and gas resources constantly dominating media and professional publications, uranium comes across as an energy source of the future. Since the cost of fuel is only a small factor in the production of nuclear energy, whereas the stockpiles and reserves of uranium have been steadily decreasing in the last decade, it is not surprising to see the price of U_3O_8 grow from $7US/lb in 2001 to over $130US/lb by June 2007.

This commodity price increase gave exploration for uranium a great boost. Major and junior mining and exploration companies are now investing millions of dollars in exploration at all stages—from strategic evaluation of potential districts to the re-starting abandoned mines. Canada is a world leader when it comes to uranium exploration and mining. The richest deposits in the world—unconformity-type deposits—are found in Proterozoic Athabasca Basin. Canada is also a world leader in U_3O_8 production: in 2005, over 30 million lbs of U_3O_8—approx. 1/3 of total world production—came from Canada (The Ux Consulting Company, LLC, 2006).

Southern Alberta was explored in the past and is again, after a 20-year lull, currently being explored for sandstone-hosted uranium deposits. These deposits differ greatly from unconformity-type deposits in geologic environment, mineralization process, age, size and grade of ore bodies. This type of deposit has been successfully mined worldwide for uranium for many decades. Since the 1960s, sandstone-hosted uranium deposits have been the main producers of uranium in the U.S.A. A brief overview of these deposits is presented to enable an understanding of the significance of the geological setting of uranium occurrences in southern Alberta. Recent staking and exploration activity in southern Alberta has led the Alberta Government to begin its own evaluation of the province's sandstone-hosted uranium potential. Preliminary results of two field visits and extensive office data compilation conducted by the Alberta Geological Survey (AGS) are presented in this report.

The 2006 AGS goals were to

- determine what methods and datasets can be used to evaluate Alberta's potential to host uranium deposits in clastic rocks of the southern Alberta foreland basin; and
- do a preliminary evaluation of the presence of favourable criteria for sandstone-hosted uranium deposits in southern Alberta.

Existing data relevant to the evaluation of uranium potential were compiled and analyzed. Geophysical well logs from 233 existing oil and gas exploration wells were studied to evaluate their suitability for locating anomalous radioactivity and favourable lithologies. Results of this study are discussed in Chapter 5. Existing regional geochemistry datasets for Alberta and adjacent areas in the U.S.A. were studied and compiled. Regional geochemistry is discussed in Chapter 6. Characteristics of sediment-hosted deposits in the U.S.A. and other countries were summarized and compared to the southern Alberta setting. Other datasets, such as water well logs and coal-hole logs, were evaluated for their applicability to uranium exploration. Existing geological maps and all other data were compiled into a GIS project.

In the field, outcrops of potentially favourable formations and radioactive occurrences were studied and sampled. The purpose of the field work was to determine if Cretaceous and Tertiary rocks, exposed in southern Alberta, include lithofacies with characteristics favourable for sediment-hosted (especially sandstone) uranium deposits. Field results are discussed in Chapters 3 and 6.

2 Overview of Sandstone-Hosted Uranium Deposits in the World—Distribution, Geology and Mining Methods

2.1 Deposit Model and World Distribution

Sandstone-hosted uranium deposits constitute about 30% of world uranium resources (International Atomic Energy Agency, 2003). They are found in reduced fluvial or shallow marine sandstone units, interbedded with and bounded by less permeable, fine-grained, shaly horizons. Uranium deposits are formed when oxidized groundwaters move through a permeable sandstone unit and encounter a reducing agent such as organic material or pyrite. Uranium is transported in oxidized groundwaters in its hexavalent state and is precipitated in a tetravalent state. The main ore minerals are uraninite (UO_2, which in the cryptocrystalline form is called pitchblende) and coffinite [$U(SiO_4)1\text{-}x(OH)_4$]. Ore bodies can be of one of three shapes: tabular, peneconcordant or roll-front. Deposits usually occur in the strata of middle Paleozoic to Tertiary age, demonstrating a possible link to the existence of lush terrestrial vegetation during this time. The decomposition of organic material created the necessary reducing environment for concentration of uranium. Orebodies are commonly low to medium-grade (0.05%–0.4% U_3O_8) and individual orebodies are small to medium in size (ranging up to a maximum of about 50 000 t U_3O_8) (Dahlkamp, 1993). Each uraniferous province and each deposit has its own unique features. For this reason, caution must always be exercised when a generalized deposit model is used for the evaluation of an area's potential for mineral exploration.

Sandstone-hosted uranium deposits exist on all continents. Recently, due to increased demand for uranium, more deposits are being explored, developed and brought to production. Old projects are being revived and new projects are being explored all over the world. The U.S.A. has large sandstone-hosted uranium resources in the Western Cordillera region: in the Powder River and Wind River Basins of Wyoming, the Colorado Plateau, New Mexico and the Gulf Coast Plain of south Texas. On the African continent, large sandstone deposits occur in Niger, Gabon (Franceville Basin) and South Africa (Karoo Basin). In Australia, the Honeymoon project recently received a development permit for the In Situ Leach (ISL) operation, with a planned production of 1000 t/year. Major production from sandstone-hosted uranium deposits is coming from Uzbekistan (over 2000 t/year). Russia is planning to increase yearly uranium oxide production to 4000 t, with a large part coming from sandstone-hosted deposits. Huge, low-grade sandstone-hosted uranium deposits are being mined and developed in Kazakhstan, with plans to increase the annual production to 15 000 t of uranium oxide by 2010. New projects are under way in the Ukraine and exploration for sandstone-hosted uranium is being actively conducted in Argentina, Columbia and China. Figure 1 summarizes locations of sandstone-hosted uranium deposits around the world, as shown on the IAEA map World Distribution of Uranium Deposits.

Since the late 1960s, sandstone-hosted deposits in the U.S.A. and the Soviet Union have been mined using the ISL method. This method allows for the extraction of uranium with minimal land disturbance. The latest developments in technology have made this method both safer and more economical. This allows for safe and profitable mining of low-grade orebodies. Continued advances in ISL technology and adaptation to individual geological and geochemical settings are of critical importance for continued economical mining of sandstone-hosted uranium deposits.

2.2 Classification of Sandstone-Hosted Uranium Deposits

Common features to all of these deposits—sedimentary clastic host rocks, mineralization process and ore composition—define the deposit model. However, differences from one region to another require the following subdivisions (Dahlkamp, 1993): roll-front, tabular/peneconcordant, mixed fluvial-marine and basal channel.

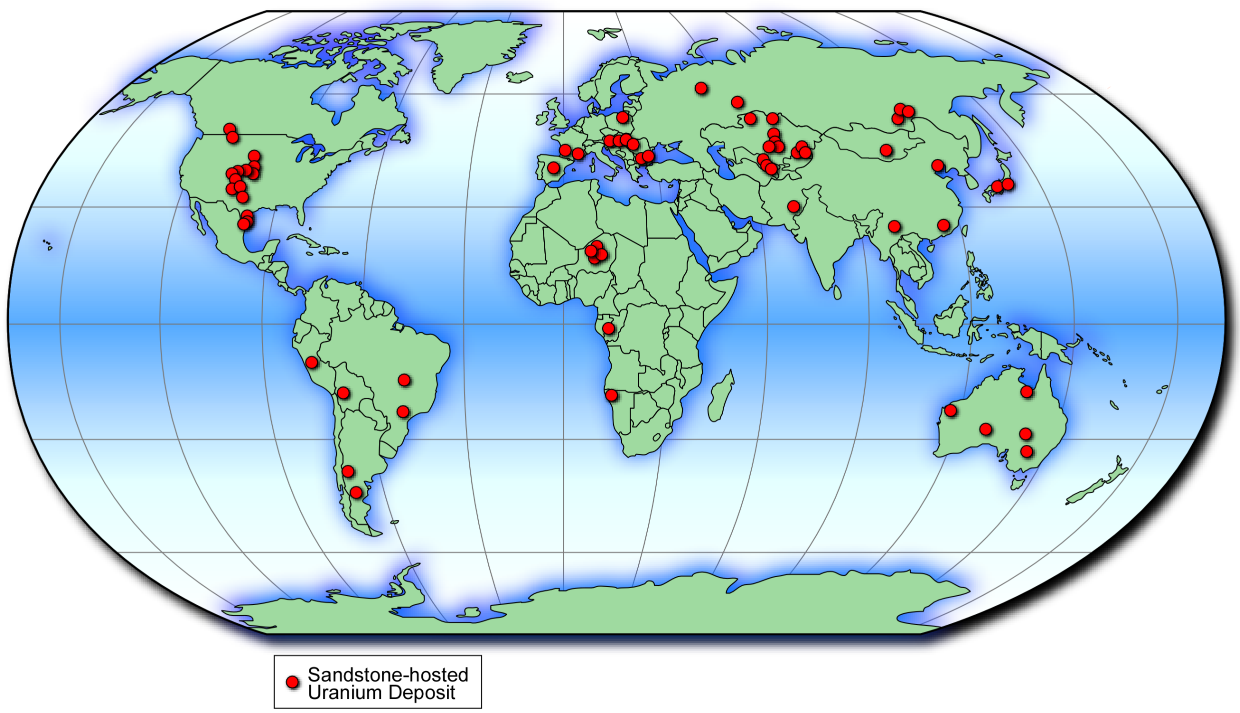

Figure 1. World distribution of sandstone-hosted uranium deposits. Data compiled from Finch et al. (1995).

2.2.1 Roll-Front Subtype

The classic examples of roll-front uranium deposits are found in Wyoming, U.S.A.; major deposits were discovered there in the early 1950s. Occurrences are distributed in a wide range of strata from Precambrian to Pleistocene in age. However, the major deposits are found in permeable fluvial sandstone units of Eocene age, and form classical C-shaped roll-fronts (Figure 2). The sandstone units range from 3 to 70 m in thickness, over 40 km in length and from 100 m to several km in width (Davis, 1969).

One possible source for uranium is Early Precambrian granite bodies. The granite intrusives were exposed during uplift related to the Laramide orogeny and were a major source of sediment deposited in Tertiary basins (Houston, 1969). Although no significant uranium mineralization exists in the granite bodies, uranium occurrences are known. The sandstone bodies that host uranium deposits are of arkosic composition and are believed to have originated from the Precambrian granite. Other authors believe that most of the uranium came from tuffaceous material that was introduced into the fluvial sediment during volcanism in late Early Eocene (Dahlkamp, 1993). Climate also could have played a very important role The warm, tropical, high-rainfall Eocene climate in Wyoming would have been favourable for the strong weathering, leaching and re-distribution of uranium.

A very important factor for the localization of ore bodies is a regional reduction-oxidation (redox) front. The position of the redox front was determined by the dynamics of regional groundwater flow at the time of uranium ore deposition. This alteration front, occurring between altered (oxidized) and unaltered (reduced) sandstone units, is most readily recognized by pinkish-red hematite staining. This red zone can extend for great distances away from the mineralized zone (Davis, 1969). Closer to mineralization, zones of limonite staining and white bleaching are characteristic. The uranium content of reduced rocks in front of the alteration front ranges from <2 ppm to 18 ppm (Davis, 1969); uranium content in the oxidized rock

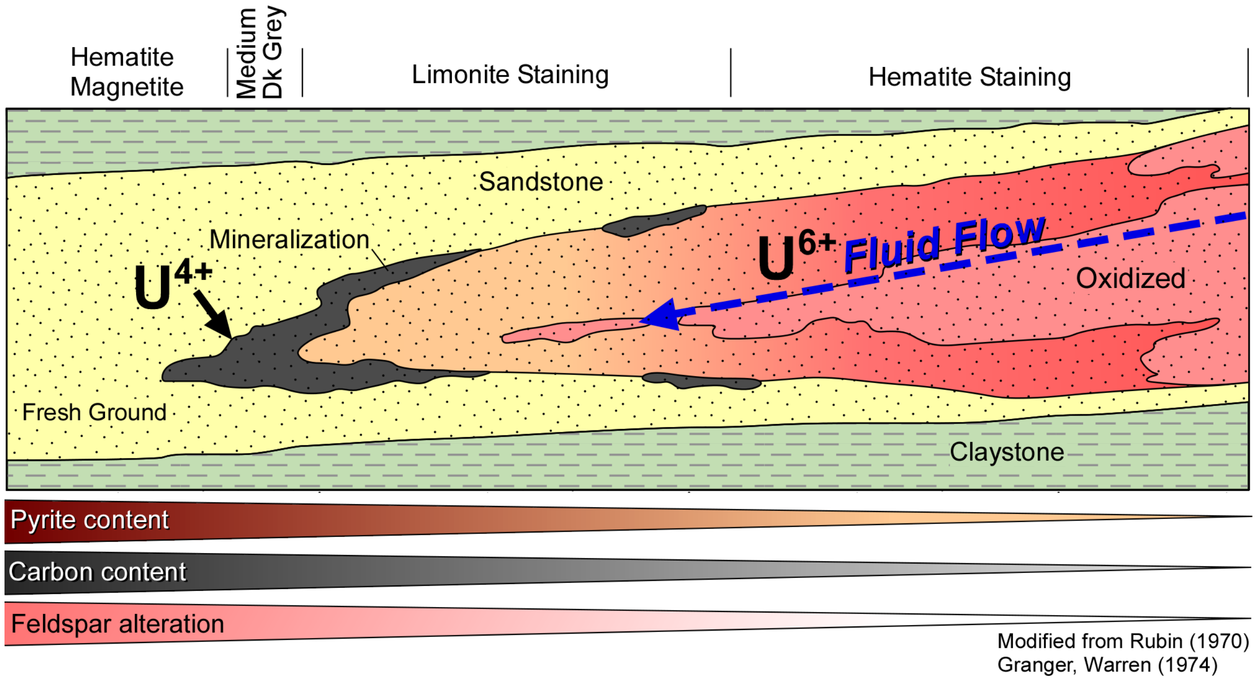

Figure 2. Roll-front deposit model.

behind the alteration front contains 5–6ppm U for a distance of several hundreds of metres (Davis, 1969; Renfro, 1969) in the Wyoming deposits.

Characteristic alteration patterns are one of the most important exploration criteria (Figure 2). Down the water flow vector the following sequence occurs: the oxidized sandstone behind the alteration front is reddish, yellowish, pinkish, whitish; then a narrow band of rusty limonitic sandstone located just before the edge of alteration front and then grey or greenish reduced sandstone. Ore bodies are found between the limonitic zone and the reduced unaltered sandstone units. This alteration colour scheme is one of the most common shared features of the various subtypes of sandstone-hosted uranium deposits. The Cherepanovskoye deposit in the Urals region of Russia occurs on the contact of grey-coloured aleurolite (siltstone) with oxidized yellow sandstone or in the grey-coloured aleurolite and clay under red-coloured aleurolite (Grushevoi, 2003). In Mongolia, the position of the ore bodies in the Ingyn deposit is along the boundary of limonitic sandstone units (Grushevoi, 2003). Similar alteration patterns are described for Kazakhstani and Australian deposits (Kochenov et al., 1995; Sanford, 1985).

2.2.2 Tabular/Peneconcordant Subtype

Typical examples of this subtype are found in Grants uranium region of New Mexico. Deposits are located within the Late Jurassic Morrison Formation. Hostrocks are coarse-grained arkosic sandstone units derived from erosion of igneous and metamorphic terranes. Widespread volcanic activity contributed the ash layers now incorporated in the fluvial and lacustrine deposits of the Morrison Formation. The reducing agent for uranium precipitation is disseminated amorphous carbonaceous material (humate).

The important feature of Grants uranium region is the distinction between ‘primary’ and ‘redistributed’ ore bodies (Crawley et al., 1985 and Dahlkamp, 1993). Primary uranium ore is found in and adjacent to humate. The ore bodies are thin (<2.5 m), tabular, lenticular or peneconcordant in shape and have sharp ore to waste boundaries. Ore grade averages are >0.20% U_3O_8 and some ore bodies are offset by later faults. The age of mineralization, at least for some ore bodies, is syngenetic or just slightly younger than the age of hostrock deposition.

Redistributed ore bodies are significantly thicker (3–40 m), lower grade (<0.20% U_3O_8) and commonly localized by faults, that offset primary ore and have diffuse ore/waste boundary. Some ore bodies have roll-front character, some are stacked deposits.

'Primary' ore-bodies cannot be described as typical sandstone-hosted deposits because the process of re-distribution by oxygenated waters did not play a fundamental role in their formation. The presence of these primary uranium concentrations made possible the formation of the 'redistributed' ore bodies by the process of redistribution of uranium by oxygenated groundwaters.

The clastic sediments of the Morrison Formation were deposited under reducing conditions. The predominant subsurface appearance of the rocks is greyish-green with widespread plant material and disseminated pyrite. However, at the present weathered surface the prevalent colour is red, due to oxidation by surface waters. This process began in the Tertiary and possibly continues today. The red, hematitic, oxidized sandstone extends kilometres from the outcrop. At the interface between red oxidized sandstone and grey pyritic subsurface sandstone, a zone of brown, limonitic sandstone is 1 km to several km wide. The majority of orebodies are located within or very near these alteration zones. Figure 3 illustrates the spatial relationships of these three different-coloured rock types.

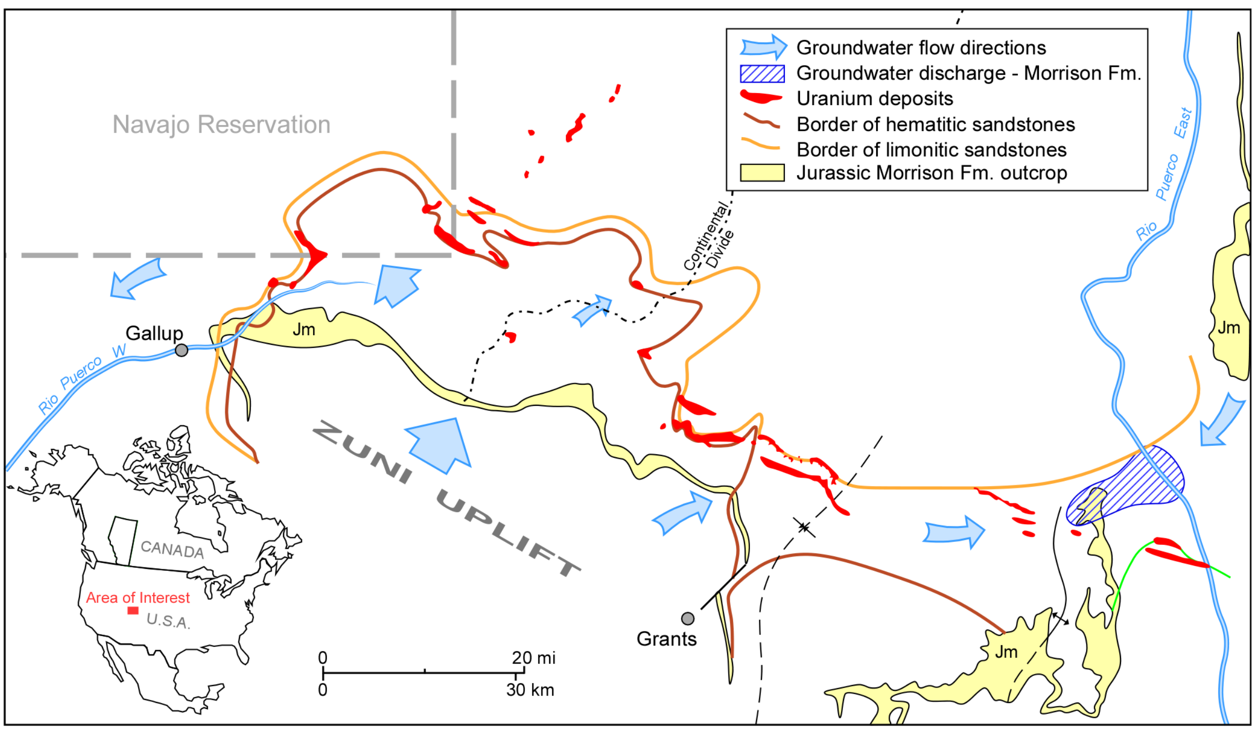

Figure 3. Distribution of Tertiary-Quaternary oxidation in sandstone of the Morrison Formation, Grants uranium region. Modified from Saucier, 1980.

2.2.3 Mixed Fluvial-Marine Subtype, Associated with Extrinsic Sulphide

Deposits of this type occur within sand facies of coastal-plain fluvial and shore-zone sand facies in South Texas. Most ore bodies occur within coarse, sand-rich strata of Oligocene through Miocene age. These sedimentary rocks were oxidized and leached simultaneously with deposition. The source of uranium is believed to be altered volcanic ash of the Catahoula Formation, whose original uranium content is believed to be approx. 10–20ppm (Galloway, 1978). Studies of different facies within this formation showed that the process of pedogenic leaching of uranium took place, and many crevasse soil and flood plain deposits show very low (<1 ppm) uranium content, whereas lacustrine deposits, which were least exposed to pedogenic alteration, have relatively high uranium content. Oxidizing uranium-enriched groundwater penetrated aquifers in areas of regional recharge and moved gulfward, following fluvial depoaxis occupying structural troughs, Figure 4 (Hobday and Galloway, 1999). Uranium deposition was controlled by geochemical gradients (Eh [standard oxidation-reduction potential] and pH fronts). Strata that were deposited originally under oxidizing conditions lack the organic material that could have served as a trap for uranium. The location of the redox front, and the deposits associated with it, is controlled by post-depositional alteration. This alteration is responsible for the introduction of reducing agents into favourable permeable horizons. As with other deposit types, the fronts separate secondarily oxidized sandstone (cream or tan in colour) from reduced (grey in colour) sandstone and are laterally continuous (several km long) (Galloway, 1978).

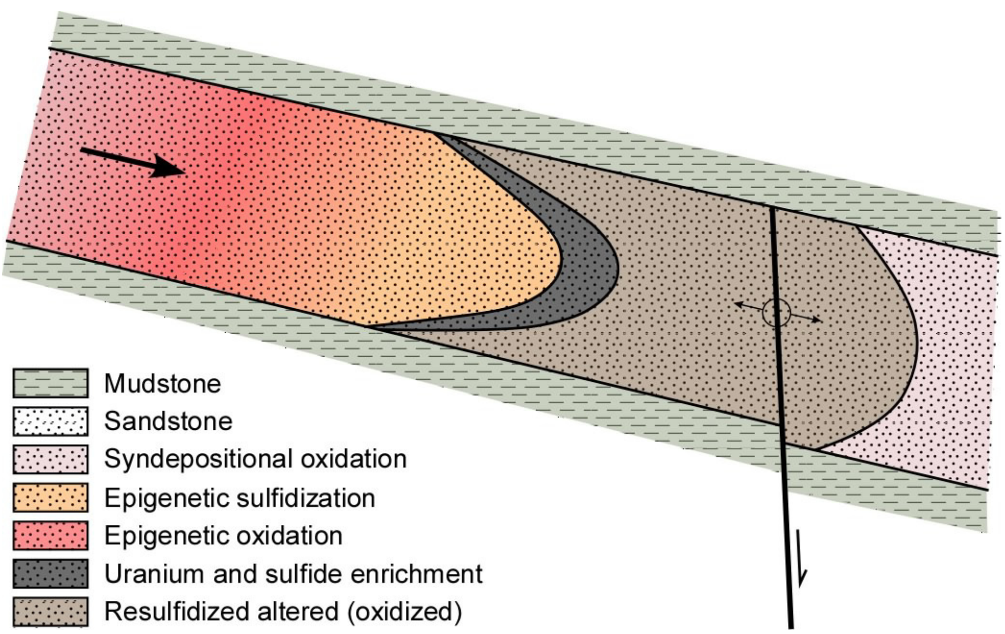

Figure 4. Geochemical zonation typical of the Oakville aquifer of the South Texas uranium province. Modified from Hobday and Galloway, 1999.

Location of the redox fronts was determined by one or more of the following criteria:

1. Facies boundaries: the ore trend follows the boundary between a major channel sand complex and mixed lithofacies containing mud, silt and clay. Location of the facies changes could, in turn, have been controlled by the location of faults. The presence of syndepositional fault zones and their role in the mineralization process are unique features of this deposit subtype (Galloway, 1985).

2. Reducing agents (epigenetic pyrite derived from sulphide-rich waters) which rose through growth faults
3. Hydrocarbon (petroleum) accumulations: vertical migration of reductants from underlying, fault trapped petroleum accumulations are responsible for the phenomena of petroleum and uranium deposits located along the same trends (Galloway, 1978).

Deposits of South Texas had a history of repetitive oxidation and reduction, and, in some cases, the deposits occur, not on the boundary between oxidized and reduced rocks, but just on the boundary between facies of variable grain size. Some ore bodies form classical rolls similar to the Wyoming type, some are of tabular shape, and some are linear and fault-related. A complex history of uranium mineralization in southern Texas resulted in complex exploration criteria and a large range of shapes, mineralogy and alteration patterns of the ore bodies.

2.2.4 Basal Channel Subtype

The only subtype of sandstone-hosted uranium deposit currently known in Canada is the Blizzard deposit in southern British Columbia (Figure 5). Basal channel deposits occur at the bottom of paleovalleys, incised into older granite massifs. The hostrocks are coarse-grained, poorly sorted, arkosic sandstone units. Uranium mineralization is associated with carbonaceous material, often plant wood and debris, that was caught within the point bars of paleochannels.

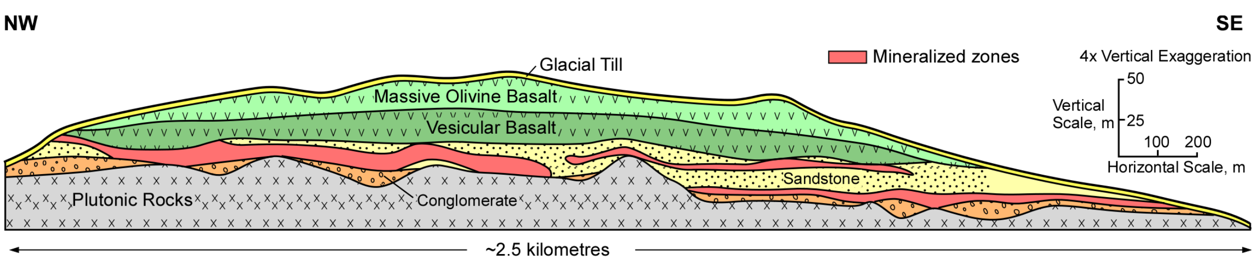

Figure 5. Schematic cross-section of the Blizzard Deposit, British Columbia (Christopher, 2005).

The Blizzard deposit is a hydrogenic paleochannel deposit. Uranium was leached from surrounding felsic intrusive and extrusive rocks and transported by deep-seated groundwaters into a structurally controlled paleochannel. The groundwaters were rapidly acidified and uranium minerals were precipitated within the Miocene sandstone and carbonaceous mudstone. The deposit was preserved by the overlying basalts and glacio-lacustrine sediments (Government of British Columbia, 2001).

In Russia, the Khiagda group of deposits has a striking resemblance to the Blizzard deposit. Paleovalleys on the slopes of granite massifs can be up to 10 km long. The mineralization is restricted to the upper portion of paleovalleys in the basal parts of poorly sorted mudstones and sandstone units of Neogene age, which were formed by the erosion of underlying granites. They are composed of quartz, feldspar and mica grains with kaolinite cement. Organic material content varies from 0.8% in the sandstone units to 10%–20% in humus-rich mudstones. Mineralized horizons are capped by a thick (up to 200 m), flat-lying basalt layer (Kochenov et al., 1995).

2.3 In Situ Leaching Technology

Since the late 1960s, sandstone-hosted uranium deposits in the U.S.A. and the republics of the former Soviet Union have been mined using the cost-efficient and low-impact In Situ Leach method (ISL). Recently, some companies are also using the term In Situ Recovery (ISR). In the ISL method, uranium is leached from a host sandstone by chemical solutions and recovered at the surface. A suitable leach solution (lixiviant) is injected into the ore zone below the water table using injection wells; uranium is mobilized and the uranium-bearing solution is recovered through production wells. The ore should be situated below the natural water table. For the deposit to be amenable for the ISL mining method, the ore should be hosted in permeable sandstone units and the sandstone body should be bordered by aquitards to prevent the loss of lixiviant. The choice of lixiviant depends on the qualities of the hostrocks and ore. The primary lixiviants are sulphuric acid and bicarbonate-carbonate lixiviants. Acid systems usually have a better recovery, but are not considered for calcareous deposits due to high acid consumption. Acid systems are prevalent in Europe, Asia and Australia, while in the U.S.A. carbonate systems are preferred (International Atomic Energy Agency, 2003). The injection and production wells are drilled in the immediate vicinity of the ore body and an extensive array of monitor wells is situated on the flanks to monitor for possible lixiviant excursions (Figure 6). ISL operations typically occur at depths of 100–250 m and rarely go deeper than 350 m.

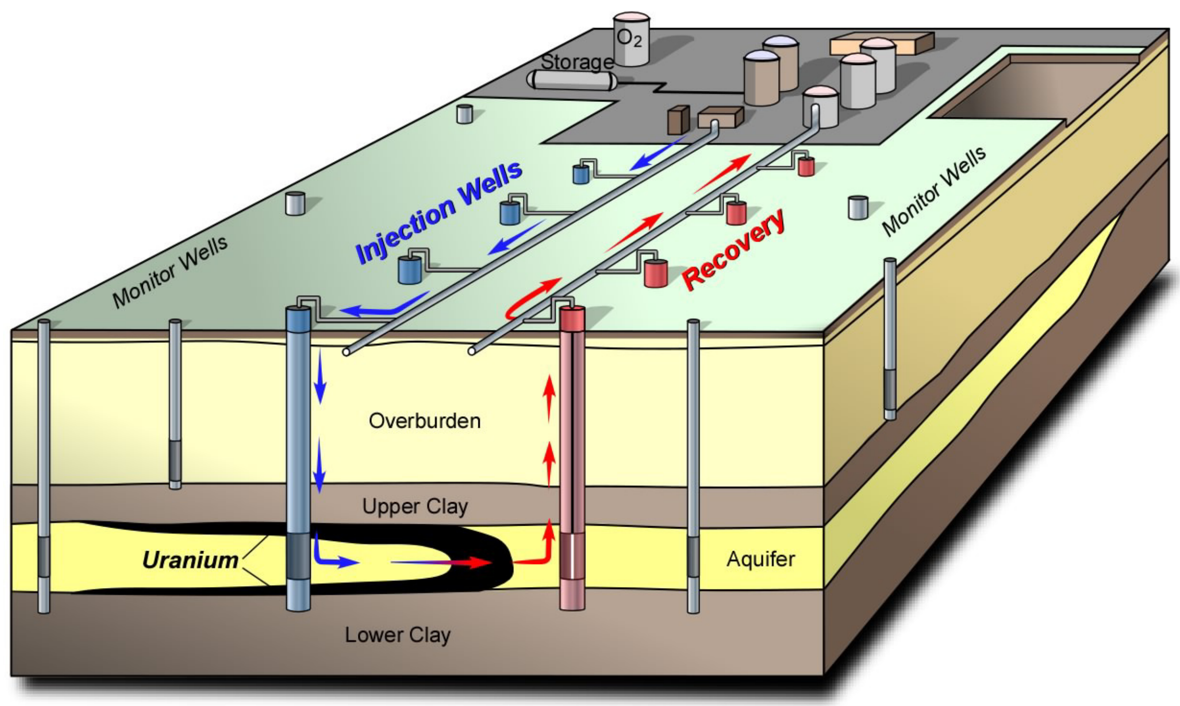

Figure 6. ISL mining—modified from International Atomic Energy Agency (2000).

The well field design depends on the shape and position of the ore bodies. Typically, the hexagon-shape (7-spot) or square shape (5-spot) grids are used (Figure 7). Distance between the wells is typically 30 m and wells are 12–15 cm in diameter. The production well is situated in the centre of the grid and is surrounded by 4 or 6 injection wells. Wells are cased and grouted to ensure that leaching fluids only flow to and from the ore zone and do not affect any overlying or underlying aquifers. During the operation, more water is recovered than is injected in order to maintain a localized depression in the natural hydrostatic pressure of the ore zone. This creates a pressure gradient, causing surrounding native groundwater to flow toward the recovery wells and minimalizing the danger of lixiviant excursions.

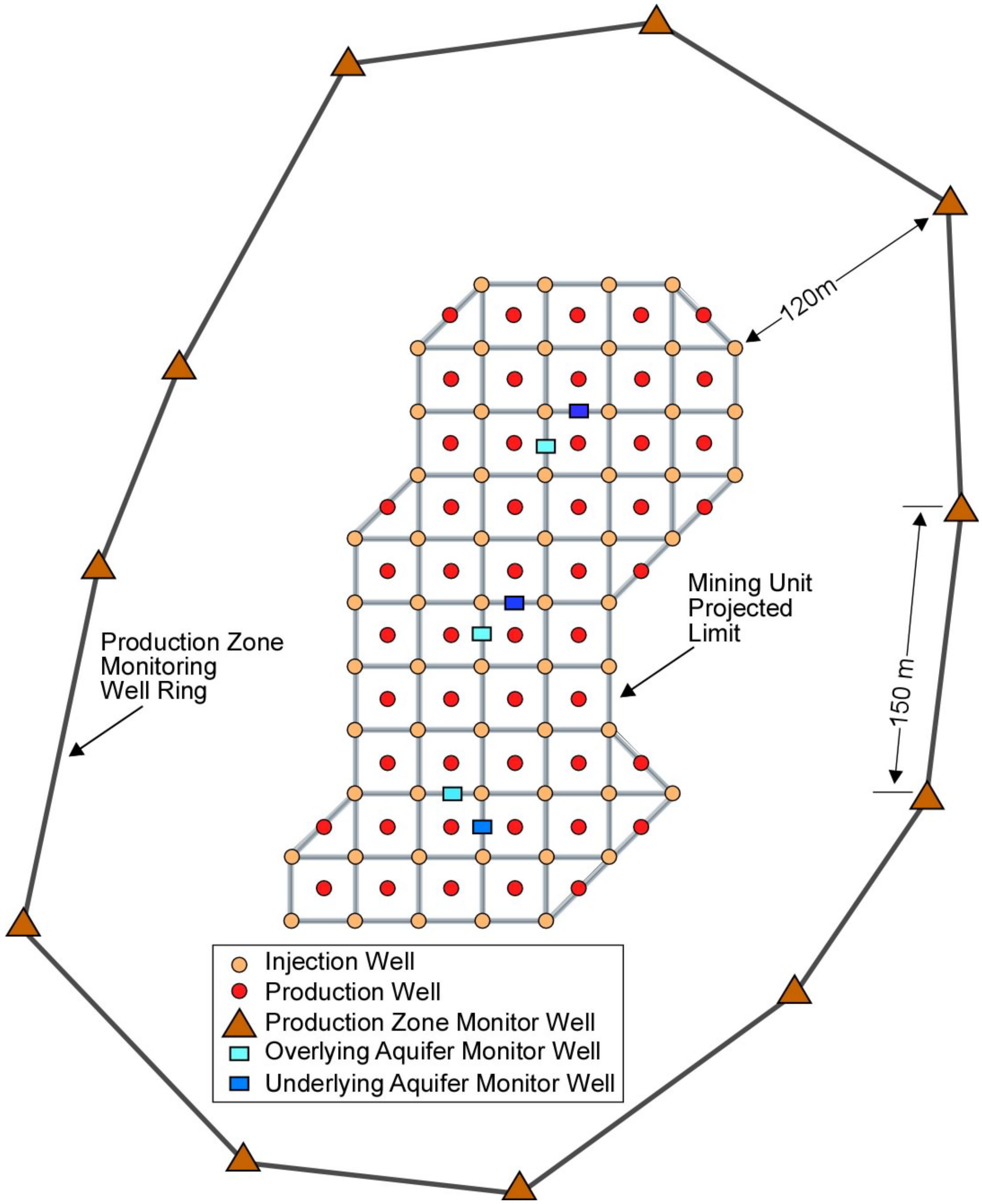

Figure 7. ISL well layout (Stout and Stover, 1997).

In situ leach mining operations are currently being used to recover uranium in the U.S.A., Russia, Kazakhstan, Uzbekistan and Australia. About 16% of the world's uranium production is by ISL (Universal Instruments Corporation, 2003).

3 Regional Geology and Stratigraphy of Southern Alberta

3.1 Regional Geology

Southern Alberta is predominantly underlain by a clastic prism of Cretaceous to Tertiary-age rocks of the Alberta Foreland basin. This clastic prism thickens from a zero m edge in eastern Saskatchewan to over 4000 m in the foothills of Alberta (Mossop and Shetsen, 1994).

The oldest sedimentary rocks included in this study belong to the Upper Milk River Formation (early Campanian) and the youngest belong to the Porcupine Hills (Paleocene) Formation. The youngest part of the clastic prism reaches a thickness of up to 3000 m in the middle part of the Alberta Basin (Jerzykiewicz, 1997). These formations were deposited during the orogenic episode, caused by continuous pressure on the North American continent from the docking of allochthonous terrains from the west (Cant and Stockmal, 1989). Eastward thrusting caused uplift and erosion of Paleozoic to Mesozoic formations, deposited earlier on the shelf of the Western Canadian Sedimentary Basin. The clastic prism is dominated by fluvial deposits with subordinate beach and shallow marine facies.

In the southeastern corner of the province, the sedimentary strata belong to the intracratonic Williston Basin that stretched all the way to North Dakota (Mossop and Shetsen, 1994). The Alberta Foreland basin and Williston basin were separated by a positive topographic feature— the Sweetgrass Arch— that also was a source of sediment for both basins. The Sweetgrass Arch refers to a large structural complex situated in the region of northwestern Montana, southeastern Alberta and southwestern Saskatchewan (Mossop and Shetsen, 1994). The prominent Milk River Ridge of southern Alberta, which is now a continental hydrogeological divide, is partially coincident with the Sweet Grass Arch spatially.

The source of sediments is of primary importance for the evaluation of sandstone-hosted uranium potential because in this deposit model the uranium sources are felsic volcanic or granitic rocks, with originally high uranium content. The provenance of upper Cretaceous sandstone formations is discussed in detail in Mack and Jerzykiewicz, 1989) (Figure 8). The lithological composition led authors to believe that volcanic clasts originated from the now-eroded volcanic beds of the Omineca Belt. The volcanic content in the sandstone units ranges from 50% to less than 5%, and generally decreases stratigraphically upward from the Belly River Formation to the Porcupine Hills Formation.

Although the stratigraphic sequence is dominated by sedimentary rocks, past volcanic activity in the area is represented by the presence of the Crowsnest volcanics, multiple beds of bentonite throughout the sequence, and, notably, the Kneehills Tuff bed within the Battle Formation. The Sweet Grass potassic intrusive suite (48–52 Ma) (Eccles and Luth, 2001), just south of Alberta border, and multiple dykes discovered in the southwestern corner of the province record magmatic activity in the late Cenozoic.

Upper Cretaceous and Tertiary strata are forming a gently west-dipping monocline, with aggregate thickness increasing towards the axis of the Alberta Syncline. The axis of the syncline is straddling parallel to the mountain ranges. Farther west, the beds dip gently to the east, and even farther west, they are complexly faulted and folded in the deformed belt.

Structural disturbance of the strata related to thrusting may extend in the subsurface as far east of the mountain front as Lethbridge, where multiple repetitions of Bearpaw and Blood Reserve formations are observed in the Monarch Fault Zone (Appendix 4, Photo 29), 65 km farther east than the currently recognised edge of the deformed belt (also known as 'triangle zone'). Seismic data suggest the Monarch Fault Zone may be partially controlled by normal faults in the basement, and the present geometry of the zone is a result of Laramide thrust-faulting along a pre-existing normal fault plane (Hiebert and Spratt,

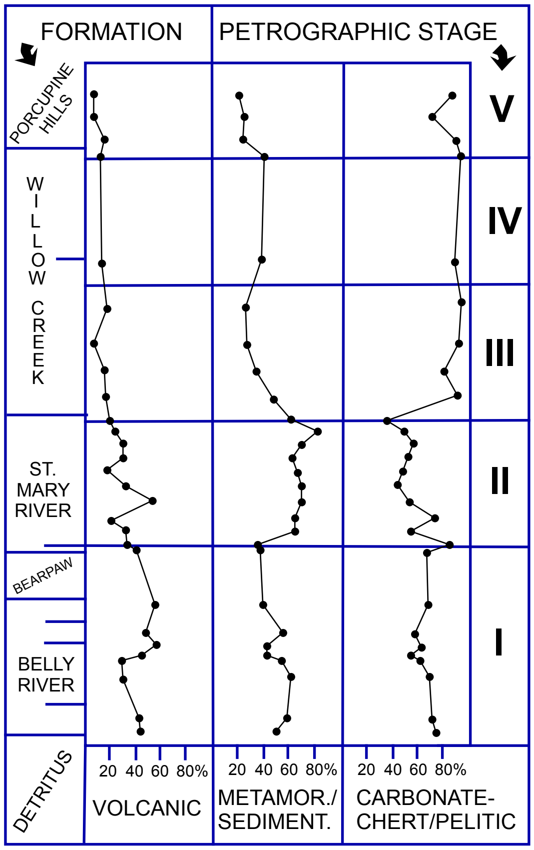

Figure 8. Petrographic trends in upper Cretaceous formations of the southern Alberta Foothills (Mack and Jerzykiewicz, 1989).

1996). Thrust-faults were also observed in the Willow Creek Formation sandstone beds on the Waterton River, near Ewelme Colony (Appendix 4, Photo 30).

Most of the area is covered by till that was deposited during several Quaternary glaciation events, and modern topographic features were formed by the Laurentide and Cordilleran glaciers.

3.2 Stratigraphy and Lithology of Upper Cretaceous Formations

Sandstone-hosted uranium deposits are hosted, of course, in sandstone. Hence, this study focused on those formations that are known to have sandstone bodies of either shallow marine or fluvial origin (Figure 9). The ages of these strata span the period from 82 Ma to about 60 Ma.

Below are brief descriptions for these sedimentary formations, from oldest to youngest. Volcanic rocks (the Crowsnest volcanics), which erupted prior to the deposition of our formations of interest, are also discussed. Their presence in the area is considered by some prospectors to be a positive criterion for the surrounding strata's potential as host to sandstone-hosted uranium deposits.

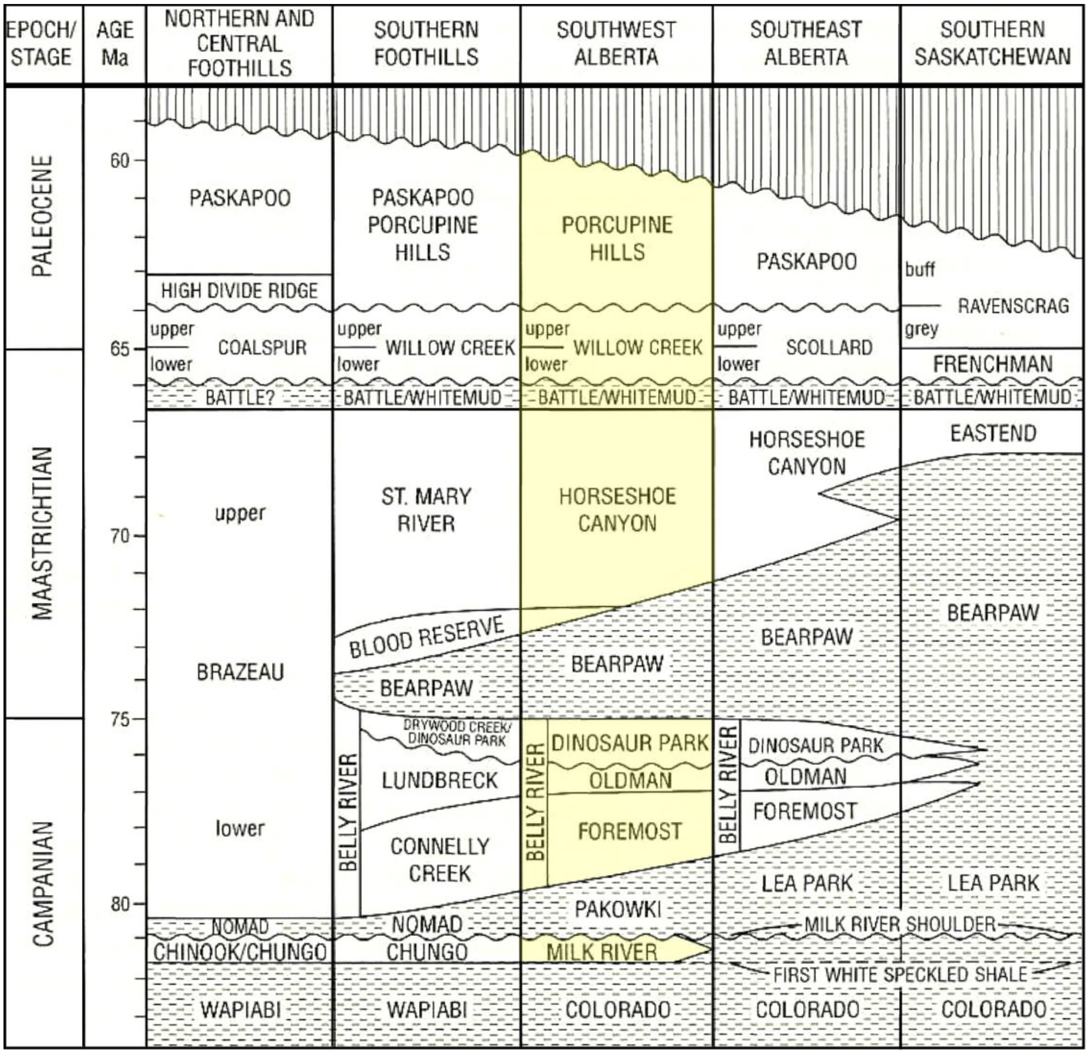

Figure 9. Stratigraphic column (Hamblin, 1997a).

3.2.1 Crowsnest Volcanics (~100 Ma)

The Crowsnest volcanics (Figure 10), the Crowsnest Formation, represent the eroded remains of an alkaline volcanic centre that erupted in a fluvial environment in which the lower Cretaceous, nonmarine, Blairmore Group was deposited (Pearce, 1993). The age of the Crowsnest Formation is ~100 Ma, based on radiometric and faunal dating (Bowerman et al., 2006). The Crowsnest volcanics were tectonically transported to their current position during eastward thrusting of the Rocky Mountains. Palinspastic reconstruction places the original location of the volcano 75 km to the west of its current location. The total volume of the formation is estimated at 209 km^3. The original volcano formed a positive topographic feature that was subsequently eroded to about 35 m. The contact between the volcanic rocks and sedimentary rocks of the Blairmore Group is gradational. Volcanism was essentially pyroclastic (agglomerates, tuffs). The chemistry of the volcanics is sodic-nepheline syenite. Crowsnest volcanics have an unusual mineralogical composition: the presence of black garnets, analcime and sanidine—together with their scenic location in the Canadian Rockies—have made these rocks the subject of extensive studies by mineralogists and petrologists (Pearce, 1993; Bowerman et al., 2006).

Figure 10. Typical texture of Crowsnest volcanics.

3.2.2 Milk River Formation (~82–81 Ma)

The Milk River-Pakowki regressive-transgressive cycle is the first of a series of Late Cretaceous clastic wedges within the Alberta Foreland Basin (Payenberg et al., 2002). Underlying the clastic wedge is a widespread calcareous mudstone with fish scales and phosphate nodules (First White Speckled Shale), belonging to the upper part of the Alberta-Colorado Group.

The Milk River Formation (Figure 11) consists of three members: Telegraph Creek, Virgelle and Deadhorse Coulee. The Telegraph Creek member overlies the First White Speckled Shale and represents the transition from offshore mudstone into shoreface sandstone of the overlying Virgelle Sandstone. The Deadhorse Coulee member, overlying the Virgelle shoreface, is composed of dominantly nonmarine shales, siltstones and sandstone units with coal seams (Payenberg et al., 2002).

The total thickness of the Milk River Formation in subsurface varies between 99.4 and 112.7 m (Glass, 1990).

3.2.3 Pakowki Formation (~81–79 Ma)

Dark-grey mudstones of the Pakowki Formation reach a maximum thickness of about 200 m in west-central Saskatchewan. The formation thins rapidly to the west and pinches out near the eastern edge of the foothills.

Figure 11. Upper Milk River Formation, Police Creek Coulee.

As the lithology of the Pakowki Formation is not considered favourable for hosting sandstone-hosted uranium deposits it was not included in the 2006 project.

3.2.4 Belly River Group (~80–75 Ma)

The Belly River Group in the study area includes the Foremost, Oldman (Figure 12) and Dinosaur Park formations. The petroleum industry universally applies the term 'Belly River'' to the clastic sandy wedge underlain by the Pakowki marine shale and overlain by the Bearpaw marine shale.

The Belly River Group belongs to petrographic Stage I (Figure 8) of Mack and Jerzykiewicz (1989). This stage is characterized by high concentration (30%–60%) of volcanic detritus. The balance of the rock comprises roughly equal amounts of two types of clasts: metamorphic clasts, derived by erosion of the Omineca Crystalline Belt, and sedimentary clasts, derived from the Rocky Mountain Belt. Sedimentary clasts are represented by chert and carbonate rock fragments, suggesting provenance from Paleozoic carbonate rocks and Mesozoic chert-arenites (Mack and Jerzykiewicz, 1989).

Figure 12. Upper Oldman Formation, south bank of Oldman River near Lethbridge.

3.2.4.1 Foremost Formation

The Foremost Formation is described in detail by Hamblin and Abrahamson (2006). The lower part of the Foremost Formation, referred to as the 'Basal Belly River,' is composed of shoreline facies and channel-fill sandstone units up to 40 m thick. Sandstone units are fine to medium-grained with diagenetic calcite cement (10%–40%). The composition of framework grains is about 30% quartz, 25% feldspar (altered volcanic plagioclase, with minor fresh igneous K-feldspar) and 45% rock fragments (chert and volcanics, with minor mudstone sedimentary rock fragments and some metamorphic rock fragments. Diagenetic clay constitutes up to 20% of the rock: kaolinite (10%), chlorite (5%) with the remaining composition made up of illite, montmorillonite and smectite. Average porosity is 18%. The upper part of the Foremost Formation is bounded by coal seams and consists of thick and thin fluvial sandstone units.

Only the upper, shaly parts of the Foremost Formation were examined during the 2006 field work. Coal-rich, dark-red shale (Appendix 1, sample 06USA0047) registered 70 cps, with the uranium content at 11.8 ppm. As shale commonly contains up to 13 ppm uranium (Dahlkamp, 1993), this level of uranium content is not anomalous. The Basal Belly River member and other sandstone units—based on their general similarity to sandstone units that host uranium deposits described in the literature (Chapter 2)—are favourable for sandstone-hosted uranium deposits and deserve further investigation. Oil and gas logs will be important sources of data as surface outcrops are sparse.

3.2.4.2 Oldman and Dinosaur Park Formations

The Oldman and Dinosaur Park formations are described by Hamblin (1997a, 1997b). The Oldman Formation constitutes the middle part of the Belly River clastic wedge, while the Dinosaur Park Formation represents the upper part. The total combined thickness of the two formations increases from about 100 m in southeastern Alberta to about 225 m in southwestern Alberta.

The Oldman Formation contains two discernible units: the lower ‘Comrey sandstone’ ranging in thickness from 2 to 30 m and the ‘Upper siltstone’ member ranging in thickness from 8 to 18 m.

- The ‘Comrey sandstone’ is light-grey to buff, well-sorted, fine-grained, quartz-rich and bentonitic. It commonly contains wood or coaly fragments, gastropod shells, dinosaur bones and calcrete nodules. The facies are interpreted as laterally and vertically stacked individual sandstone bodies, deposited by an extensive fluvial system. Paleoflow measurements indicate that general flow direction was toward the east.
- The ‘upper siltstone’ member is composed of interbedded greenish-grey siltstone, light grey, very-fine sandstone and minor carbonaceous shale.

The Dinosaur Park Formation in the study area ranges in thickness up to 50 m. The formation has a lower, sandier member, and an upper, finer-grained member. The lower member consists of light-grey, thick-bedded, fine to coarse-grained, friable sandstone and thinner beds of grey, sandy siltstone. The sandstone to siltstone ratio is 5:1; individual sandstone beds range up to 10 m thick. In general, the sandstone units are rich in lithic fragments, including the following: volcanics, quartzite, plagioclase and chert. A bentonitic matrix is common. The upper member consists of grey to dark greenish-grey, thin-bedded, interbedded mudstone, and very-fine to medium-grained sandstone. Sandstone is subordinate to siltstone in ratios of about 1:3; individual sandstone bodies range up to 6 m thick. The top of Dinosaur Park Formation is marked by the Lethbridge Coal Zone.

3.2.5 Bearpaw Formation (~75–73 Ma)

In southern Alberta the Bearpaw Formation (Figure 13) is composed of marine shale and grey clay that were deposited during a major westward and northwestward transgression of the epeiric Bearpaw Sea. The marine shale thins to the west and north, but thickens to the east and south (Hamblin, 1998). Sandstone bodies within the Bearpaw Formation represent distal shoreline related units, which are extensions of St. Mary River Formation out into the Bearpaw marine shale. The lithological composition of this formation is not considered prospective for the sandstone-hosted uranium deposit model, and it was not evaluated in the course of the 2006 study. However, thin sandstone bodies within the Bearpaw are currently being explored for gas, and when new information about distribution of such bodies becomes available, it might be a factor in re-evaluating its uranium potential.

3.2.6 Blood Reserve Formation (~73–72 Ma)

The Blood Reserve Formation (Figure 14) consists of massive, light-grey to light-yellow medium-grained sandstone, with either calcareous or argillaceous cement. Thickness of this formation ranges from 30 m in the south to 12 m near the Monarch Fault Zone (Glass, 1990). It is interpreted as a barrier beach-tidal inlet sequence on the embayed western shoreline of the Bearpaw Sea (Hamblin, 1998). Blood Reserve Formation is the regional expression of the basal shoreline-related facies of the St. Mary River Formation. The formation outcrops in a narrow, north-south–trending band from the international boundary to the Monarch Fault Zone (Enclosure 1).

Figure 13. Bearpaw shales, south bank of Oldman River near Lethbridge.

Figure 14. Blood Reserve Formation outcrops at McIntyre Ranch.

3.2.7 St. Mary River Formation (~72–67 Ma)

The St. Mary River Formation (Figure 15) represents a nonmarine clastic wedge and is composed of interbedded siltstone, shale and sandstone, with minor bentonite and coal. Sandstone units are greenish, calcareous, fine-grained, and interbedded with grey and green silty shales. The basal portion—up to 30 m thick—is composed of grey shale and siltstone with abundant wood fragments and thin coal beds. The bulk of the unit is composed of nonmarine, interbedded sandstone that is deposited in meandering and anastomosed fluvial channels, splay channels, and overbank siltstone and shale sediments (Hamblin, 1998). Average thicknesses of the formation (provided by several authors) range from 275 m to 450 m (Hamblin, 1998).

Figure 15. St. Mary River Formation, north shore of St. Mary River across from the Dudley homestead.

The St. Mary River Formation conformably overlies the Blood Reserve Formation (or Bearpaw Formation) and is intertongued northward with the Horseshoe Canyon Formation of the Alberta Plains. While it has a conformable upper contact with the Willow Creek Formation on the west side of the Alberta Syncline, it can be disconformable on the east side of the syncline (Hamblin, 1998).

The St. Mary River Formation, characterized by an increase in metamorphic rock fragments and a decrease in carbonate and chert sedimentary rock fragments, is represented by petrographic stage II (Figure 8) of Mack and Jerzykiewicz (1989). The change in composition is interpreted as evidence for the increased importance of the Omineca Belt as a sediment source while volcanism remained significant (Mack and Jerzykiewicz, 1989). In the southern Alberta Foothills, the St. Mary River Formation has 20%–70% volcanics fragments, 40%–80% metamorphic/sedimentary fragments and 40%–90% carbonate chert fragments (Figure 8).

3.2.8 Whitemud Formation (~67 Ma)

Whitemud Formation (Figure 16) was previously defined as a separate formation, but is currently believed to be a weathered, altered part of the St. Mary River Formation (Hamblin, 2004). An important defining feature of the Whitemud Formation is a sharp increase in the content of volcanic rock fragments, which indicates an increase in explosive volcanic activity in the area at the time of deposition. Detailed studies of the distribution of volcanic ash within the Whitemud Formation suggest a western source area for diagenetically altered volcanic ash (Gibson, 1977).

Figure 16. Whitemud Formation, north shore of Oldman River.

Weathering during exposure and erosion of the upper St. Mary River Formation took place before the deposition of the Willow Creek Formation. Whitemud sandstone samples were point-counted in thin sections and described as lithic sandstone with the following composition: up to 25%–60% quartz, 5%–20% feldspar and 30%–60% rock fragments (Binda and Lerbekmo, 1973). The interstitial material was described as montmorillonite and kaolinite derived from the in situ alteration of volcanic rock fragments.

3.2.9 Battle Formation and Kneehills Tuff Zone (~67–66 Ma)

The boundary between Whitemud and Battle formations represents a major regional disconformity (Hamblin, 2004) consistently overlain by the dark organic-rich Battle shales.

In the 2006 study area, the Battle Formation is either very thin or not present. Where present, it is a distinctive dark-brown to black bentonitic silty mudstone with few sand grains and abundant organic matter. The Battle Formation records a volcanic maximum where the slow aggradation of airborne ash in calm shallow lakes and swamps took place on a floodplain (Hamblin, 1998).

The Kneehills Tuff is an important stratigraphic marker because it is distinctive and nearly continuous over much of Alberta (Hamblin, 1998). Kneehills Tuff occurs as one or several beds within the Battle Formation and its radiogenic age is given as 66 Ma (Hamblin, 1998). The tuff is light-grey, hard (siliceous), with opal/chalcedony-filled vugs. The cement is an isotropic opaline silica and montmorillonitic clay (Hamblin, 1998).

3.2.10 Willow Creek Formation (~66–64 Ma)

The Willow Creek Formation (Figure 17) is distinguished from underlying and overlying formations based on the red and greyish-green coloured mudstone beds that constitute its main lithology (Jerzykiewicz, 1997).

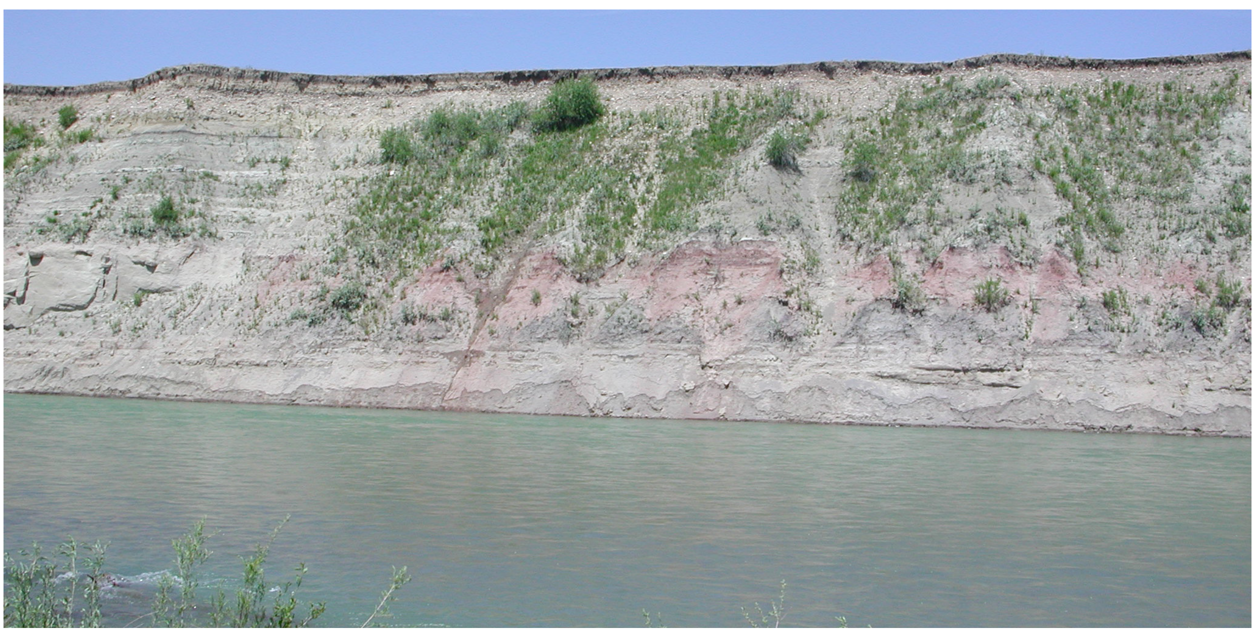

Figure 17. Willow Creek Formation, Waterton River.

The Willow Creek Formation forms an asymmetric wedge. In the core of the Alberta Syncline the thickness reaches 650 m (Jerzykiewicz, 1997) and 1006 m (Glass, 1990). In the plains, near the Oldman River on the eastern limb of the Alberta Syncline, the thickness is 320 m; in the Foothills, where the thickness increases through thrusting and deformation, it exceeds 1000 m (Jerzykiewicz, 1997).

Caliche concretions are the most conspicuous feature of Willow Creek Formation. They were formed by calcium carbonate accumulation in a subaerially-exposed diagenetic environment. Some of the concretions coalesce into irregular bodies or extensive layers of ancient hardpan (Appendix 4, Photo 18). Caliche forms in regions where annual rainfall is between 400 and 600 mm, and where periods of rainfall alternate with long-lasting droughts (Jerzykiewicz, 1997).

The Cretaceous-Tertiary boundary divides the Willow Creek Formation into lower and upper members. The lower member consists of soft, medium-grained sandstone interbedded with mudstone interbeds that are grey, green, pink or purple in colour (Jerzykiewicz, 1997). In the mudstone, pedogenic caliche— red limestone concretions—is commonly developed. This was observed during the 2006 study on the banks of the Waterton River and in outcrops within the Whiskey Gap area. The lower member of the Willow Creek Formation belongs to petrographic stage III (Figure 8) of Mack and Jerzykiewicz (1989), and is characterized by a decreased metamorphic detritus and increased sedimentary detritus (chert and carbonate rocks fragments). These trends were interpreted as representing a period of thrusting in the Front Ranges or Eastern Main Ranges, and are sourced from the erosion of Paleozoic cherty carbonates and Mesozoic chert arenite units (Mack and Jerzykiewicz, 1989).

The upper member of the Willow Creek Formation consists of mudstone interbedded with thin layers of siltstone and fine-grained sandstone. The lower part consists of fine-grained sediments deposited in floodplain and lacustrine settings. In the upper part of the formation, near the contact with the overlying Porcupine Hills Formation, thicker, medium-grained sandstone layers are much more common (Jerzykiewicz, 1997). The Upper Willow Creek Formation corresponds to petrographic stage IV (Figure 8) of Mack and Jerzykiewicz (1989). It is characterized by an increase in metamorphic detritus, reflecting the erosion of the Front Ranges and Eastern Main Ranges and reintroduction of metamorphic rock fragments from the Omineca Crystalline Belt into the drainage basin (Mack and Jerzykiewicz, 1989).

3.2.11 Porcupine Hills Formation (~64–59 Ma)

The Porcupine Hills Formation (Figure 18) constitutes the uppermost foreland basin strata in the southern part of the Alberta Basin. It reaches preserved thicknesses of 1220 m in the Porcupine Hills region, but because the upper boundary is defined by Late Tertiary and by recent erosion the original depositional thickness has not been determined (Glass, 1990).

The contact between the upper Maastrichtian/lower Paleocene Willow Creek Formation and the overlying Paleocene Porcupine Hills Formation has been commonly placed on the basis of the first appearance of major sandstone units (Lerbekmo and Sweet, 2000). Lerbekmo and Sweet (2000) and Jerzykiewicz (1997) discuss the stratigraphy and relationships between the Porcupine Hills, Paskapoo, Willow Creek and Scollard formations in detail.

The Porcupine Hills Formation consists of recessive weathering, poorly exposed mudstone interbedded with thick, resistant sandstone units that are cliff-forming (Appendix 4, Photo 26). Mudstone beds commonly exceed 50 m and the thickest sandstone bodies are about 30 m (Jerzykiewicz, 1997). Total thickness of mudstone units in the Porcupine Hills Formation exceeds that of the sandstone units. However, in outcrop, only sandstone units are well exposed (creating the misperception that the Porcupine Hills Formation is dominated by sandstone). Two types of sandstone bodies were identified by Jerzykiewicz (1997): (1) stacked channel complexes, comprising laterally discontinuous sandstone bodies and (2) broad continuous channel-fill complexes.

Figure 18. Porcupine Hills Formation, in Porcupine Hills.

The Porcupine Hills Formation corresponds to petrographic stage V (Figure 8) of Mack and Jerzykiewicz (1989). It is characterized by a sharp increase in sedimentary detritus enriched in carbonate rock fragments and chert, reflecting a possible thrust event in the eastern Main Ranges or Front Ranges.

The sedimentary environment of the Porcupine Hills Formation is described as mid-fan to distal alluvial fan conglomerates, fluvial channels of various styles (anastomosing, braided and meandering), blanket sandstone units of sheet-flood origin, lacustrine and off-shore lacustrine sediments (Jerzykiewicz, 1997).

3.2.12 Quaternary Geology (~2 Ma–Present)

Understanding and knowledge of Quaternary geology of the area is essential for its mineral exploration—both for ground-based studies and airborne surveys. Thick drift (Figure 19) can mute signals from airborne surveys, reduce access to bedrock and obscure interpretation of regional geochemical data.

Quaternary deposits are the surface materials and form the local landforms over virtually all of the Interior Plains. Bedrock, which controls the broad elements of the physiography, rarely outcrops except in incised river valleys. Most of the surficial deposits that occur were deposited during the Pleistocene glaciations. For the most part, the surficial materials and present-day landforms are a result of the last glacial event during the late Wisconsin (25–12 ka BP). The bedrock topography is the result of erosion during the Tertiary and, probably, at least the early Quaternary (Fenton et al., 1994); with the high and lows in the bedrock surface being reflected in the surface topography. Two basic topographic elements

Figure 19. Quaternary till deposits, near Lethbridge.

are evident: one, the broad generally northward and eastward-trending valleys and, two, intervening uplands (e.g., Cyprus Hills) formed by eroded bedrock remnants. The bedrock topographic lows within Alberta are primarily the major preglacial valleys. Most of these valleys were likely eroded prior to the first glacial advance to reach the region. However, the existence of pre-Laurentide sediment at the base of these valleys is needed to confirm this assumption. Pre-Laurentide (commonly referred to as preglacial) sediment within Alberta consists of coarse fluvial deposits—predominantly quartzite clasts—derived from the Cordillera. The thick deposits in the Cyprus Hills are excellent examples of pre-Laurentide Cordilleran fluvial gravels. The drift thickness varies from less than 2 m in a few areas to in excess of 300 m in some buried valleys.

As southern Alberta was the place where glaciers terminated it was therefore the place where drift deposition dominated over bedrock erosion. Only three upland areas in the south escaped glaciation: the Porcupine Hills, the Del Bonita area and the Cypress Hills (Stalker and Vincent, 1993).

The importance of Quaternary deposits to uranium exploration revolves around the thickness of the drift preserved in exploration areas. The drift thickness varies from less than 2 m in a few areas to in excess of 300 m in some buried valleys. Some broad areas are covered by some 100 m of glacial sediments, but over most of the region the drift averages 20–30m. A drift thickness isopach map for the main exploration areas in southern Alberta (Figure 20) shows that most of the staked areas have drift thicknesses between 0 and 50 m. See Appendix 5 for a detailed description on the creation of the drift thickness isopach map.

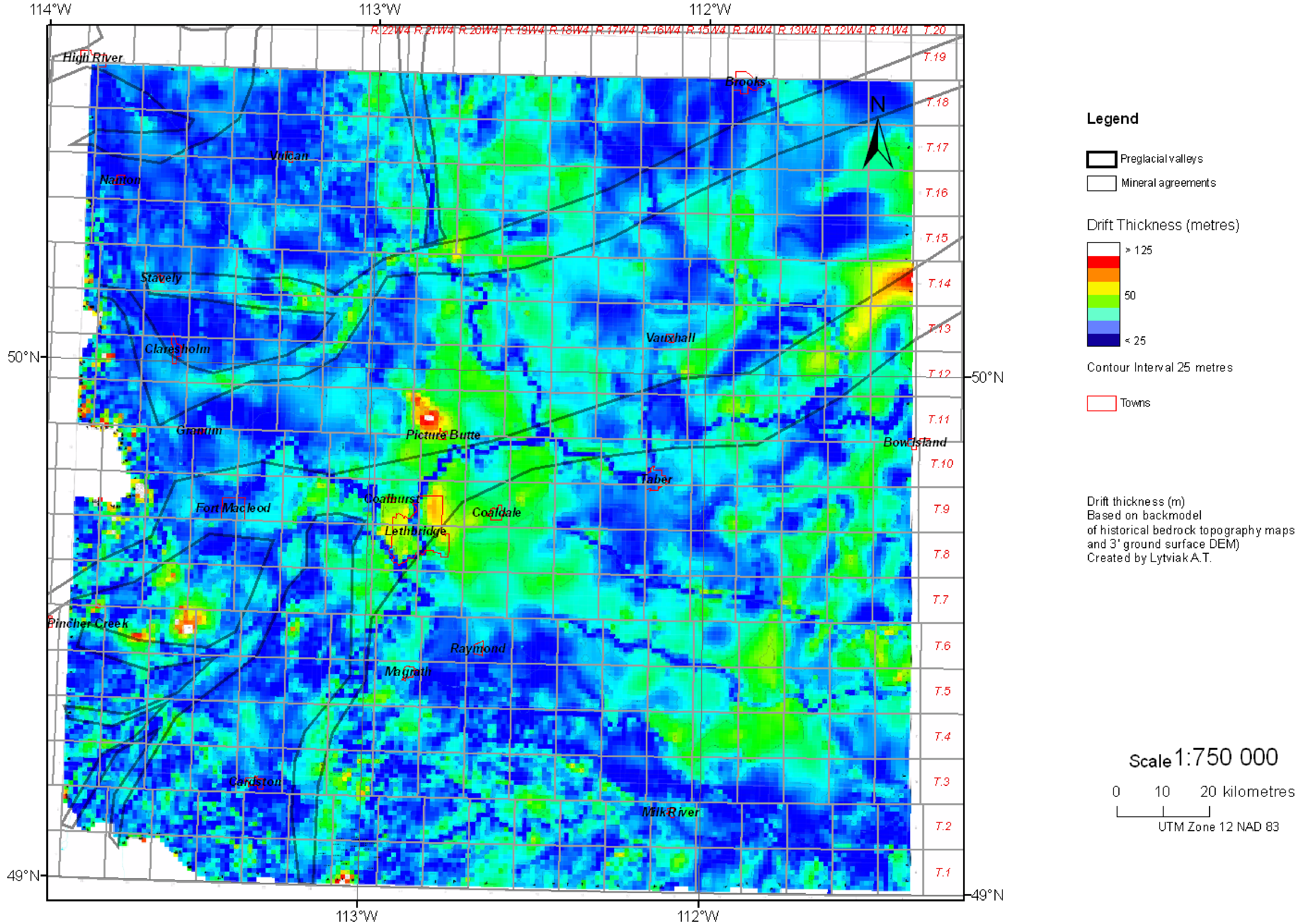

Figure 20. Drift thickness for southern Alberta.

4 Overview of Uranium Exploration in Southern Alberta

4.1 Previous Exploration

Previous sediment-hosted uranium deposits exploration predominantly occurred in the late 1960s to the early 1980s (Olson et al., 1994). Projects efforts concentrated mostly within southern Alberta (south of Edmonton), with the exception of some exploration conducted in the Grande Prairie area. Exploration was based on the geological model of sediment-hosted uranium deposits found around the world (Olson et al., 1994). Companies studied oil and gas exploration, well-cuttings and geophysical well logs, and sampled water wells, stream sediments and outcrops. Minimal drilling and radiometric surveys were conducted at this time. Initial results were significant enough to warrant follow-up exploration in several areas.

This first round of uranium exploration (1960–1980) can be separated into seven general geographic regions: the Cypress Hills, Milk River, Fort MacLeod, Vulcan, Sundre, Rocky Mountain House and Grande Prairie areas (Figure 21). Each geographic area features a stratigraphic unit of Cretaceous-Tertiary age: one of the Ravenscrag, Milk River, Willow Creek, Porcupine Hills formations or the Wapiti Group (Olson et al., 1994). Reported results for this first round exploration were presented by Olson et al. (1994) and are summarized in the following paragraphs.

In the Cypress Hills area (Figure 21), a uranium-bearing lignite was the objective within the Ravenscrag Formation. The best reported result was obtained by drilling—0.01% U_3O_8 over 2.44 m of core in a carbonaceous claystone. Follow-up drilling to delineate the zone intersected in this hole was unsuccessful. Also within the Cypress Hills area, near Thelma, a lignite seam yielded a gamma-ray signature 30 times background during gamma-ray logging of water wells. No further exploration near Thelma has been recorded.

In the Milk River area (Figure 21), water well samples and rock samples of argillaceous sandstone from the Milk River Formation were assayed. Water well anomalies of up to 144 ppb uranium and rock sample anomalies of 18 ppm uranium were found. A follow-up investigation of this area, conducted by a second party, attributed the anomaly to ‘natural variations’ rather than uranium mineralization.

The Fort MacLeod area (Figure 21) was part of a reconnaissance project that included car-borne spectrometer surveying, ground radiometric prospecting, geochemical stream sediment sampling and geological examinations. Results focused on a coal-rich, limonitic zone within the Willow Creek Formation where anomalies from rock sample assays were up to 114 ppm molybdenum, 120 ppm vanadium and 3 ppm uranium. When follow-up work was conducted on the Willow Creek Formation, more localized anomalies in a silty limestone were found. One rock sample reported uranium > 2000 ppm, 13 ppm molybdenum, 78 ppm vanadium and 4 ppm selenium, and another sample reported 85 ppm uranium; scintillometer (SPRAT SPP2N) readings were up to 2000 cps and 900 cps, respectively. No additional follow-up work was completed at the time.

The Vulcan, Sundre and Rocky Mountain House areas (Figure 21) were part of the same reconnaissance project as the Fort MacLeod area. Three hundred and twenty-five stream sediment samples revealed anomalies of 4–6 ppm uranium in these three areas. No follow-up work was reported.

The Grande Prairie exploration area (Figure 21) in west-central Alberta was the follow-up to a large reconnaissance program that had included parts of Saskatchewan and Alberta. Sandstone units of the Wapiti Group were targeted by petrographic and geochemical studies of cuttings from oil and gas exploration wells and an airborne radiometric survey. Cuttings at two locations yielded assay anomalies

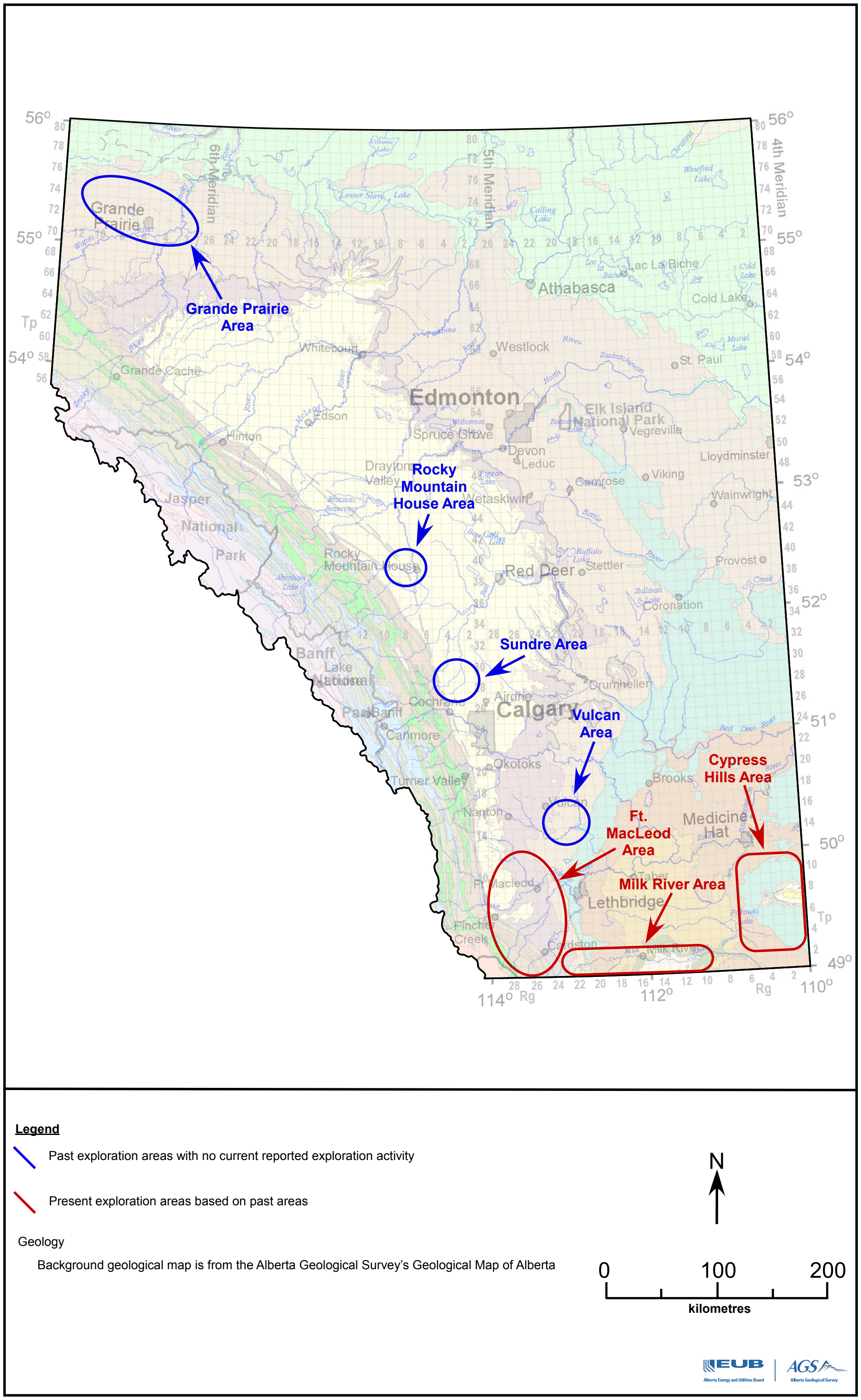

Figure 21. Past and present sediment-hosted uranium exploration areas of central and southern Alberta. Background is the Geological Map of Alberta (Hamilton et al., 1999).

of up to 100 ppm uranium over 3.05 m and 100 ppm uranium over a 6.10 m drill interval. Anomalies for pathfinder elements such as zinc and lead (up to 2000 ppm and 200 ppm over 3.05 m of core), and nickel and vanadium (400 ppm over 9.14 m and 400 ppm over 6.10 m of core) were reported in this area. As of 1994, no additional follow-up work had been reported for this area.

4.2 Present Exploration

After a two-decade hiatus in uranium exploration, interest in uranium increased in late 2004 when companies began to stake land in southern Alberta (Olson, 2005). Currently active areas include three former areas of interest: Cypress Hills, Milk River and Fort MacLeod (Figure 21). Although recently reported exploration results have been concentrated in these southern-most areas of the province, staking has been much more extensive, including areas north of Calgary and west of Edmonton (Figure 22). The availability of past exploration results has provided a framework on which to base current exploration strategies. Target stratigraphic units have been expanded to include the Willow Creek, Cypress Hills, Ravenscrag, Whitemud and Eastend formations, and the channel sand units within the Bearpaw Formation. The focus to date has been on field reconnaissance programs: outcrop sampling, water sampling, mapping, prospecting and data evaluation. Several drill programs have been initiated based on the data collected and interpreted by the companies involved.

The Fort MacLeod area is now separated into three projects in two project areas: the Fort MacLeod Property, the Fort MacLeod Project and the Alberta Sun Project (project names were assigned by industry). Land staking for these two projects began in March 2005 (Marum Resources Inc., 2005; Firestone Ventures Inc., 2005).

The Fort MacLeod Property is the latest of the three properties to be staked. Staking took place in February 2006. Information that has been reported on this property includes two trends of anomalous radioactivity (mostly within the Willow Creek or Paskapoo formations) found through the examination of geophysical logs from oil and gas exploration wells (Strathmore Minerals Corp., 2007).

On the Fort MacLeod Project reconnaissance programs and drilling have been completed. Previously, two samples assayed had anomalous uranium of 4990 ppm and 5700 ppm (Olson, 2005). These results were followed up by a shallow-hole drill program targeting sandstones for roll-front uranium in upper Cretaceous continental strata. Of the 19 reverse circulation holes drilled, none reported positive results—no sandstones or anomalous radioactivity were discovered (Olson, 2006).

The Alberta Sun Project is exploring for roll-front uranium within the Willow Creek Formation, along the shores of Waterton River, and the St. Mary River Formation, near the village of Kimball. The exploration program for this project includes prospecting, sampling, mapping, radon cup orientation surveys and data evaluation (Olson, 2005, 2006). Geochemical assays of samples from the Willow Creek Formation resulted in three isolated organic debris samples with anomalous uranium (5630 ppm, 6830 ppm and 7640 ppm), vanadium, arsenic, selenium, molybdenum and lead. Three rock samples from the St. Mary River Formation—a carbonaceous mudstone, limonitic carbonaceous mudstone and a grey sandstone—had anomalous uranium (57 ppm, 92 ppm and 150 ppm, respectively), vanadium (52 ppm, 117 ppm, and 57 ppm, respectively) and some lead, molybdenum and chromium anomalies. The grey sandstone reported high scintillometer readings of 1250 cps (Olson, 2005).

On the Whiskey Gap property, exploration methods have included radon in wellwater surveys and drilling, followed by gamma-ray logging. Results for the initial radon survey, completed in 2005, reported that 8 out of 26 samples taken throughout the property had values of at least 1000 picocuries/L; 2 of these exceeded 2000 picocuries/L (Olson, 2005). Uranium content in wellwaters ranged up to

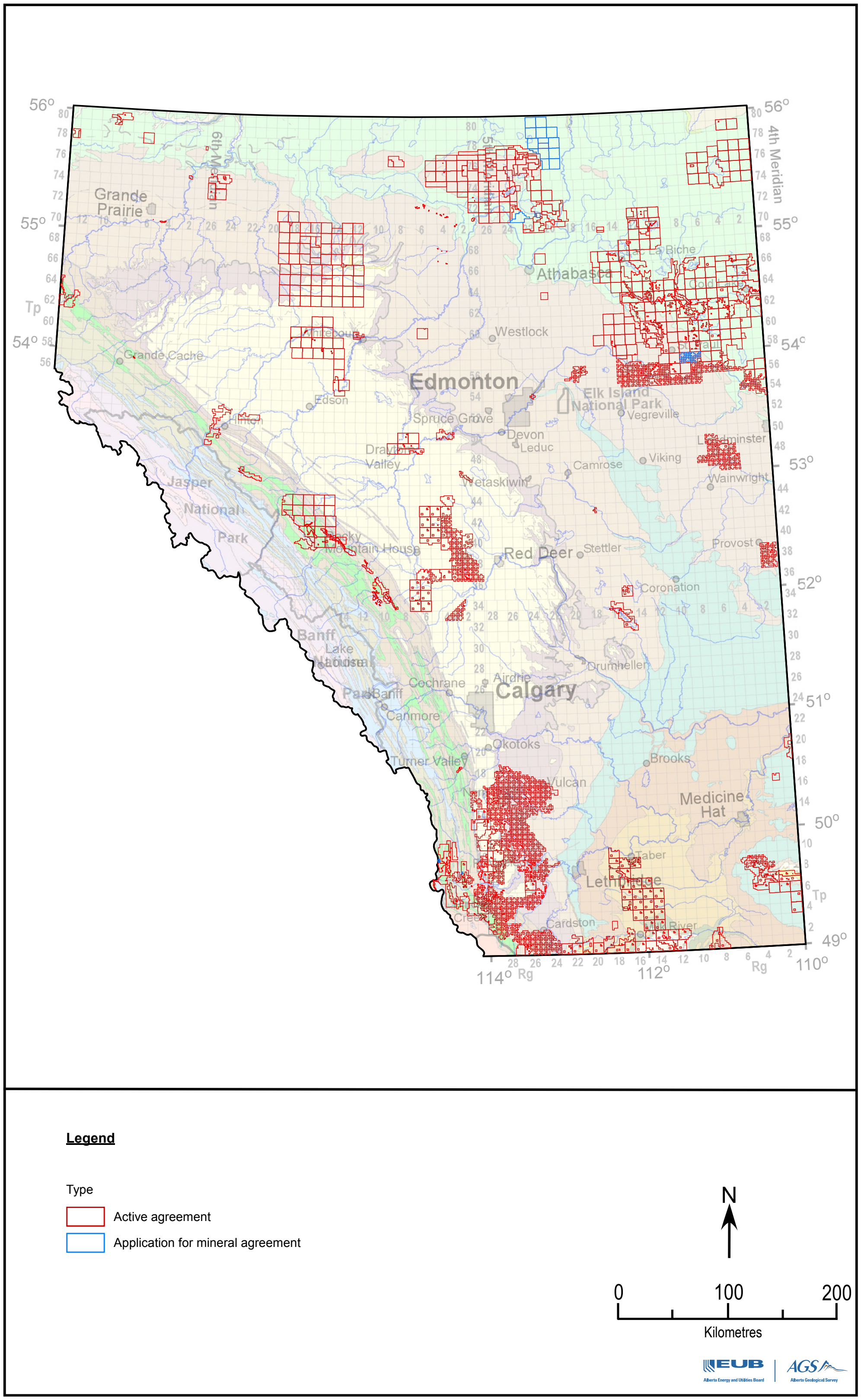

Figure 22. Land-staking for southern and central Alberta, mineral agreements (February 2007). Most of the land staked south of Calgary is for uranium.

30 ppm, with an average of 11 ppm. These positive results prompted a first-phase drill program. It was reported that of the 10 holes drilled with 10 m grid spacing (to a maximum depth of 150 m), all 10 holes intersected anomalously radioactive zones up to 5 m thick (North American Gem Inc., 2006). In seven of these holes, gamma-ray logging recorded API (American Petroleum Institute) values from 175 units to as high as 782 units (for more details on API units refer to Chapter 7). Petrographic descriptions of the anomalous rocks by the company characterize them as fine-grained greywacke with angular quartz and plagioclase grains and local patches of carbonaceous grains (Olson, 2006). The second phase of drilling planned eight holes on another zone of anomalous radon in wellwaters, 6.4 km west of the Phase 1 drilling program. To date, no results have been reported from this drilling.

In the Cypress Hills area, on the Ravenscrag uranium property, formations targeted sandstone-hosted uranium are the Cypress Hills, Ravenscrag, Whitemud and Eastend formations, and channel sand bodies within the overall shaly Bearpaw Formation (Olson, 2005). Uranium potential on the Ravenscrag property is considered to be enhanced by the Eagle Butte Structure, a meteor impact site. The faults and fractures created from the impact are believed to have provided conduits for uranium-rich fluids to flow into the favourable sandstone hosts. Prospecting, outcrop and wellwater sampling were conducted in the summer of 2006 to delineate drill targets (Olson, 2006).

5 Results of 2006 Alberta Geological Survey Field Studies

Note: all readings of radioactivity from outcrops were taken using SRAT SPP2 scintillometer set at a slow-reading mode. (See Appendix 6 for sample location, results and bedrock geology)

5.1 Crowsnest Volcanics

Outcrops of Crowsnest volcanics, examined in the summer of 2006, showed high radioactivity ranging from 225 cps to 300 cps. Assays of the 3 samples (Appendix 1, samples 06USA0010, 0102, 0103) showed that uranium values vary from 4 to14 ppm, thorium from 10 to 24 ppm and potassium from 6% to 14%. Thus, the total gamma-ray counts of the Crowsnest volcanics represent roughly equal amounts of thorium, potassium and uranium.

5.2 Milk River Formation

Outcrops of Milk River Formation were examined at Stop 060605_01, 060605_02, 060605_03 (Appendix 1), on the banks of the Milk River and in the Police Creek Coulee. Outcrops consist of massive light-yellow to light-grey, porous, poorly cemented, coarse-grained sandstone, with big calcareous concretions, and widespread limonite alteration banding (Appendix 4, Photo 1). One of the radioactive occurrences, with up to 200 cps is located in rusty zone within massive sandstone unit of the upper Milk River Formation. Assay of the sample 06USA0045 (Appendix 1) showed enrichment in thorium (69 ppm) and weak enrichment in uranium content (7 ppm). A thin section study of this sample showed that it contains numerous well-rounded monazite grains (Appendix 4, Photo 21).

5.3 Belly River Group

Seven samples (Appendix 1, samples 06USA0035-37, 39, 65-67) were collected from the Oldman and Dinosaur Park formations. Massive sandstone units, coal measures and shale interbeds were sampled on the shores of the Oldman River near Lethbridge (Appendix 4, Photo 2). Uranium content ranges from 0.3 ppm in coals to 2 ppm in siltstone and mudstone. Thin-section analysis of sandstone from the Oldman

Formation (Appendix 4, Photo 3) resulted in a very fine-grained litharenite rich in chert fragments, biotite and quartz, with calcite cement and 5%–7% organic material.

Thick sandstone bodies, containing abundant bentonite and volcanic fragments, are a favourable environment to host uranium deposits. The low uranium values shown by only 7 samples cannot be considered sufficient evidence for discarding these formations as possible host formations, although the research team has yet to find any significant oxidized zones that would be evidence of the redox processes that are necessary to create such deposits. The Dinosaur Park and Oldman formations have good exposure in areas that were not visited in 2006.

5.4 Blood Reserve Formation

The Blood Reserve Formation forms prominent cliffs on the shores of the Milk River (Appendix 4, Photo 4). At this location, large, well-preserved plant imprints were found (Appendix 4, Photo 5). At the McIntyre Ranch, Blood Reserve sandstone units form cliffs and hoodoos (Appendix 4, Photo 6). The formation is interpreted as beach facies sands of the St. Mary River clastic wedge (Hamblin, 1998). Beach and shallow marine trace fossils were found in the upper part of the Blood Reserve outcrops (*Ophiomorpha* in the middle part of the outcrop and *Macaronichnus* at the very top) (Appendix 4, Photo 7 and 8). Two types of alteration were found in the Blood Reserve Formation. First, subtle light-grey vs. light-yellow bands, most likely caused by various iron oxides contents and compositions (Appendix 4, Photo 9). Samples were taken from both types of rocks (Appendix 1, samples 06USA0029, 30) but no significant differences in uranium content exists between the two samples (0.8 ppm). Another type of alteration observed is a strong calcite cement that results in a competency contrast so that the altered rock forms a positive topographic features (approx. 3 m across, 1 m high) (Appendix 4, Photo 10) as well as loose residual blocks left behind by erosion of the less-cemented sandstone. Uranium content of the calcite-cemented sandstone is similarly low at 0.9 ppm.

Six samples were collected from Blood Reserve Formation at the locations described above. Uranium content is uniformly low (0.7–0.9 ppm). Thin section analysis indicates composition of upper-fine grained litharenite with angular quartz grains, chert grains, sparse fresh plagioclase, muscovite, biotite, chlorite (up to 5% organic material, and calcite cement (Appendix 1, samples 06USA0027, 28).

5.5 St. Mary River Formation

Deformed beds of the upper St. Mary River Formation, near the village of Kimball, host one of the known uranium occurrences in southern Alberta. Two anomalous zones (15 and >50 cm thick) occur within steeply dipping dark-grey to black shaly horizons near the nose of an anticline fold (Appendix 4, Photo 11 and 12). Massive pyrite concretions (Appendix 1, sample 06USA0060) were found on the contact of the second zone with overlying sandstone bed. Thin section analysis of one concretion shows that pyrite constitutes a matrix, and the framework grains are angular fresh quartz, mica, carbonate and chert.

On the outcrop, measured radioactivity was 300–350 cps (counts per second). Assays show uranium contents of 26–29 ppm and 66 ppm (Appendix 1, samples 06USA0018, 19, 24). Thin section analysis of the shale (Appendix 4, Photo 13) shows high organic content, a laminated texture, angular to subrounded fine quartz grains and calcite cement.

5.6 Whitemud Formation

Massive, white sandstone units of the Whitemud Formation were sampled on the north shore of the Oldman River (Appendix 4, Photo 14, 15 and 16). Oxidized plant roots are well-preserved in the upper portions of sandstone body, recording vegetative growth during breaks in sedimentation. Uranium content of sample 06USA0069 was 1.15 ppm.

5.7 Battle Formation and Kneehills Tuff Zone

The Battle Formation: A thin (~50 cm) dark-brown recessive bed that overlies the Whitemud Formation sandstone was sampled on the north shore of the Oldman River (Appendix 4, Photo 17). Uranium content in two samples (Appendix 1, samples 06USA0070, 72) was 2.5–3.2 ppm.

Kneehills Tuff: In thin section, fresh angular quartz and feldspar fragments can be identified (Appendix 1, sample 06USA0073). The Kneehills Tuff was sampled at two locations: on the north shore of the Oldman River (Appendix 1, sample 06USA0073 – 1.2 ppm uranium) and near Drumheller (Appendix 1, sample 06USA0106 – 4 ppm uranium).

5.8 Willow Creek Formation

Paleosol horizons with caliche concretions were observed in Willow Creek Formation on the shores of Waterton River (Appendix 4, photo 18, 19).

Sample 06USA0105 (Appendix 1), previously collected on the south shore of Waterton River, assayed 3810 ppm U and registered 1500 cps. Thin section analysis showed that the sample is composed of bone with calcite cement (Appendix 4, Photo 20).

Several massive sandstone units up to 12 m thick that crop out on the Waterton River (Appendix 4, Photos 22, 23, 24 and 25) were studied and sampled in 2006 (samples 06USA0094, 97, 98, 99) .

5.9 Porcupine Hills Formation

Twelve samples collected from the outcrops of the Porcupine Hills Formation had uniform uranium values of approx. 1 ppm. Scintillometer readings were 20–40 cps. These results show that outcrops of the Porcupine Hills Formation sandstone units, which were visited in 2006, have uniform very-low background uranium content. Most samples tested with 10% HCl acid indicate the presence of calcite. Iron oxide films and manganese dendrites (Appendix 4, Photos 26, 27 and 28) were observed on several outcrops, but no obvious pervasive oxidation or other alteration was noted.

6 Discussion of Field Studies Results

6.1 Milk River Formation

The radioactive anomaly in rusty sandstone bed is interpreted as a small Thorium placer deposit, possibly similar to the Thorium placers of the upper Cretaceous Claggett Formation in Montana. Monazite-enriched placers are the principal thorium-producing deposits in the U.S.A. (Jarrard, 1957).

Milk River Formation sandstone units have several characteristics favourable for hosting uranium mineralization. Sandstone bodies are of substantial thickness, porous and show extensive limonite alteration. The Milk River Formation is a regional aquifer (Ivanovich et al., 1991a). A well-defined redox front was outlined during the study of 21 wells for uranium isotopes. Uranium content in groundwaters of the Milk River aquifer varies from ~10^{-5} mmol/l (1–10ppb) in oxic waters to ~10^{-7} mmol/l (0.01–0.1 ppb) in anoxic waters (Ivanovich et al., 1991b).

6.2 Blood Reserve Formation

The massive sandstone bodies and observed organic material of this formation are favourable criteria for sandstone-hosted uranium mineralization. Although the Blood Reserve Formation is not fluvial, this does not preclude it from hosting sandstone-hosted uranium deposits. Deposits in Texas, for example, are sitting within beach-facies sandstone bodies.

6.3 St. Mary River Formation

To our knowledge, no detailed exploration work was done to study the radioactive occurrence on the bank of St. Mary River. From outcrop studies it appears that uranium enrichment is possibly related to deformation and fluid movement. No detailed structural analysis has been done on the occurrence, but from the outcrop it appears that beds of the upper St. Mary River Formation are folded into a tight anticline near the outcrop (Appendix 4, Photo 12). It is possible that groundwaters were moving into the low-pressure zone at the nose of the anticline and that any uranium carried in the waters would have been preferentially absorbed by the organic-rich shales.

6.4 Battle Formation and Kneehills Tuff Zone

The Whitemud Formation, Battle Formation and Kneehills Tuff may play an important role in understanding the uranium potential of southern Alberta because of the prevalence of volcanic material in these units. The source of uranium in the Texas uranium district is altered volcanic ash of the Catahoula Formation, where original uranium content is believed to be 10–20 ppm (International Atomic Energy Agency, 2005). At the current level of knowledge, it would be premature to make any conclusions as to prospectivity of the Whitemud and Battle formations as hosts for uranium mineralization or as potential uranium sources.

6.5 Willow Creek Formation

High-grade uranium occurrences (up to 2000 ppm) (Olson et al., 1994) on the shores of the Waterton River were discovered in the 1980s and re-kindled interest in uranium exploration in the recent past (see Chapter 4). Several anomalously high gamma responses were identified during the 2006 analysis of oil and gas exploration well logs (see Chapter 5).

High uranium contents in bone material have been reported from a variety of locations around the world. Values up to 820 ppm were reported from fossil bones in Olduvai Gorge; these high uranium values are believed to be a result of the favourable redox potential of deposition environment (Williams and Marlow 1987). Up to 862 ppm uranium in bone fragments are reported in Castel di Guido, Italy, where the surrounding sediment is reported to contain 4–8 ppm uranium (Michel et al., 2001). Marine bone beds in the Harz Mountains (Germany) have isolated bones containing up to 3500 ppm uranium (Schlüter et al., 2001). In the Minjingu phosphate beds in Tanzania, up to 930 ppm uranium was measured in isolated bones. Uranium is believed to be leached from surrounding young volcanic rocks by either circulating groundwater or surficial waters, and re-deposited in bone fragments (Schlüter et al., 2001).

Several outcrops of massive sandstone units on the Waterton River, up to 12 m thick (Appendix 4, Photos 21, 22, 23 and 24), were visited in 2006. On existing geology maps of Alberta they fall within the Willow Creek Formation. However, such sandstone units are uncharacteristic of the upper part of the Willow Creek Formation and should be placed in the lower parts of Porcupine Hills Formation instead. Current geology maps should be revised to reflect the position of the contact between the Willow Creek and Porcupine Hills formations. Magnetostratigraphic and palynological studies show the type Porcupine Hills Formation to be correlative with the upper part of the upper Scollard Formation (Willow Creek time equivalent to the north) (Lerbekmo and Sweet, 2000).

6.6 Porcupine Hills Formation

Massive sandstone units have the right shape and properties as hostrocks for uranium mineralization. However, evidence given in Mack and Jerzykiewicz (1989) suggesting mainly sedimentary origins for these sandstone bodies, may indicate a lower uranium potential of this formation. To date, no thin sections were made from the samples collected in the field during the 2006 program. Further studies of existing oil and gas exploration well logs and outcrops will help evaluate the potential of the formation.

7 Results for Preliminary Well Log Interpretation

7.1 Datasets Overview

The first round of well log interpretation was conducted in the summer of 2006 with four main goals:

(1) to assess the possibility of identifying anomalous radioactivity and sand bodies in gamma-ray logs,

(2) to determine which well log database would be best for adequate interpretation,

(3) to determine whether trends of anomalous gamma-ray activity can be identified, and

(4) to explore the prospect of mapping sand bodies in the study area.

To refine the main goals and keep the study in context for sand-hosted uranium exploration stratigraphic objectives were limited to formations shallower than the Bearpaw Formation, which include the St. Mary River, Willow Creek and Porcupine Hills formations (Figure 9).

For this study the gamma-ray log was used, complemented by the resistivity log. The main log used was the natural gamma-ray log; its main use to oil and gas industry is to interpret lithology. The log records the natural gamma radiation of formations and has a resolution of approx. 33 cm. The source of gamma-ray activity comes from a sum of radiation, mostly from uranium, thorium and potassium. It is recorded in American Petroleum Institute units (API units) (Schlumberger, 2007) (Figure 23).

Because the natural gamma-ray log records a combination of all radioactive elements present, it is not possible to convert the API unit into a quantitative amount of uranium. Instead, the signatures for the lithologies of the study area were examined and ranges of API values were assigned based on the average values in the area. In general, sandstone units in the Claresholm study area have signatures between 15 and 80 API units, while mudstones units range from approx. 100 to 150 API units. Three API unit divisions were created: ‘normal,’ ‘high’ and ‘anomalous.’ Division boundaries were chosen based on two criteria: (1) typical API unit values for micas and clays, and (2) the typical values for mudstones in this area as discussed above. API unit values for micas are typically around 270 and clays have a range of 80–300 API units (Schlumberger, 1988); therefore, signatures were considered ‘anomalous’ only if they reached values greater than 300 API units. Any signatures less than 300 API units but greater than 165

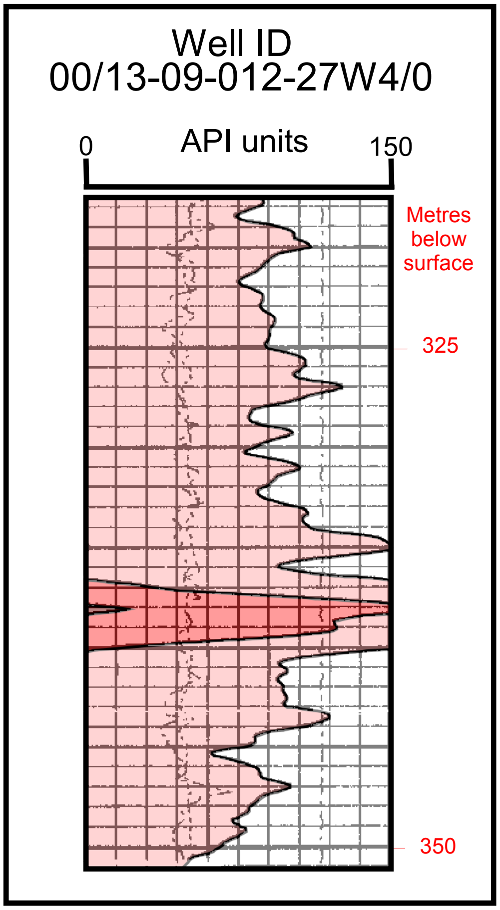

Figure 23. 'Wrap around' gamma-ray signature. A gamma-ray geophysical well log signature showing the signature going over the 0–150 API unit scale in a manner called a 'wrap around.'

API units were recorded as 'high' intervals, and anything less than 165 API units was assigned to the 'normal' range.

Resistivity logs measure the electrical conductivity of a rock: the higher the resistivity, the higher resistance the rock will have to an electrical current. Most sedimentary rocks are made up of minerals that do not conduct electricity (carbonates, oxides, silicates, coal, etc.) but porous rocks can be conductive through conductive fluids in the interconnected pore spaces (Pirson, 1963). Rocks containing clays are conductive due to an electrically active surface layer on the clay minerals (Morrison et al., 2004); therefore, they have a low resistivity. In general, rocks containing little or no pore space are not conductive; therefore, they have high resistivity. Typically, shale and bentonite units (specifically with large clay contents) have a lower resistivity due to the presence of clay minerals. Sandstone units that have little to no porosity (defined as 'tight') would have a higher resistivity. Clearly, many other factors can affect resistivity; this is the reason it is not used as a direct source for determine lithology but it is a good complement to the gamma-ray log.

Two databases were studied: (1) a coal drillhole database, maintained by the Alberta Energy and Utilities Board is a compilation of information obtained from coal drillholes. It is possible to search for drillhole log holdings. The distribution of coal drillholes in Alberta is less extensive than oil and gas exploration wells; (2) an oil and gas exploration well database commercially available data management and analysis tool, which provides access to well, land, seismic, logs, core and other information. The database program is set up for detailed queries of the wells drilled in the Western Canadian Sedimentary Basin and Frontier areas.

7.2 Cole Drillholes Database Search Results

A study of the coal holes drilled in southern Alberta was conducted using the Coal Hole Data File. First, a query was done to obtain the number of coal holes in southern Alberta (from township 1 to township 12 west of the 4th meridian) that had gamma-ray logs completed, depth of well <700 m and wells logged to a depth greater than 0 m—a total of 639 holes met the requirements. Most of these 639 holes are located in areas not of interest to the uranium study at this time. Only a very small area near Magrath contained 10 coal drillholes that were studied. The well logs of these coal drillholes are useful mostly because they had lithological descriptions recorded. This was a remarkable aid to the understanding of how the gamma log behaves in certain formations. Gamma-ray signatures within the upper portion of the St. Mary River Formation are higher and more erratic than typical signatures for the same lithology in a different formation. This is an encouraging observation: upper parts of the St. Mary River Formation, including the Whitemud and Battle formations, are considered as potentially favourable for uranium due to high content of volcanic material in this part of the stratigraphy.

Several new ideas and concepts arose after completion of the oil and gas exploration well section that favour re-approaching the coal hole section of the study. After a study of the 233 oil and gas wells, summarised below, a strong understanding of the gamma-ray signatures for the target formations was created. Newly acquired knowledge should make picking the tops of formations in coal drillholes possible. In addition, the criteria used for initial queries could be reassessed. Coal drillhole data could give sufficient coverage of the shallow subsurface intervals to supplement a larger database study.

7.3 Claresholm Oil and Gas Exploration Wells Study

The area for initial study was selected based on an industry report where an anomalous radioactive trend was described from geophysical logs of oil and gas exploration wells (Figure 24). Radioactivity that was considered anomalous was based on a comparison of the gamma-ray levels to the local background noise in 468 wells (in which 69 were found to have anomalous radioactivity) (Grant, 1982). Nine of these wells defined the Claresholm Trend (Figure 24).

The present study area is located near the town of Claresholm. It includes townships 10–14 and ranges 26–30 west of the 4th meridian. A total of 395 oil and gas exploration wells were in the general 'Claresholm Trend' area (Figure 24). The distribution of oil and gas exploration wells (outlined in blue on Figure 24) ranges from dense in the northeast to sparse in the southwest. Of these, 233 were selected for detail examination. Of the wells that had gamma-ray logs, every log had some portion of the St. Mary River Formation recorded, and more than one half of the wells contained some portion of the Willow Creek Formation. In contrast, the Porcupine Hills Formation was logged in only 7% of the total wells examined. The lack of the Porcupine Hills Formation was not a result of its absence in the subsurface but was due to lack of geophysical well logs at shallow depths from behind the casing.

Nine wells in the study area have anomalous intervals: eight of them have anomalous intervals within the Willow Creek Formation while one well has an anomalous interval within the St. Mary River Formation. Anomalous intervals within the Willow Creek Formation range from 2 to 3.5 m thick. Depths below the surface ranged from 310 m to 540 m. The anomalous interval within the St. Mary River Formation is located about 790 m below the surface and is 2 m thick. It is unique in that the signature is much greater than 450 API units (Figure 25), but its maximum is uncertain as it appears the gamma curve wrapped

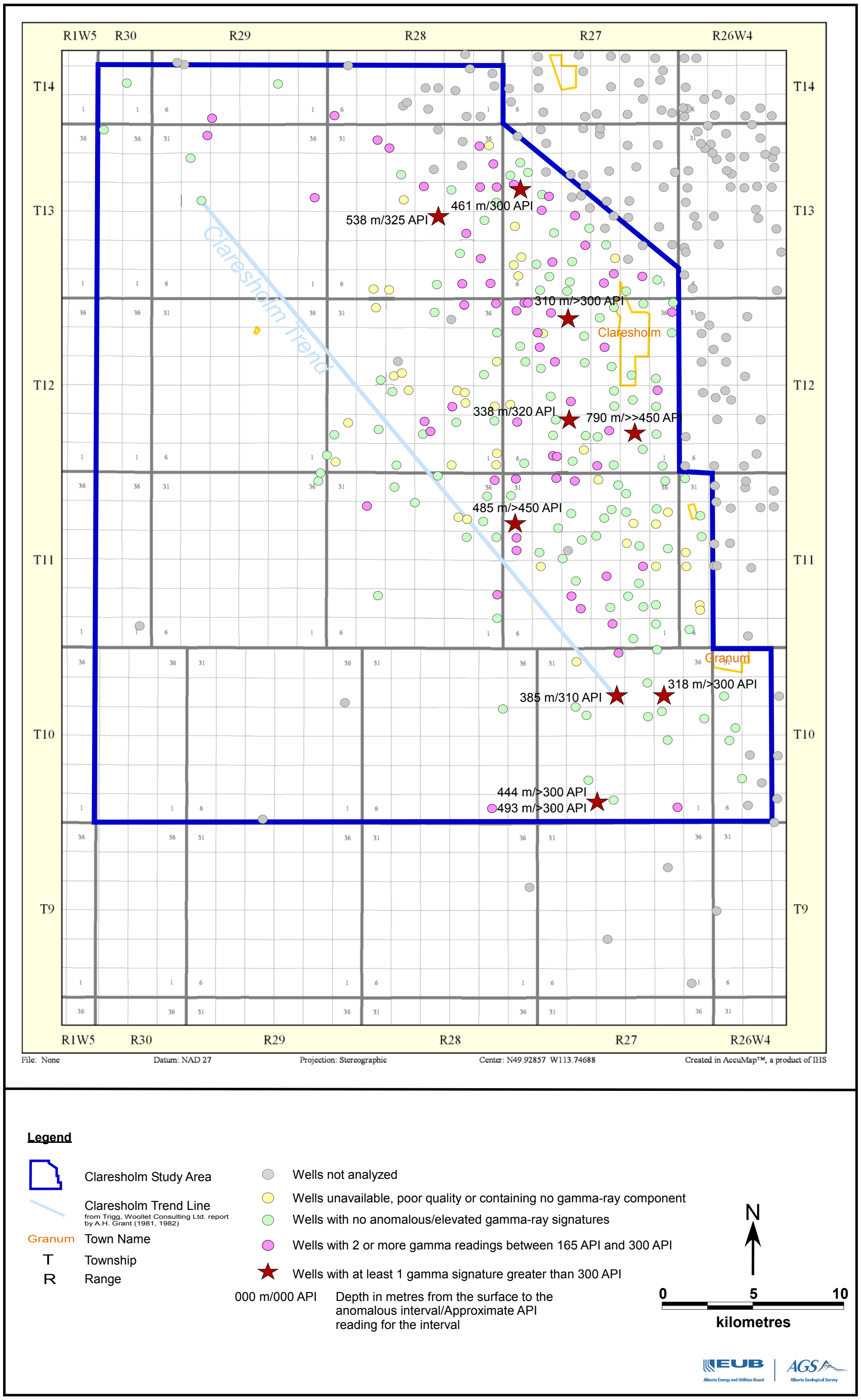

Figure 24. Anomalous wells in the Claresholm Study Area. Red stars represent wells with anomalous gamma-ray signatures; pink dots represent wells with high gamma-ray signatures; green dots represent wells with normal gamma-ray signatures; yellow and grey dots represent wells not of interest or wells not analyzed, respectively.

around the graph several times. The resistivity of this interval is quite high, which may indicate that the lithology is sandstone rather than mudstone (Figure 25).

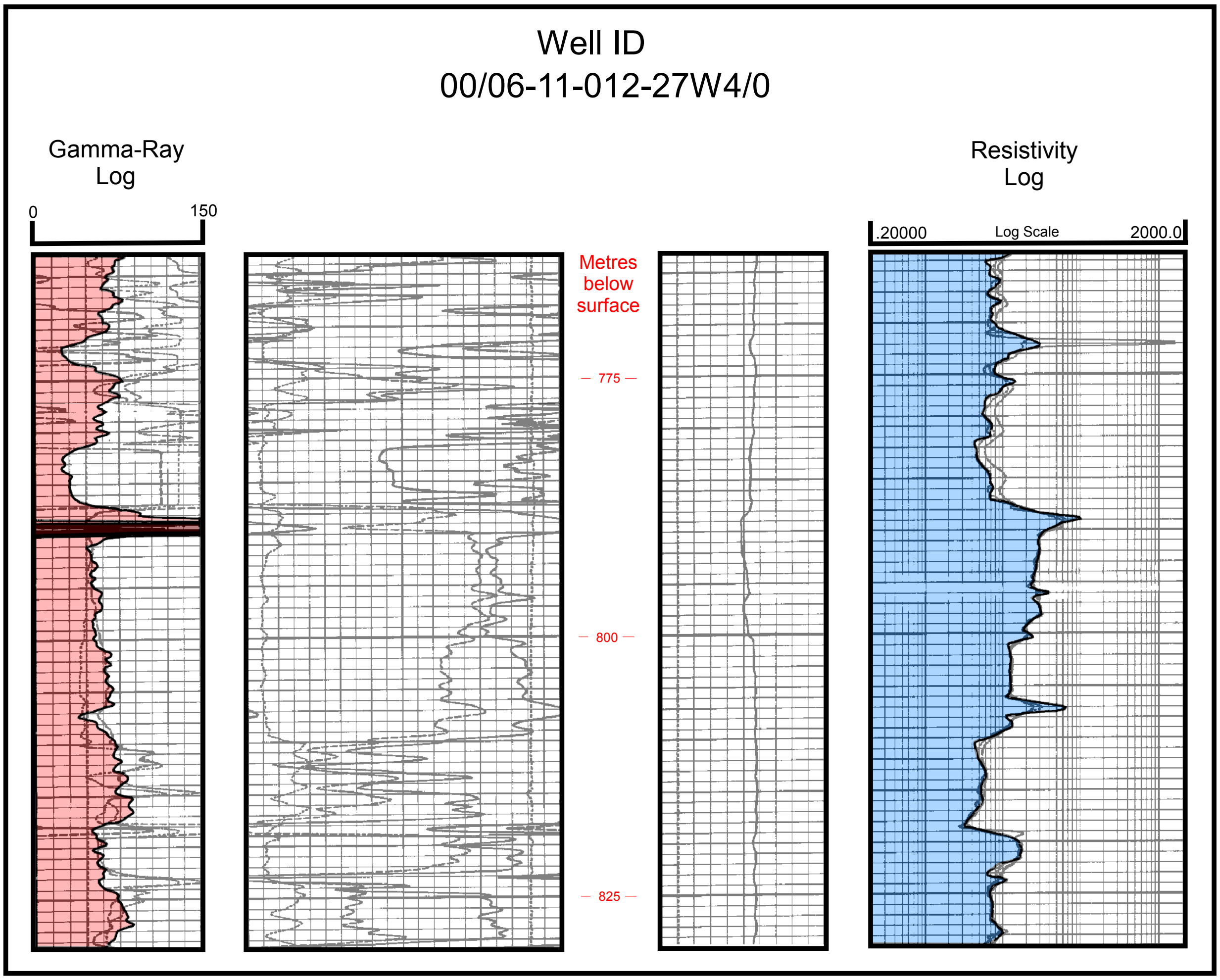

Figure 25. Well 00/06-11-012-27W4/0 geophysical log. The logged interval within the St. Mary River Formation is showing an anomalous gamma-ray signature corresponding with high resistivity. The gamma-ray log is shown in red with the dark red area indicating an anomalous gamma-ray signature. The resistivity log is shown in blue.

There appears to be no obvious spatial connection between the wells with anomalous radioactivity and no strong trend for spatial connection within this study area. Only one of the 9 original wells used to define Grant's 1982 Claresholm trend has an anomalous gamma-ray interval, as defined by the anomalous thresholds of the present study. The discrepancy is most likely due to the difference in what is considered anomalous between this study and Grant's 1982 report.

Thick sandstone intervals were interpreted where more than 8 m of continuous gamma-ray signature less than 75 API units was recorded in the table (Appendix 2). Low gamma-ray intervals, interpreted as thick sandstone packages, were found consistently only within the Porcupine Hills Formation. The Willow Creek and St. Mary River formations had few such intervals. Correlation of sand bodies between the wells does not seem plausible within the scope of this project, due to inconsistent distribution of the wells, limited thicknesses, and most likely, limited aerial extent of the sandstone bodies.

All results for the oil and gas exploration well log interpretation were compiled into a single dataset. Information in the dataset includes the following: well identification, geographic coordinates, casing depth, depths to the top of target formations, depths to high and anomalous radioactive intervals as defined by this study, API values for the anomalous intervals, and the depths to as many as four sand packages as defined by this study. The dataset is tabulated in Appendix 2.

7.4 Conclusions and Recommendations from the Well Log Study

The results for the first round of well log interpretation were very positive. It was determined that sand bodies and anomalously radioactive intervals could be successfully identified using the gamma-ray log.

Highlights from the examination of oil and gas exploration wells include the following: nine wells with anomalous gamma-ray intervals and 68 wells containing at least one sand body. The wells with anomalous intervals were spatially isolated; therefore, there was no evident trend. Of the nine anomalous wells, there was one particularly interesting interval in the St. Mary River Formation. This interval had a high gamma-ray count coincident with high resistivity, which is not the expected combination for radioactive shale, and, thus, can be interpreted as radioactive interval in sandstone.

Multiple thick sandstone bodies were interpreted using a combination of geophysical logs. No attempts were made to determine the correlative nature and extent of individual bodies. Interpretation and correlation between the wells requires an understanding of the fluvial architecture and depositional environment of the target formation. Much more close-spaced drilling is required to reconstruct the shape of the sandstone channels.

The important issue with geophysical well logs from oil and gas exploration wells has been the casing depths, which, in some cases, can be several hundred metres deep. Companies have not routinely run geophysical well logs behind the casing (commonly termed ‘casing collar logs’ and ‘cement bond logs’) and the casing distorts the log signatures. High gamma-ray signatures will be subdued in casing collar logs and cement bond logs; however, Schlumberger has methods to successfully correct for casing distortion in logs (D. Rokosh, pers. comm., 2007). At present, geophysical well logs are stored in microfiche form at the EUB in Calgary. The technology is being made available in order to address the shallow log data gap (less than 500 m below surface) predicament in Alberta. Problems include the sparse, unequal distribution of wells with shallow logs and interference of the casing with gamma-ray logging. A.P. Hamblin (2004) clearly captured the problem in the following statements: “A persistent problem occurs in attempting to utilize subsurface data for a shallow unit …the potential lack of wells with geophysical logging shallow enough to give adequate coverage of the unit…In many wells, the strata studied are behind surface casing and, thus, inadequately logged.”

The EUB recognized this gap in the geologic knowledge of the province and, as a result, introduced Directive 043 on November 1, 2006. The directive requires that, effective December 1, 2006, all new oil and gas exploration wells must log the entire cased interval from the surface with both natural gamma-ray and neutron logs (Alberta Energy and Utilities Board, 2006). With the tools to correct for the casing and this new directive, the already impressive oil and gas exploration well databases in Alberta will provide an even greater advantage to resource evaluation in the province.

8 Regional Geochemistry

8.1 Stream Sediment Sampling and Till Sampling

The very limited nature of public domain data on the regional geochemistry of the study area prompted a compilation of existing data from surrounding areas. Three datasets were involved in this analysis:

- Dataset 1) Stream Sediment Geochemistry, Southern Alberta Rift (Figure 26): comprises 40 elements for 415 samples from the foothills and mountains west of the study area. (AGS Open File Reports 1993-13A and 1993-13B, file Stream Sediment Geochemistry, Digital Dataset 2005-0532[1]. Neutron activation and atomic absorption were the main analytical methods. Uranium was analyzed by neutron activation with values listed in parts per million (ppm) (Williamson et al., 1993).

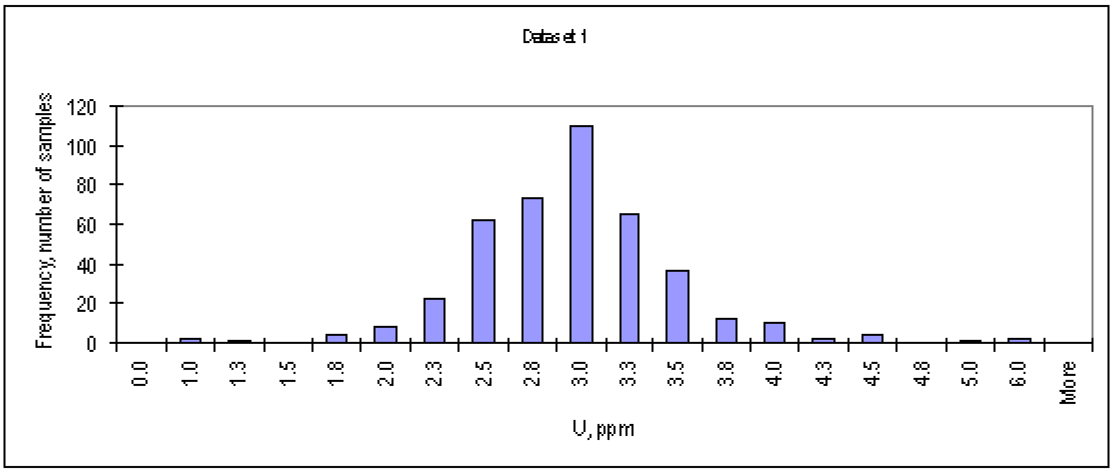

Figure 26. Histogram of uranium values distribution in stream sediment dataset for the Southern Alberta Rift.

- Dataset 2) National Uranium Resource Evaluation (NURE) Hydrogeochemical and Stream Sediment Reconnaissance Data (Smith, 1997): covers areas immediately south of the study area. Multiple parameters were recorded for most samples: water pH, scintillometer readings, conductance, alkalinity and sample site description. Up to 60 elements and components were analyzed in over 2600 stream sediment samples. Uranium values in the areas immediately south of the Alberta border were analyzed by delayed neutron counting and are reported in parts per million (ppm). The distribution of uranium values in these samples is shown on the histogram (Figure 27).

- Dataset 3) 1992 Prairie-Wide Till Survey: In the summer of 1992, 816 till samples (≈25 kg and 3 kg) were collected from depths of 1–2 m below surface (Figure 28) (Thorleifson and Garrett, 1993). The till matrix trace element data are for Neutron Activation (INAA (10 g)) and Atomic Absorption (AAS (1 g - HF-HNO3-HClO4)) analysis of the fraction of the till samples <63 µ. Uranium values were analyzed by INAA and are reported in parts per million (ppm). A total of 322 samples were used in this analysis.

Due to the three different distribution functions of the above three datasets, Figure 29 and its accompanying legend Figure 30 are based on different break values for uranium content for each of the datasets. Low uranium values (highest value is 6 ppm) in the till survey (Dataset 3) can be explained by low overall background uranium in the region, or by the sampled till that includes a high proportion of far-travelled material, thereby diluting any possible high geochemical signatures of underlying

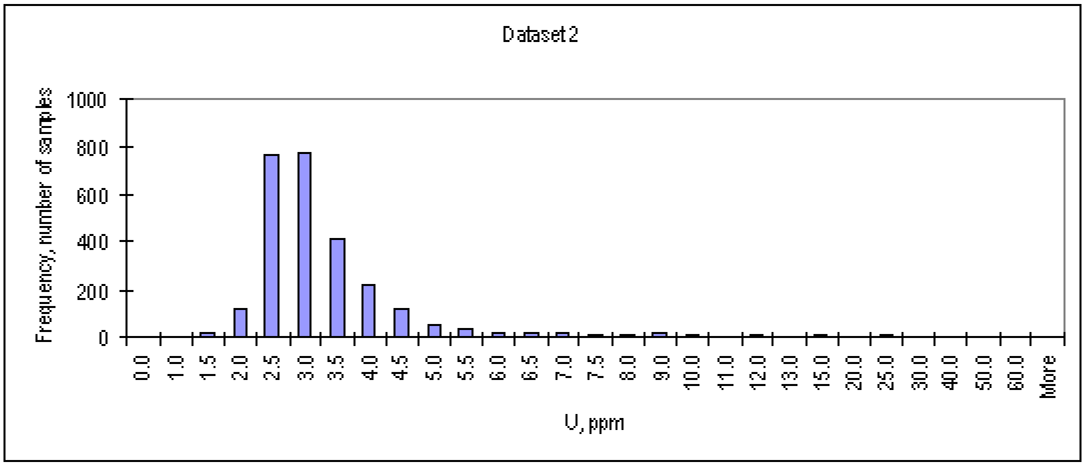

Figure 27. Histogram of uranium values distribution in National Uranium Resource Evaluation stream sediment reconnaissance data (data from Smith, 1997).

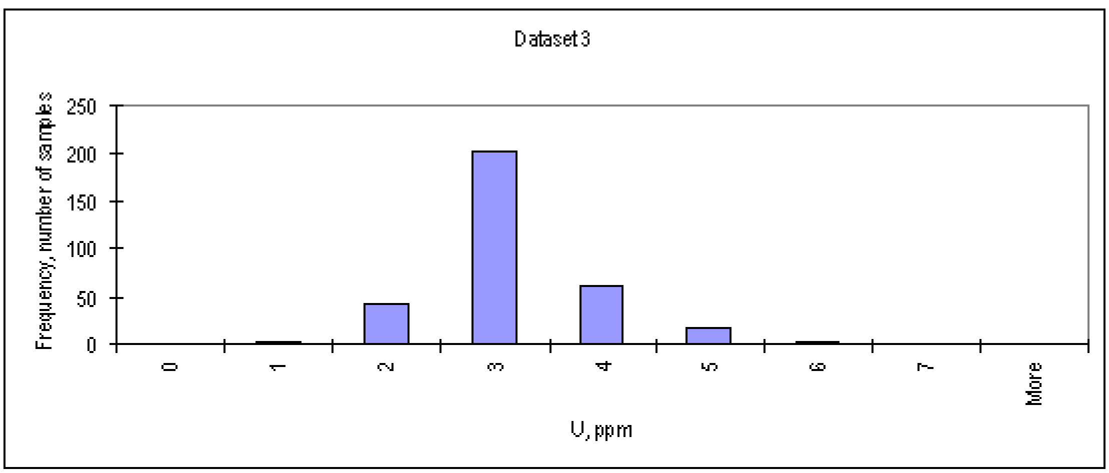

Figure 28. Histogram of uranium values distribution in prairie-wide till survey (data from Thorleifson and Garrett, 1993).

formations. In addition, the till sample density is extremely sparse, and needs at least to be brought up to the same density as Datasets 1 and 2. The low values (highest value of 5.1 ppm) of Dataset 1—the stream sediment geochemistry in the Rocky Mountains and Foothills of Alberta—might be considered surprising given that similar sampling media in the U.S.A. immediately to the south generally yielded higher numbers (up to 57 ppm). The first explanation may be the different distribution and areal extent of uraniferous units that could have contributed uranium to the stream sediments; however, this needs to be assessed by spatial analysis. A second explanation may be differences in the sampling methodology, or sample processing, and analysis; this needs to be assessed by re-analysis of archived samples from Montana using the same methods as the Dataset 1, or vice-versa. Stream sediment samples on the U.S.A. side of the border show that the uranium geochemical signature of underlying geological formations shows up in stream sediment samples' assay results; for example, higher uranium values in the stream sediments over the Sweet Grass intrusive massifs. These rock units are much less extensive in Alberta. Another important observation from the Montana dataset is that U concentration in stream sediments is

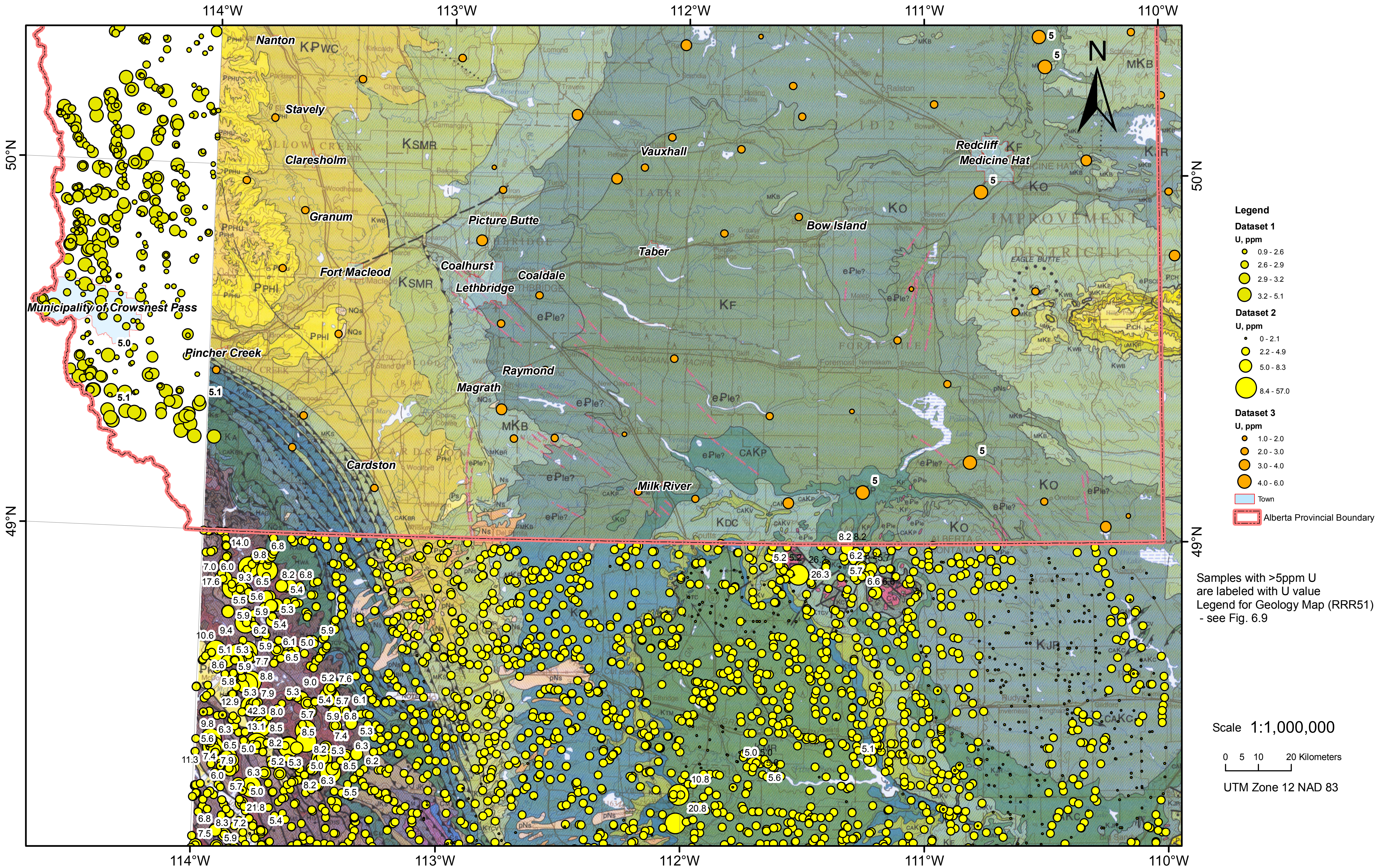

Figure 29. Uranium in stream sediments and till samples.

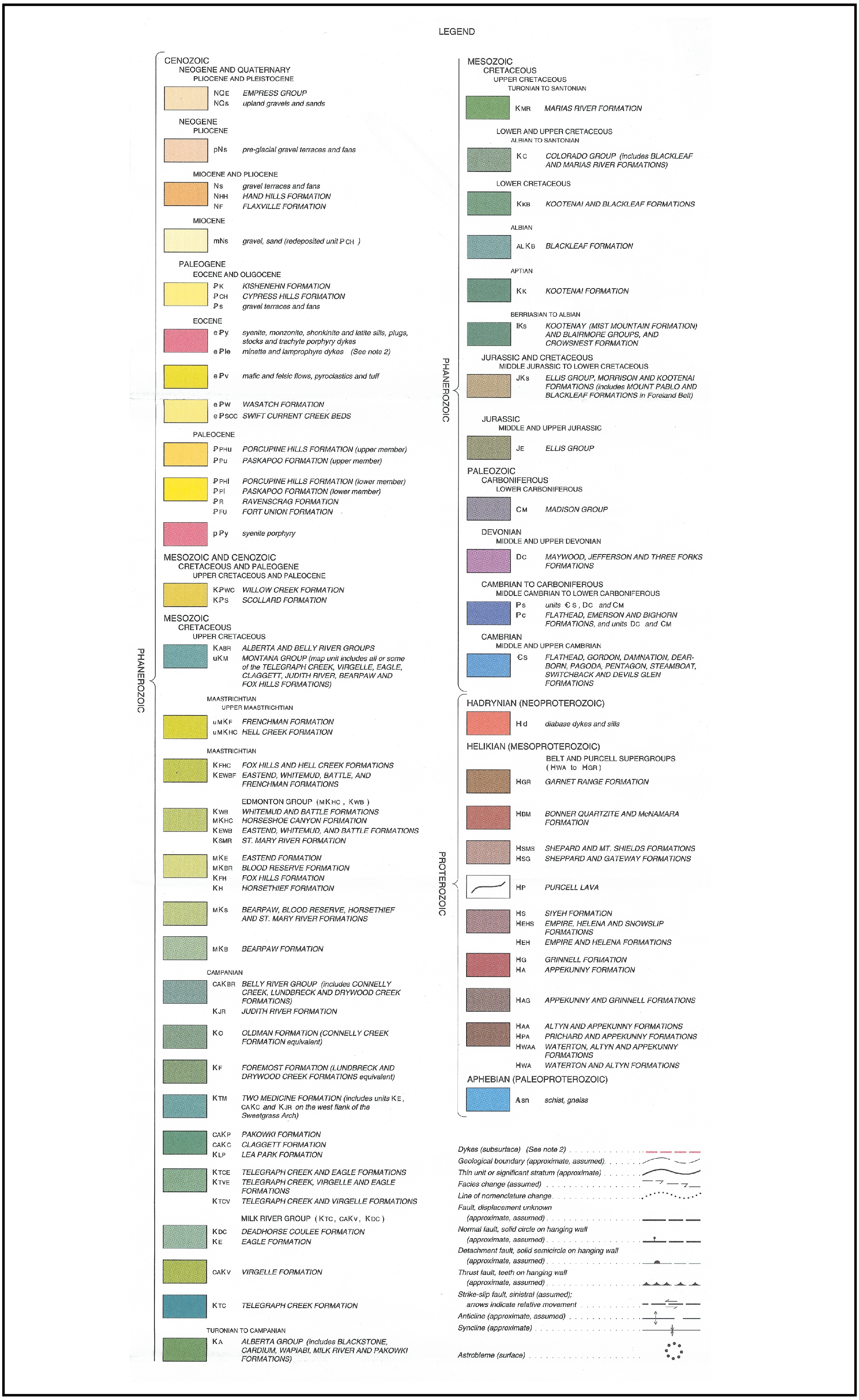

Figure 30. Bedrock Geology Legend for Figure 29. From Okulich et al. (1996).

generally higher in the mountain streams and in the foothills than in stream sediments on the prairies. This may partially explain the difference between the Canadian datasets 1 (mountain stream sediments) and 3 (prairie till).

The Montana data show that regional stream sediment sampling should be an effective tool to evaluate the uranium potential in southern Alberta. However, 325 samples of a regional stream sediment program in the western part of the area reported in Olson et al. (1994) yielded few values with a maximum of 4–6 ppm uranium. To ensure equivalency of results, an orientation survey duplicating the Montana stream sediment data would help to design and implement an Alberta stream sediment sampling program with results that are continuous across the border; this would provide uniform data to evaluate the regional uranium potential of southern Alberta.

8.2 Wellwater Sampling

Four water wells datasets are available in and around the project area, as follows:

- **Dataset 1)** Database from Alberta Environment: This database contains extensive data about multiple parameters of water wells in Alberta. However, very few wells have chemical analysis of elements traditionally associated with uranium mineralization (U, V, Mo, Cu, Ni, Pb, etc.). Isolated anomalous values of V and Ni have been picked up from the database (Figures 31 and 32). Information about pH and Eh, as well as sulphate content (SO_4), has been collected for many samples.

- **Dataset 2)** National Uranium Resource Evaluation (NURE) Hydrogeochemical and Stream Sediment Reconnaissance data: covers areas immediately south of the study area. Multiple parameters were recorded during the sampling (water pH, scintillometer readings, conductance, alkalinity, sample site description). The data are not complete for all samples. Data were obtained for both surface and subsurface waters. Data plotted on Figure 33 are results of wellwater samples only. The concentration of uranium in water is in parts per billion, determined by fluorescence spectroscopy. Vanadium and nickel are reported in parts per billion, determined by Emission Spectrochemical Analysis of waters. A total of 525 samples were analysed for this dataset. The highest U content in wellwaters is 278 ppb.

- **Dataset 3)** This is a dataset of 26 samples collected from the water wells on the Whiskey Gap uranium property as reported in Hartley (2007). The distribution of uranium values is shown on Figure 34.

- **Dataset 4)** During the 2006 AGS project a total of 30 water samples were collected from private wells. Twenty of these samples were analyzed for radon and uranium content, the results of which are reported in Olson and Anderson. (2007). Results of 10 water samples are reported here (Figure 36) (Appendix 3). Samples were analyzed using ISP-Mass Spectrometry Scan. Uranium, arsenic, copper, iron, selenium and vanadium were analyzed.

The NURE dataset was used as a background information dataset for statistical analysis and separating anomalous values vs. background values. There are two possible interpretations of this dataset:

1) The histogram on Figure 33 shows that U values above 50 ppb likely include the lower end of an anomalous population; values 2–20 ppb are considered as weakly elevated representatives of a normal population distribution. The highest U content in wellwater measured south of the Alberta border is 278 ppb. Some 40 out of the total 525 samples contained >50 ppb U. Compared

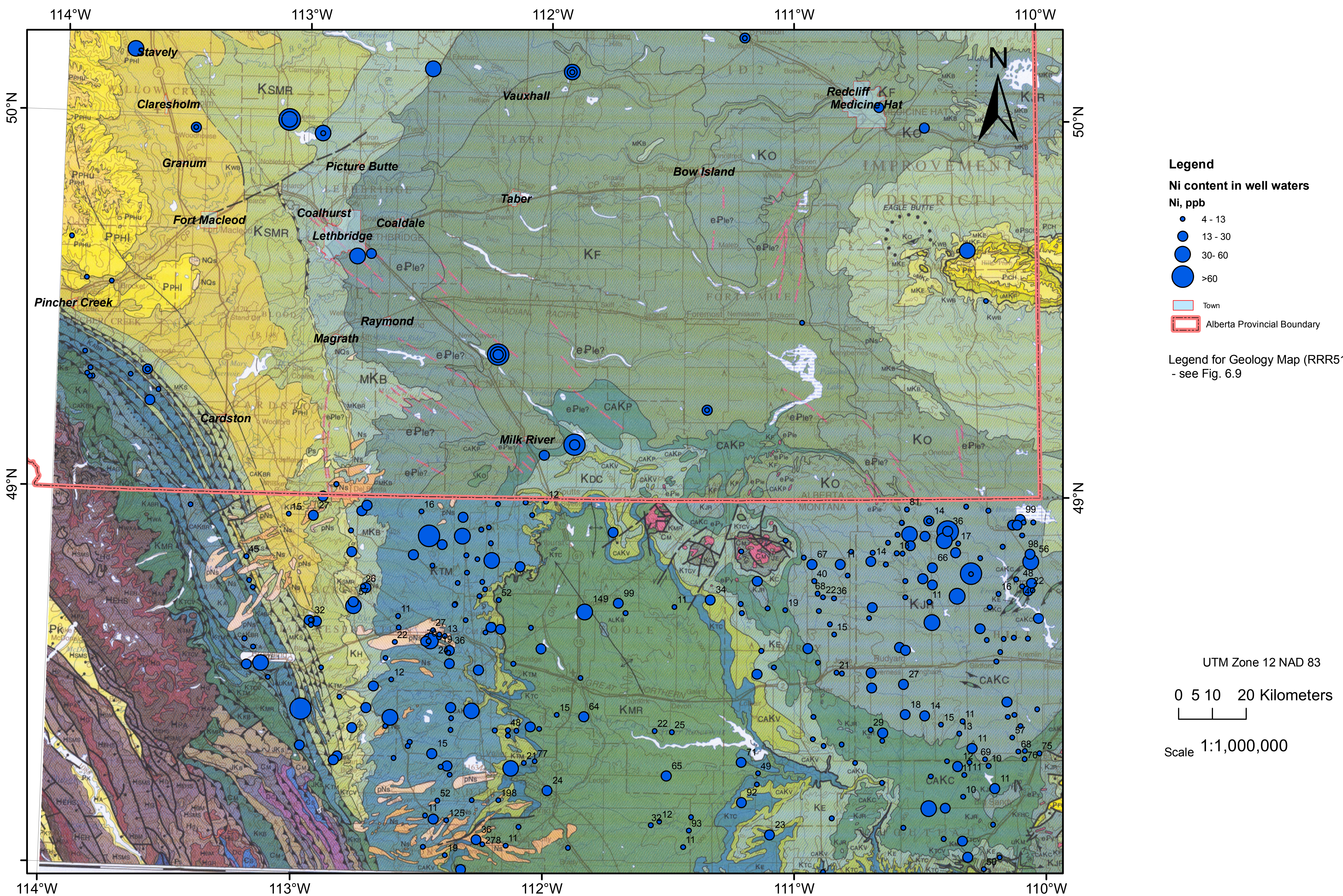

Figure 31. Nickel content in wellwater samples, from the Alberta Environment database.

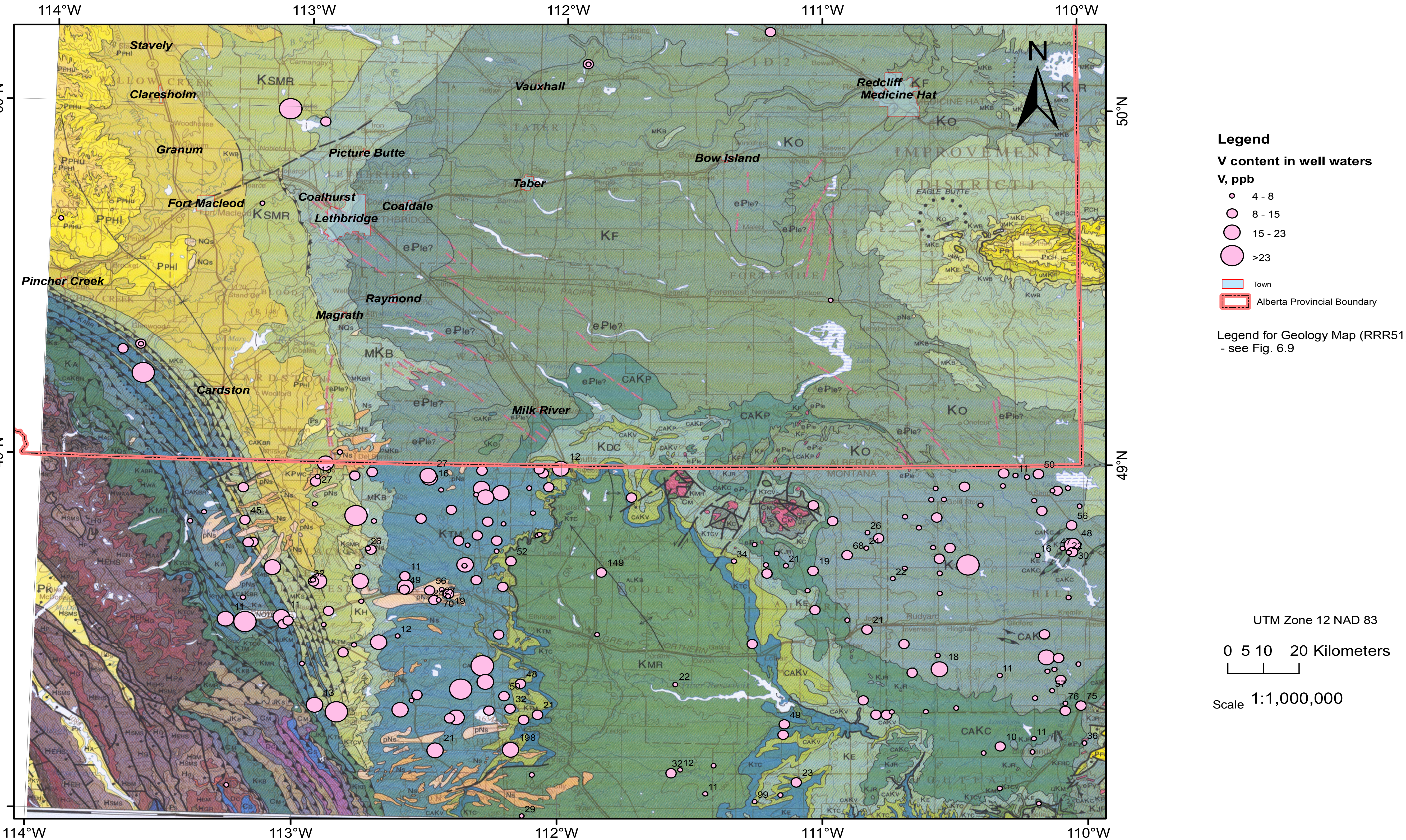

Figure 32.Vanadium content in wellwater samples, from the Alberta Environment database.

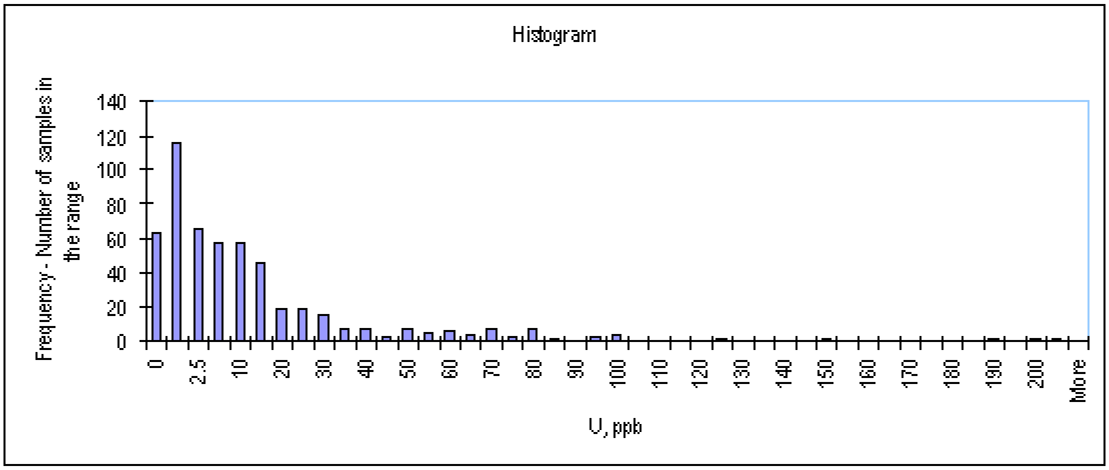

Figure 33. Distribution of uranium abundance in wellwater, from the National Uranium Resource Evaluation Hydrogeochemical Reconnaissance dataset.

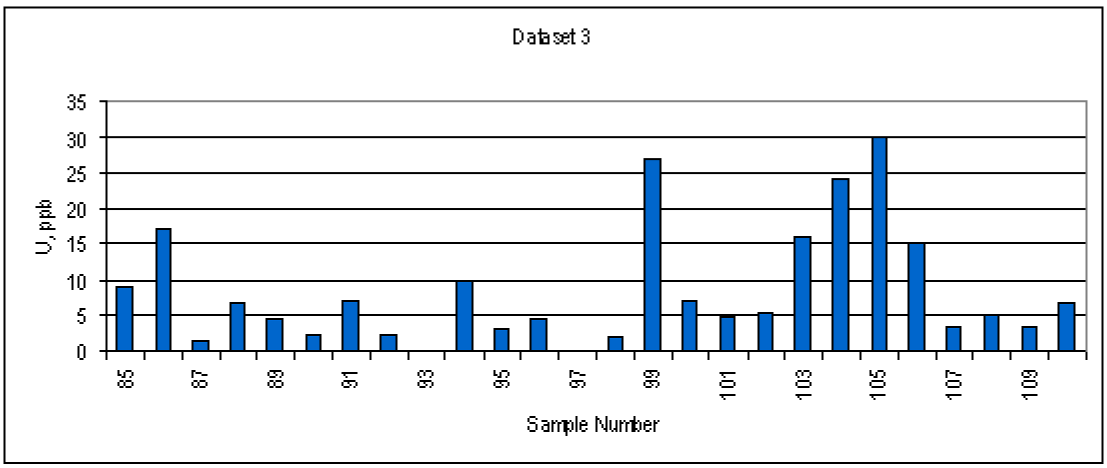

Figure 34. Uranium values (ppb) in dataset of 26 water well samples collected on the Whiskey Gap uranium property.

to the NURE dataset, all samples in the Alberta datasets 3 and 4 are within the normal population distribution.

2) The histogram on Figure 33 shows that U values above 20 ppb are anomalous; values 2–20 ppb are somewhat anomalous, but quite common. The highest U content in wellwaters measured south of the Alberta border is 278 ppb. A total of 100 out of total 525 samples assayed >20 ppb U. Five samples assayed >100 ppb U. Comparing results of the NURE dataset with the Alberta data we see that, in both Dataset 3 and 4, some samples come close or are in the medium-anomalous range. Canadian Environmental Quality Guidelines (as of December 2003) for community water state that uranium value of <20 ppb is acceptable standard.

No known uranium deposit exists immediately south of the Alberta border, and, thus, we cannot relate existing high values of uranium in the wellwaters correlate with possible uranium enrichment in underlying rocks. The distribution of U values in wellwater samples is shown on Figure 35.

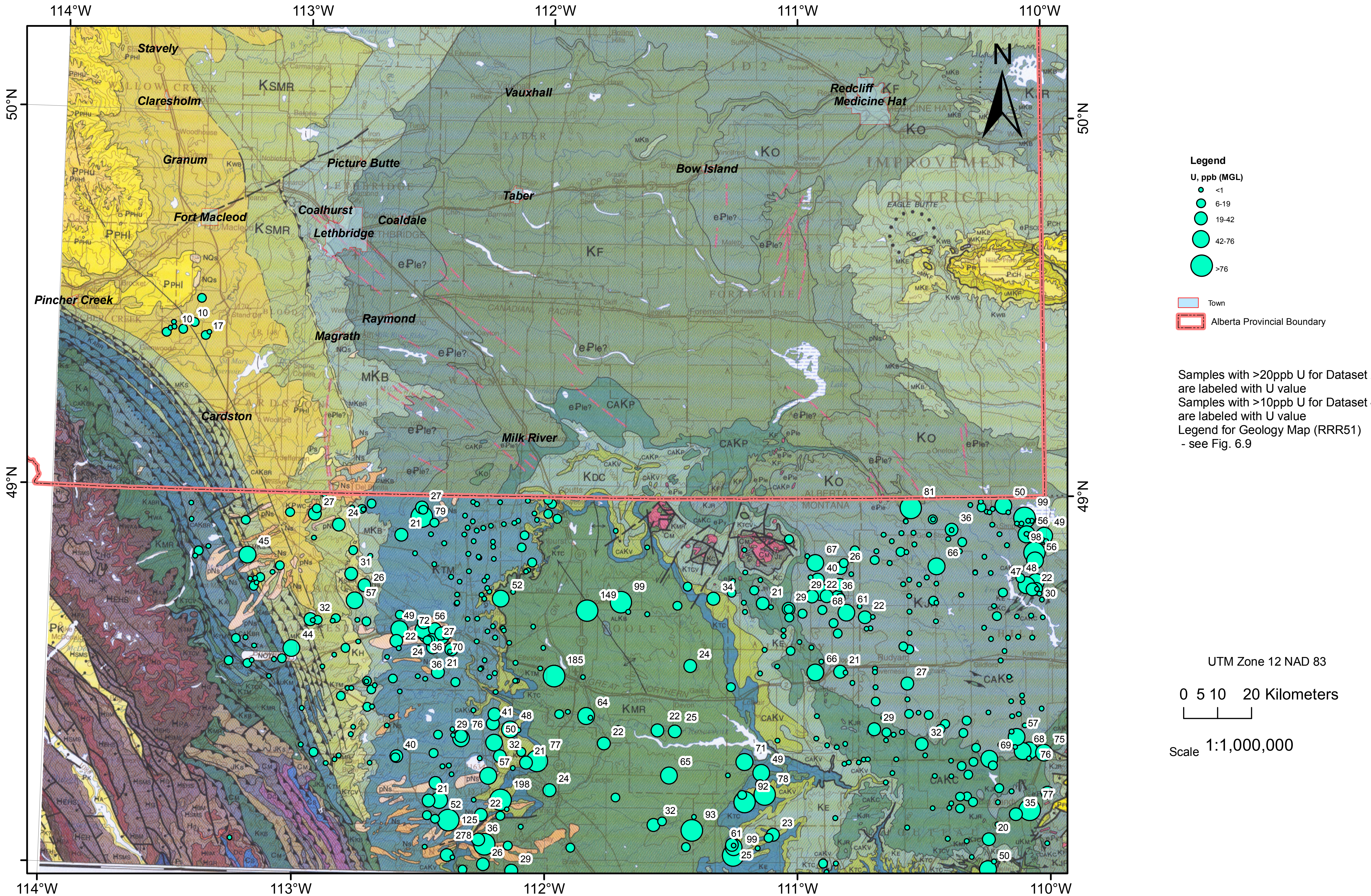

Figure 35. Uranium in northern Montana wellwater, from the National Uranium Resource Evaluation hydrogeochemical reconnaissance dataset.

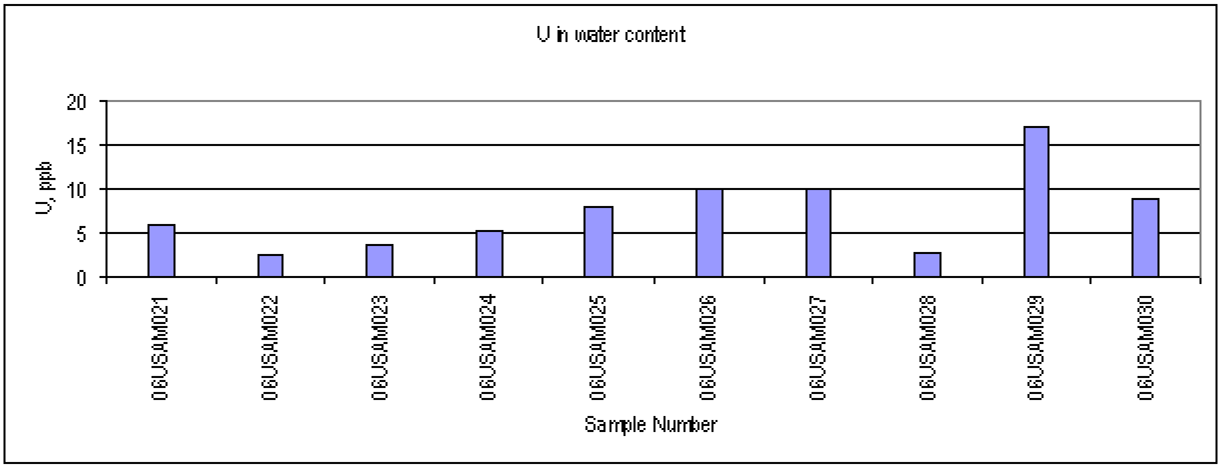

Figure 36. Uranium values in dataset of 10 samples collected during the 2006 AGS project.

8.3 Comparison with Regional Geochemistry over the Wyoming Uranium District

The NURE dataset over known mineralized systems in Wyoming shows that both wellwater (Figure 37) and stream sediment (Figure 38) samples are anomalous in the same areas. However, subsurface and surface geology, as well as climate and the architecture of aquifers, are quite different in Wyoming; therefore, absolute values of uranium in stream sediments and wellwaters should only be compared with caution between Wyoming and Alberta.

Anomalies in stream sediment samples appear to show good spatial correlation with the Ruth and Highland uranium deposits, and show samples have generally higher background uranium values around the Gas Hills and Shirley Basin areas (Figure 38). In Wyoming, the highest value in stream sediments was 221 ppm, which is 4 times higher than the highest value (57 ppm) in the NURE dataset immediately south of the Alberta border. Many values in Wyoming exceed 15 ppm, whereas south of Alberta few samples show over 8 ppm uranium.

Uranium in wellwaters of Wyoming correlates closely with the Ruth, Highland, Gas Hills and Shirley Basin mines, with some samples over 100 ppb and generally higher background readings, but correlations are weak with the Whiskey Peak and Sweetwater mine areas (Figure 37). However, there are fewer samples in the latter three areas, which could account for the inconsistent correlations. The highest value recorded in the NURE dataset for Wyoming is almost 700 ppb uranium. The first anomalous threshold in Wyoming can be seen at 20 ppb. The very anomalous second threshold, judging from the histogram in Figure 39, can be set above 100 ppb.

9 Conclusions

The first year project goals were

- to determine what methods and datasets can be used to evaluate Alberta’s potential to host uranium deposits in clastic rocks of the Western Canada Foreland Basin; and
- to conduct a preliminary evaluation of the presence or absence of favourable criteria for sandstone-hosted uranium deposits in southern Alberta.

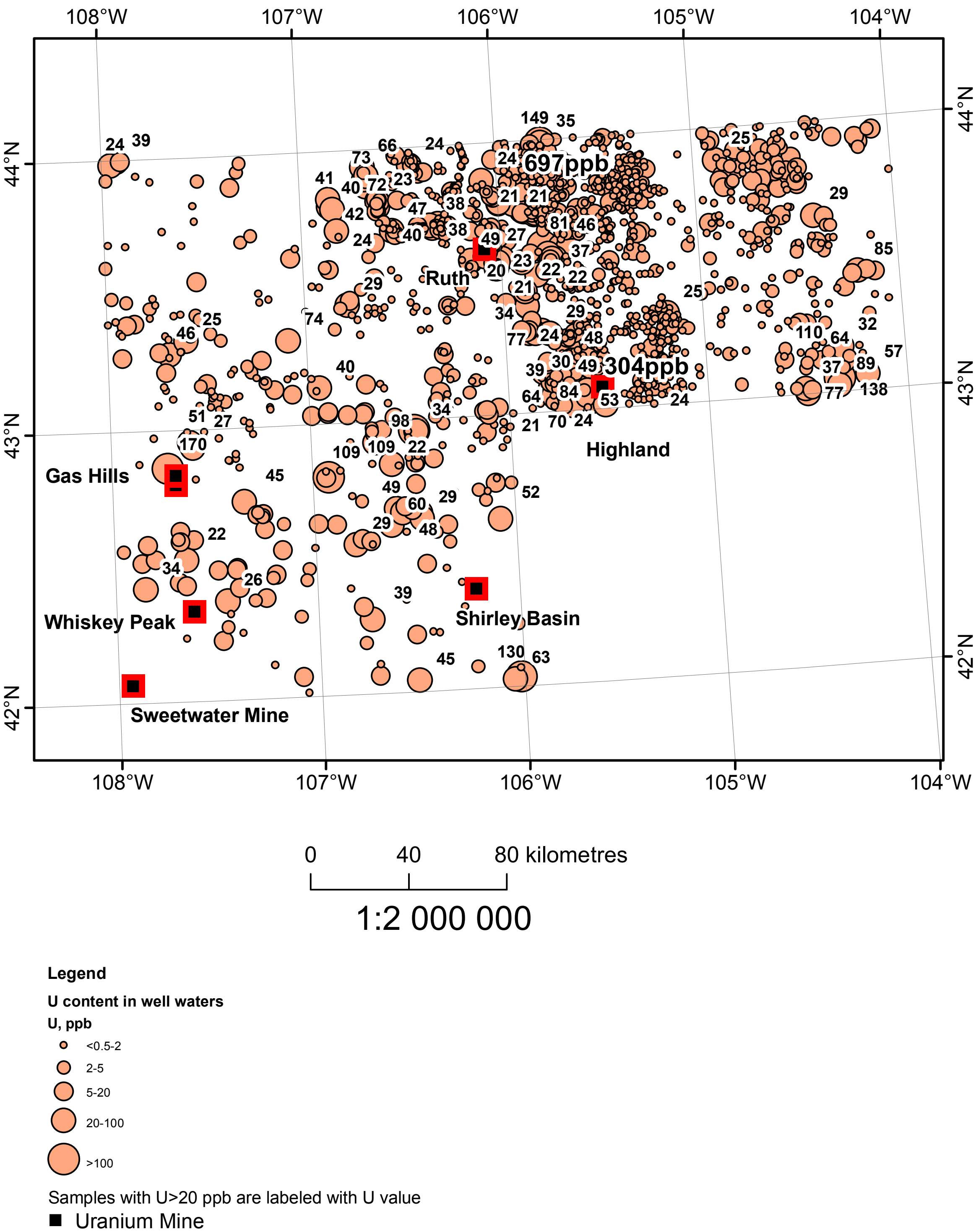

Figure 37. Uranium content in wellwater Samples, Wyoming.

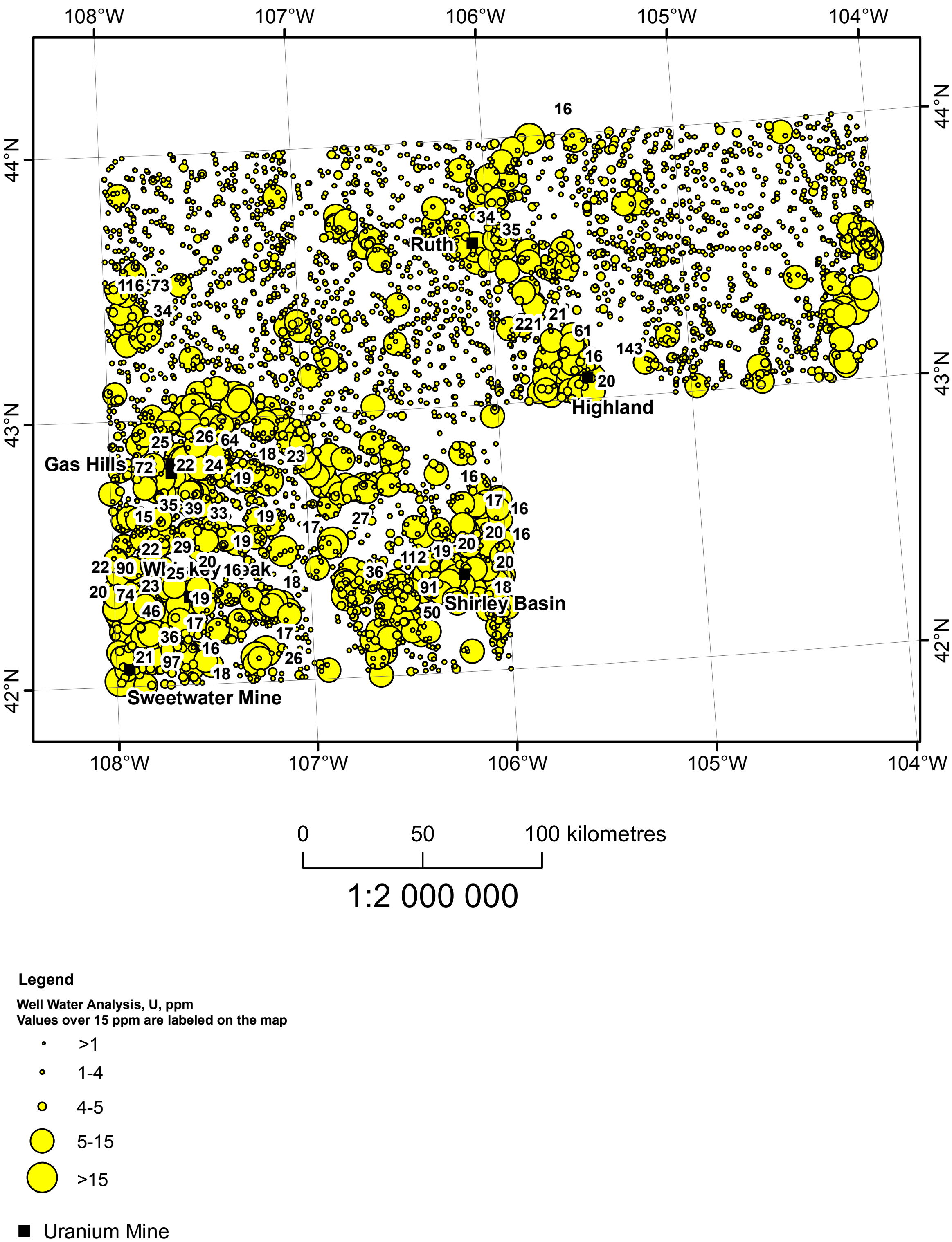

Figure 38. Uranium content of stream sediments samples in Wyoming, from the National Uranium Resource Evaluation hydrogeochemical reconnaissance dataset.

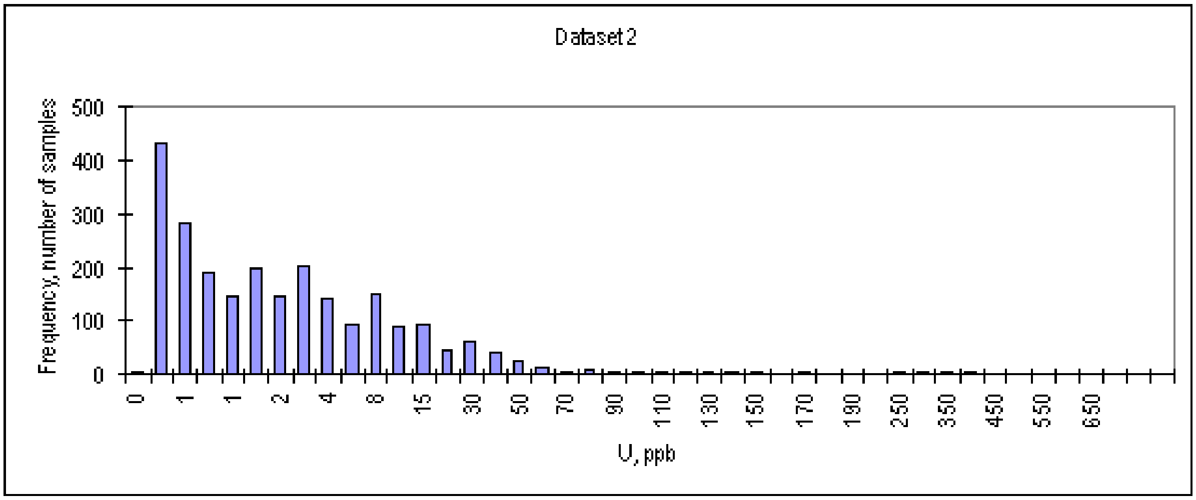

Figure 39. Histogram distribution of uranium values in wellwater samples from NURE dataset over the Wyoming uranium district.

This project was initiated with a sandstone-hosted uranium deposit model in mind. For sandstone-hosted uranium deposits to form, the following elements are essential:

1. A uranium source—felsic volcanic tuffs or granites with elevated uranium content
2. A mechanism of re-distribution—active hydrogeological processes, leaching uranium from the source rock under oxidizing conditions and re-depositing it in higher concentrations under reducing conditions (usually requires artesian flow)
3. The presence of porous sandstone aquiver bounded by aquitards—through the constrained aquifer uranium-enriched waters can easily travel and remain focused until the point where uranium will be precipitated
4. The presence of 'traps' for uranium in favourable formations—reducing agents (organic material, pyrite, H2S gas) usually spatially associated with structural focusing mechanisms, such as faults and stratigraphic pinch-outs of sandstone aquifers.

It is difficult to address the questions of the uranium source due to the possibility that rocks that may have been excellent sources are now eroded. This question is both theoretical and practical, but at this stage there is insufficient knowledge as to whether the presence of tuff in Cretaceous clastic rocks and a greater distribution of volcanic rocks in the ancestral Omineca belt are sufficient evidence to document a viable uranium source. Thus, given the available research resources, it is more practical to concentrate on more direct exploration criteria: the search for radioactive anomalies and the location of possible redox fronts in outcrops and the study of gamma logs of gas and petroleum wells and regional wellwater sampling data.

The mechanism of uranium re-distribution will also be studied during the next stage of the project. This can be done using two methods:

1. Analysis of the existing wellwaters database from Alberta Environment (Alberta Environment, 2001). This database should be analyzed to help locate current redox boundaries and gradients in sulphate content, thus highlighting areas for more detail work in the future.

2. Study of rock alteration patterns in the outcrops and possibly oil and gas well cuttings. The alteration colour scheme, common to all re-distributed sandstone-hosted deposits, will serve as a guide for this work.

The first year of evaluating uranium potential of southern Alberta brought some encouraging results, highlighted knowledge gaps and outlined efficient methods for further study. The known uranium occurrences in southern Alberta are evidence that some sort of uranium concentration process was active at some point in time, although none of these occurrences is clearly associated with redox fronts and all of them can possibly be explained by in situ diagenetic redistribution rather than mass movement of uranium. Literature research and preliminary field work have shown that several geological formations have some characteristics that are favourable for the sandstone-hosted uranium deposit type: reduced permeable sandstone bodies, enclosing shale aquitards, known uranium occurrences and presence of volcanic material.

Outcrop studies have provided a good understanding of lithology; physical characteristics such as structure, shapes and sizes of favourable sandstone bodies; and mineral-chemical attributes such as diagenetic cementation, incipient oxidation and the prior presence of organic debris in basal channel deposits.

10 Recommendations for Further Work

As only a small portion of known outcrops were studied in 2006, further outcrop study is recommended to improve our knowledge of lithology, alteration and potential uranium occurrences. The mechanism of uranium concentration in known occurrences can be identified through precise documentation of lateral changes visible in the outcrop in the vicinity of occurrences, and by using advanced laboratory methods on systematic samples. The results of these studies can be compared with other types of sandstone uranium deposits and their mineralization mechanisms.

Undoubtedly, the dataset with the greatest potential for impact on resource assessment is the accumulated data from thousands of oil and gas wells. Gamma-ray logs, lithologs, cuttings—all can and should be used to advance our evaluation project. The small study of just over 200 wells, using commercially available software, showed this as a rapid, effective and direct method to search for radioactive anomalies and favourable lithologies. However this study also documented that the upper 500 m of stratigraphy are often poorly represented due to geophysical logging through the casing either not being done or not being available. This very important ‘knowledge gap’ can be addressed through the study of ‘cement bond logs’—geophysical logs recorded from behind the casing.

Another important information gap is the lack of regional geochemical surveys, such as stream sediment sampling, soil sampling or airborne gamma-ray spectrometry. Although such regional surveys are not guaranteed to directly detect undiscovered uranium deposits, they could give important information about geochemical characteristics of southern Alberta rocks, and, thus, indirect criteria for evaluating uranium potential.

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Appendix 1 – 2006 Outcrop Sampling Results

Sample	Stop	Easting (N83, UTMZ12)	Northing (N83, UTMZ12)	Description	Formation	Scintillometer reading, Counts Per Second*	U, ppm Fluorimetry, Partial digestion***	K2O, %, ICP, Total digestion**	Th, ppm, ICP, Total digestion**	U, ppm, ICP, Total digestion**
06USA0001	060530_02	356319	5431730	Dark-grey mudstone right below the sandstone/mustone contact, limonite concretions	St. Mary River	180	4.17	3.01	8	6
06USA0002	060530_03	374008	5434977	Yellow and black shale	Bearpaw	90	1.28	2.03	7	2
06USA0003	060530_05	360837	5441349	Light-grey medium-grained layered sandstone, rusty blocks	St. Mary River	70	1.25	1.29	4	2
06USA0004	060531_01	272717	5521863	Dark grey shale with many organic debris	St. Mary River	90	1.5	2.16	9	2
06USA0005	060531_01	272717	5521863	Light-grey, yellowish sandstone	St. Mary River	50	1.21	1.61	5	2
06USA0006	060531_01a	272868	5521765	25 cm thick bed of black organic shale	St. Mary River	65	7.69	2.96	11	10
06USA0007	060531_01a	272868	5521765	50 cm thick bed or crumbly black shale	St. Mary River		2.2	2.72	9	3
06USA0008	060531_02	273276	5520981	Dark-grey shale	St. Mary River	90	1.34	3.72	11	2
06USA0009	060531_03	273548	5520820	Crumbly grey coarse-grained flaky sandstone	Willow Creek	50	0.77	1.44	6	2
06USA0010	060531_04	244550	5504060	Massive dark-green-black, very coarse lithic pyroclastics with lenses of fine grained massive pyroclastics	Crowsnest Volcanics	300	5.96	14.1	24	14
06USA0011	060601_02	337553	5437224	Kimball occurrence. Fine-grained maroon sandstone with shale partings, sample across 2 m	St. Mary River	60	0.84	2.07	7	2
06USA0012	060601_02	337553	5437224	Kimball occurrence. Sandstone, light-grey, semi-massive, medium-grained, across 1.7 m	St. Mary River	55	0.75	1.92	6	2
06USA0013	060601_02	337553	5437224	Kimball occurrence. Sandstone, light-grey, semi-massive, medium-grained, across 1.65 m	St. Mary River	55	0.78	1.87	6	2
06USA0014	060601_02	337553	5437224	Kimball occurrence. Yellow shale, across 15 cm	St. Mary River	70	1.97	2.8	9	2
06USA0015	060601_02	337553	5437224	Kimball occurrence. Grey shale, across 20 cm	St. Mary River	80	1.78	4.17	11	4

Sample	Stop	Easting (N83, UTMZ12)	Northing (N83, UTMZ12)	Description	Formation	Scintillometer reading, Counts Per Second*	U, ppm Fluorimetry, Partial digestion***	K2O, %, ICP, Total digestion**	Th, ppm, ICP, Total digestion**	U, ppm, ICP, Total digestion**
06USA0016	060601_02	337553	5437224	Kimball occurrence. Light-grey crumbly sandstone, across 35 cm	St. Mary River	80	4.79	1.77	7	6
06USA0017	060601_02	337553	5437224	Very light-grey, crumbly sandstone, possibly close to shear zone, with some rootlets	St. Mary River	80	4.8	1.76	7	8
06USA0018	060601_02	337553	5437224	Kimball occurrence. Black crumbly shale with light-yellow veinlets, separate pieces diam. 1.5 cm - radioactive zone, sample across 45 cm	St. Mary River	300	29.7	3.47	11	40
06USA0019	060601_02	337553	5437224	Kimball occurrence. Black crumbly shale with light-yellow veinlets, separate pieces diam. 1.5 cm - radioactive zone, sample across 45 cm	St. Mary River	300	26.7	3.38	10	40
06USA0020	060601_02	337553	5437224	Kimball occurrence. Orange shale, across 50 cm	St. Mary River	150	13.8	4.35	10	18
06USA0021	060601_02	337553	5437224	Kimball occurrence. Green shale, across 40 cm	St. Mary River	120	9.79	3.14	10	11
06USA0022	060601_02	337553	5437224	Kimball occurrence. Grey shale, across 70 cm	St. Mary River	90	1.66	4.05	11	3
06USA0023	060601_03	337532	5437219	Kimball occurrence. Sandstone massive, medium-grained (light-grey, calcareous - moderate reaction with HCL) above the contact with radioactive zone, sample across 50 cm	St. Mary River		6.64	1.61	6	5
06USA0025	060601_03	337532	5437219	Kimball occurrence. Grey limy (moderate reaction with HCL) shale below radioactive zone, sample across 20 cm	St. Mary River		17.2	3.73	9	19
06USA0026	060602_01	362254	5439529	Upper unit of massive cross-bedded sandstone with thin fine-grained unit in it	Blood Reserve	55	0.8	1.65	5	2
06USA0027	060602_01	362254	5439529	Dark green slaty sandstone with carbonate cement (moderate reaction with HCL), many plant prints	Blood Reserve	50	0.73	1.51	3	2
06USA0028	060602_02	362269	5439443	Light-grey yellowish sandstone	Blood Reserve	50	0.7	1.79	4	2

Sample	Stop	Easting (N83, UTMZ12)	Northing (N83, UTMZ12)	Description	Formation	Scintillometer reading, Counts Per Second*	U, ppm Fluorimetry, Partial digestion***	K2O, %, ICP, Total digestion**	Th, ppm, ICP, Total digestion**	U, ppm, ICP, Total digestion**
06USA0029	060602_03	366930	5454072	McIntyre Ranch. Grey crumbly coarse-grained sandstone	Blood Reserve	50	0.85	2.07	3	2
06USA0030	060602_03	366930	5454072	McIntyre Ranch. Light-yellow-orange sandstone in the centre of little alteration front	Blood Reserve	50	0.8	2.24	4	2
06USA0031	060603_03	337472	5524581	McIntyre Ranch. Siltstone, greenish-grey, massive with many plants imprints, no reaction with HCl	St. Mary River	75	1	2.83	9	2
06USA0032	060603_03	337472	5524581	Very rusty on surface, crumbly black shale, no reaction with HCl, sample across 35 cm	St. Mary River	75	7.32	3.71	9	6
06USA0033	060603_03	337472	5524581	Greenish-grey dark crumbly shale, sample across 30cm	St. Mary River		1.59	3.96	10	2
06USA0034	060603_03	337472	5524581	Sandstone, massive, light yellow-grey, weak reaction with HCl, unit approx. 30 cm thick	St. Mary River	75	1.6	3.21	10	2
06USA0035	060604_01	364399	5499227	2.5 m thick thinly-bedded sandstone, fine-grained, grey-blueish, calcareous (moderate reaction with HCL)	Oldman	50	1.12	1.76	5	2
06USA0036	060604_01	364399	5499227	Below the sandstone - 10 cm thick greenish shaly unit with white shells	Oldman	70	3	2.11	9	5
06USA0037	060604_02	364446	5499050	Coal - Lethbridge coal zone	Oldman	35	0.3	0.017	1	2
06USA0039	060604_03	365269	5499439	Light-green coarse-grained friable sandstone with many logs and plants prints, coarse-grained, with mudstone fragments	Oldman	47	0.98	1.16	4	2
06USA0040	060604_04	362367	5498926	Bentonite - white-yellow clay	Bearpaw	75	3.62	0.359	20	5
06USA0041	060604_04	362367	5498926	Shale, dark-grey to black	Bearpaw	55	1.27	2.48	9	2
06USA0042	060605_01	460828	5437607	Light-yellow, coarse-grained, cross-bedded sandstone	Milk River	40	0.99	1.66	3	2
06USA0043	060605_01	460828	5437607	Purple-yellowish-grey shale with multiple concretions diam. Up to 30 cm and sandy clasts diam. up to 10cm	Milk River	50	1.25	1.81	8	2
06USA0044	060605_03	451850	5430499	Police Creek Canyon. Yellow frail sandstone	Milk River		6.14	1.71	55	3

Sample	Stop	Easting (N83, UTMZ12)	Northing (N83, UTMZ12)	Description	Formation	Scintillometer reading, Counts Per Second*	U, ppm Fluorimetry, Partial digestion***	K2O, %, ICP, Total digestion**	Th, ppm, ICP, Total digestion**	U, ppm, ICP, Total digestion**
06USA0045	060605_03	451850	5430499	Police Creek Canyon. 15cm thick zone, sample taken in 2 places 2 m apart - rusty, frail, banded sandstone from anomalously radioactive zone	Milk River	190	7.36	1.74	69	4
06USA0046	060605_03	451850	5430499	Police Creek Canyon. White coarse-grained frail sandstone, approx. 30 cm above anomalous zone	Milk River		0.45	2.63	4	2
06USA0047	060605_04	411540	5438141	Coal-rich dark red shale	Foremost	70	11.8	1.01	4	9
06USA0048	060606_01	318899	5478402	Sandstone, grey, medium-grained, with organic-rich bands up to 2 mm thick	Willow Creek	50	0.95	0.725	3	2
06USA0049	060606_01	318899	5478402	Dark grey shale at the bottom of the sandstone channel, over 5 cm	Willow Creek	60	1.15	2.26	8	2
06USA0050	060606_01	318899	5478402	Grey shale just below darker shale	Willow Creek		1.17	1.55	6	2
06USA0051	060606_01	318899	5478402	coarse-grained, colourful sandstone, competent	Willow Creek		1.27	0.48	2	2
06USA0052	060606_03B	318755	5478451	Red silty, sandy siltstone-mudstone, paleosol	Willow Creek		0.87	1.32	8	2
06USA0053	060606_03B	318755	5478451	Caliche concretions	Willow Creek		1.28	1.28	4	2
06USA0054	060606_03B	318755	5478451	Red siltstone-mudstone	Willow Creek		1.53	2.82	9	2
06USA0055	060606_03B	318755	5478451	Green-grey siltstone-mudstone lense across 10cm	Willow Creek		1.55	2.22	6	2
06USA0056	060606_04	307441	5473026	Medium-grained massive light-grey yellowish sandstone from 1.5 m thick bed	St. Mary River		0.99	1.9	7	2
06USA0057	060606_05	308270	5473311	Grey silty mudstone, massive, concoidal fracture	Willow Creek	90	0.89	2.73	9	2
06USA0058	060606_05	308270	5473311	Brownish-red silty mudstone with concoidal fracture from approx. 2 m thick red zone	Willow Creek	90	1.47	2.58	8	2
06USA0059	060606_05	308270	5473311	coarse-grained, competent, coarse-grained sandstone from 1.5 m thick unit	Willow Creek		0.92	0.743	4	2
06USA0060	060601_02	337553	5437224	Pyrite concretions	St. Mary River		2	0.79	3	12

Sample	Stop	Easting (N83, UTMZ12)	Northing (N83, UTMZ12)	Description	Formation	Scintillometer reading, Counts Per Second*	U, ppm Fluorimetry, Partial digestion***	K2O, %, ICP, Total digestion**	Th, ppm, ICP, Total digestion**	U, ppm, ICP, Total digestion**
06USA0062	060607_01	337510	5437191	Black shale from anticline nose	St. Mary River		2.03	3.38	15	6
06USA0063	060607_02	337788	5437438	Micaceous light-grey ripple laminated sandstone from 0.7 m thick unit	Willow Creek		0.74	1.56	5	2
06USA0064	060607_03	366897	5454130	McIntyre Ranch. Brown massive sandstone from 3D alteration front - carbonate cement, strong reaction with HCl, breaks in sharp blocks - more competent, than surrounding yellow and white sandstones	Blood Reserve	55	0.9	1.38	3	2
06USA0065	060608_02	368236	5501115	Thick (2.5 m) grey coarse-grained friable massive sandstone, caliche and rip-up mudclusts at the base of sandstone section	Oldman	55	0.76	1.72	6	3
06USA0066	060608_02	368236	5501115	Grey-blueish mudstone layer with rusty spots diam. 2 cm	Oldman	75	2	3.18	9	4
06USA0067	060608_02	368236	5501115	Grey siltstone, bentonitic, no reaction with HCl	Oldman		2	2.7	9	4
06USA0068	060608_03	337101	5524555	Black shale with rusty, discoloured linear burrows	St. Mary River		4.24	3.47	10	5
06USA0069	060608_03	337101	5524555	Whitemud (?) sandstone, 2m thick, massive, light yellow-whitish, medium-grained, with rusty roots.	Whitemud		1.15	1.55	7	2
06USA0070	060608_03	337101	5524555	Dark-grey shale - Battle formation (?), greenish, silty, popcorn texture on surface, very carbonaceous seam 15 cm thick	Battle		2.46	3.17	10	4
06USA0071	060608_03	337101	5524555	Whitish-yellow weakly cemented sandstone with plant roots	Battle		4	2.05	8	2
06USA0072	060608_03	337101	5524555	Black shale	Battle		3.17	0.639	12	4
06USA0073	060608_03	337101	5524555	Silicified, blueish-greenish, very fine-grained, glassy-looking, milky tuff - up to 25 cm thick unit	Kneehills tuff		1.21	0.587	9	4
06USA0074	060611_02	354311	5432399	coarse-grained, friable, colourful sandstone: purple, green, black grains, white mica grains	St. Mary River/ WillowCreek	50	0.83	1.86	6	2

Sample	Stop	Easting (N83, UTMZ12)	Northing (N83, UTMZ12)	Description	Formation	Scintillometer reading, Counts Per Second*	U, ppm Fluorimetry, Partial digestion***	K2O, %, ICP, Total digestion**	Th, ppm, ICP, Total digestion**	U, ppm, ICP, Total digestion**
06USA0075	060611_02	354311	5432399	Grey siltstone, slaty, overlaying the sandstone unit sample 06USA0074	St. Mary River/ WillowCreek		0.78	1.75	6	2
06USA0076	060611_03	354198	5432419	Grey mudstone	St. Mary River/ WillowCreek		1.22	3.65	10	2
06USA0077	060611_03	354198	5432419	Bright green blueish siltstone	St. Mary River/ WillowCreek		1.09	3.5	10	2
06USA0078	060611_04	356231	5431762	Limestone, reddish, competent, strong reaction with HCl	St. Mary River		1.41	1.96	6	2
06USA0079	060611_04	356231	5431762	Grey shale with concretions	St. Mary River		1.11	3.21	9	2
06USA0080	060611_04	356231	5431762	Black shale	St. Mary River		2.19	3.52	9	4
06USA0081	060611_04	356231	5431762	Light-grey-yellow sandstone, frail, very micaceous	St. Mary River		1.05	1.49	6	2
06USA0082	060611_03	354198	5432419	Reddish brown siltstone immediately above 06USA077	St. Mary River/ WillowCreek		1.13	2.21	8	2
06USA0083	060611_05	353036	5432784	Weakly consolidated, grey-blue-greenish micaceous, very fine-grained silt- sandstone	St. Mary River/ WillowCreek		0.44	1.22	7	2
06USA0084	060611_05	353036	5432784	Grey massive mudstone	St. Mary River/ WillowCreek		0.73	3.23	7	2
06USA0085	060612_01	305262	5482843	Buff weathering, crossbedded, medium-grained, carbonaceous (moderate reaction with HCL) sandstone	Porcupine Hills	30	0.91	1.18	3	2
06USA0086	060612_02	306273	5482605	Medium-coarse-grained, grey to yellow, massive, crossbedded sandstones, very carbonate-rich, organic-rich, plant imprints	Porcupine Hills		0.46	0.871	2	2
06USA0087	060612_03	285059	5485295	Grey-purplish-dark brown siltstone, no reaction with HCl	St. Mary River	60	0.72	3.39	12	2
06USA0088	060612_03	285059	5485295	Bright green-blueish mudstone, no reaction with HCl	St. Mary River	75	1.21	3.3	10	2
06USA0089	060612_03	285059	5485295	Dark grey-greenish, coarse-grained massive, carbonate cemented sandstone up to 1m thick	St. Mary River	50	0.57	1.68	6	2

Sample	Stop	Easting (N83, UTMZ12)	Northing (N83, UTMZ12)	Description	Formation	Scintillometer reading, Counts Per Second*	U, ppm Fluorimetry, Partial digestion***	K2O, %, ICP, Total digestion**	Th, ppm, ICP, Total digestion**	U, ppm, ICP, Total digestion**
06USA0090	060612_04	284967	5485483	15 cm thick, very organic rich, black-brown bed, loaded with shell fragments	St. Mary River	80	13.4	0.662	7	11
06USA0091	060612_04	284967	5485483	White weathering, grey massive frail sandstone, fine-grained, silty, micaceous, with many organic fragments	St. Mary River	60	1.78	1.92	6	2
06USA0092	060612_05	284960	5485466	Blueish-greenish, massive sandstone bed 1.5 m thick, fine-grained, silty, consolidated, no reaction with HCl	St. Mary River	50	0.58	1.94	6	2
06USA0093	060612_06	305671	5467687	Sandstone, silty, blueish-grey, fine-grained, calcite cement - from deformed beds of sandstones and shales	uncertain	50	0.73	1.5	5	2
06USA0094	060613_02	316422	5478152	Trough-crossbedded sandstone at least 6 m thick, cliff	Willow Creek		3	0.805	3	2
06USA0097	060613_07	312357	5476365	Dark grey bleuish sandstone bed, up to 3 m thick, rusty bands parallel to bedding	Willow Creek	35	0.78	0.741	4	2
06USA0098	060613_08	313024	5476207	Organic rich bed, strongly weathered (limonitic), 35 cm thick	Willow Creek	50	3.26	0.419	2	4
06USA0099	060613_08	313024	5476207	coarse-grained, organic rich light-grey yellowish sandstone	Willow Creek		0.6	0.355	2	2
06USA0100	060614_03	314348	5476385	Grey blueish mudstone (orange limonite staining along blocky surfaces)	Willow Creek	70	1.22	2.53	8	2
06USA0101	060614_03	314348	5476385	Sandstone, grey, abundant carbonaceous material, calcite cement - strong reaction with HCl	Willow Creek	50	1.09	0.477	5	3
06USA0102	060615_01	244788	5504033	Pink-green-black, coarse-grained, massive breccia	Crowsnest Volcanics	150	1.41	6.64	10	4
06USA0103	060615_02	244627	5504050	Very dark-green, very coarse lithic breccia	Crowsnest Volcanics	225	2.29	12.1	20	7
06USA0104	060615_05	273608	5520809	Sandstone bed, white weathering, 2 m thick	St. Mary River		0.99	1.76	6	2
06USA0024	060601_03	337532	5437219	Rusty radioactive shale, across 15 cm	St. Mary River	350	66.9	2.89	8	74

Sample	Stop	Easting (N83, UTMZ12)	Northing (N83, UTMZ12)	Description	Formation	Scintillometer reading, Counts Per Second*	U, ppm Fluorimetry, Partial digestion***	K2O, %, ICP, Total digestion**	Th, ppm, ICP, Total digestion**	U, ppm, ICP, Total digestion**
06USA0105	U bones	0	0	Black, competent pieces of organic material	Willow Creek	1500	3810	0.975	8	3930
06USA0106	060923_02	364860	5756176	Siliceous, massive, glassy, very fine grained light-grey Kneehills tuff.	Kneehills tuff		4.13	0.78	8	5
06USA0107	060924_01	406801	5681561	10 m thick bentonite layer	Horseshoe Canyon		5.7	0.708	12	6
06USA0108	060924_02	404070	5684273	Organic material in shale	Horseshoe Canyon		6.13	4.4	6	7
06USA0130	061031_01	282597	5570300	Grey-light-brown, medium-grained sandstone, with some woodchips, calcite cement	Porcupine Hills	40	1.31	0.996	4	6
06USA0131	061031_02	279359	5570300	Yellow-grey medium-grained sand-stone, calcite cement	Porcupine Hills	25	0.99	1.2	3	5
06USA0132	061031_03	283096	5566959	Grey-light-brown medium-grained sandstone, calcite cement	Porcupine Hills	20	0.62	0.589	1	5
06USA0133	061031_06	285401	5539618	Light-yellow fine-grained sandstone, calcite cement	Porcupine Hills	40	1.2	0.914	3	8
06USA0134	061031_07	284736	5539906	Sandstones with Mn dendrites and rusty films on fracture surfaces	Porcupine Hills	40	1.16	1.24	5	7
06USA0135	061031_08	279970	5540183	Sandstone with Mn dendrites	Porcupine Hills	25	1.1	1.1	4	5
06USA0136	061031_10	277445	5539997	Light-yellow-grey sandstone	Porcupine Hills	25	0.75	0.844	3	4
06USA0137	061031_10	277445	5539997	Crumbly black shale	Porcupine Hills	40	0.9	2.8	8	4
06USA0138	061101_04	313021	5476185	Coarse-grained multicoloured sand-stone with rusty plant remains	Willow Creek	50	1.42	0.449	2	5
06USA0139	061102_01	301005	5561074	Light-yellow, fine-grained sandstone, calcite cement	Porcupine Hills	25	1.03	0.695	3	5
06USA0140	061102_01	301005	5561074	Light-yellow-grey fine to medium-grained sandstone, calcite cement	Porcupine Hills	20	0.81	0.632	3	5

* Scintillometer readings were collected using SRAT SPP2 Scintillometer at a slow-reading setting

** Samples were assayed in SRC Laboratories using ICP analysis, Uranium Exploration Major and Trace Element package (HNO3/HCl partial digestion and Hf/HNO3/HCLO4 Total digestion)

*** U was also analyzed using Fluorimetry, HNO3/HCl digestion

Appendix 2 – Oil and Gas Well Logs Interpretation Results

Legend	
Well_ID	Well ID based on the DLS System
Latitude	Geographic location
Longitude	Geographic location
Casing_Depth	Depth from surface that the well is cased to
Units_Present	Formations present on the gamma-ray log
M	St. Mary River Formation
W	Willow Creek Formation
P	Porcupine Hills Formation
WillowCreek	Depth in metres to the top of the Willow Creek Formation
St. MaryRiver	Depth in metres to the top of the St. Mary River Formation
Bearpaw	Depth in metres to the top of the Bearpaw Formation
Anomalous Radioactivity	Depth from surface to gamma-ray signatures >300 API units
Anomalous_API_Value	API values for anomalous signatures
High Radioactivity	Depth from surface to gamma-ray signatures between 165 and 300 API units
Sand_A	Depth interval from surface of a sand package >8 metres thick
Sand_B	Depth interval from surface of a sand package >8 metres thick
Sand_C	Depth interval from surface of a sand package >8 metres thick
Sand_D	Depth interval from surface of a sand package >8 metres thick
*	Units are recorded in feet
	Logs showing anomolous gamma-ray intervals (API>300)
	Logs either have no gamma-ray or are not available
Notes	
Sand packages are recorded only if less than 75 API and >8 metres in thickness	
All depths are in metres unless otherwise stated (see legend)	

Well_ID	Latitude	Longitude	Casing_Depth	Units_Present	Willow Creek	St. Mary River	Bearpaw	Anomalous Radioactivity	Anomalous_API_Value	High Radioactivity	Sand_A	Sand_B	Sand_C	Sand_D
00/08-07-010-26W4/0	49.807	-113.503	405	M	-	-	775	-		-	-	-	-	-
00/15-18-010-26W4/0	49.827	-113.511	225	M	-	-	855	-		-	757 - 767	-	-	-
00/01-19-010-26W4/0	49.833	-113.507	373	M	-	-	845	-		-	667 - 675	752 - 766	824 - 837	-
00/06-30-010-26W4/0	49.849	-113.516	208	MW	-	321	758	-		-	208 - 248	725 - 746	749 - 746	-
00/10-24-010-27W4/0	49.838	-113.531	452	M	-	-	902	-		-	-	-	-	-
00/08-02-010-27W4/0	49.793	-113.552	271	M	-	-	939	-		391,404,416,428,430	882 - 900	-	-	-
00/14-14-010-27W4/0	49.827	-113.560	238	MW	-	527	858	-		-	-	-	-	-
00/14-23-010-27W4/0	49.841	-113.563	112	MW	-	442	854	-		-	841 - 852	-	-	-
00/06-26-010-27W4/0	49.849	-113.563	250	MW	-	429	970	318	>300	352,462,524,731,940	-	-	-	-
00/13-35-010-27W4/0	49.872	-113.567	400	MW	-	485	978	-		434	-	-	-	-
00/01-15-010-27W4/0	49.818	-113.575	-	-	-	-	-	-		-	-	-	-	-
00/09-22-010-27W4/0	49.838	-113.575	228	M	-	-	907	-		808	-	-	-	-
00/16-27-010-27W4/0	49.856	-113.575	405	M	-	-	932	-		411	-	-	-	-
00/12-04-010-27W4/0	49.796	-113.614	350	MW	-	538	1084	444,493	>300,>300	412,510,553	430 - 443	-	-	-
00/15-04-010-27W4/0	49.797	-113.601	405	MW	-	519	966	-		-	-	-	-	-
00/07-28-010-27W4/0	49.849	-113.599	273	MW	-	497	1036	385	310	379	-	-	-	-
00/16-33-010-27W4/2	49.870	-113.597	401	M	-	-	1034	-		529,539,808	-	-	-	-
00/08-08-010-27W4/0	49.807	-113.620	312	MW	-	580	1095	-		-	-	-	-	-
*00/10-20-010-27W4/0	49.839	-113.622	817	MW	-	1839	3554	-		-	-	-	-	-
00/14-20-010-27W4/0	49.843	-113.631	454	MW	-	535	1106	-		-	1097 - 1106	-	-	-
00/11-32-010-27W4/0	49.866	-113.630	-	-	-	-	-	-		-	-	-	-	-
00/06-02-010-28W4/0	49.792	-113.695	461	MW		784	1377	-		539,777	589 - 598	1231 - 1273	1257 - 1273	1292 - 1300
00/16-23-010-28W4/0	49.842	-113.687	464	MW	-	730	1310	-		1275	1208 - 1226	-	-	-
00/11-06-011-26W4/0	49.881	-113.543	215	MW	-	335	916	-		375	761 - 789	-	-	-
00/07-07-011-26W4/0	49.892	-113.534	-	-	-	-	-	-		-	-	-	-	-
02/07-07-011-26W4/0	49.895	-113.534	-	-	-	-	-	-		-	-	-	-	-
00/13-18-011-26W4/0	49.914	-113.545	-	-	-	-	-	-		-	-	-	-	-
00/04-19-011-26W4/0	49.921	-113.545	-	-	-	-	-	-		-	-	-	-	-
00/16-19-011-26W4/0	49.929	-113.532	322	MW	-	350	844	-		-	-	-	-	-
00/07-30-011-26W4/0	49.939	-113.534	304	M	-	-	770	-		-	670 - 681	762 - 770	-	-
00/13-31-011-26W4/0	49.958	-113.545	289	M	-	-	860	-		-	677 - 702	713 - 740	785 - 813	850 - 860
00/13-01-011-27W4/0	49.885	-113.568	111	MW	-	420	873	-		-	773 - 782	-	-	-
00/05-12-011-27W4/0	49.895	-113.568	258	MW	-	400	862	-		-	275 - 292	302 - 333	-	-
00/14-13-011-27W4/0	49.914	-113.566	-	-	-	-	-	-		-	-	-	-	-
00/07-24-011-27W4/0	49.923	-113.559	355	M	-	-	890	-		442	-	-	-	-
00/04-25-011-27W4/0	49.935	-113.568	-	-	-	-	-	-		-	-	-	-	-
00/12-25-011-27W4/0	49.943	-113.568	357	M	-	-	615	-		-	-	-	-	-
00/10-25-011-27W4/0	49.941	-113.559	638	MW	-	1190	2877	-		-	-	-	-	-
00/10-36-011-27W4/0	49.955	-113.561	392	M	-	-	880	-		-	-	-	-	-

Well_ID	Latitude	Longitude	Casing_Depth	Units_Present	Willow Creek	St. Mary River	Bearpaw	Anomalous Radioactivity	Anomalous_API_Value	High Radioactivity	Sand_A	Sand_B	Sand_C	Sand_D
00/06-02-011-27W4/0	49.878	-113.585	231	MW	-	465	1000	-		-	830 - 843	894 - 910	-	-
00/08-11-011-27W4/0	49.894	-113.578	450	M	-	-	952	-		-	-	-	-	-
00/11-11-011-27W4/0	49.899	-113.591	376	M	-	-	973	-		-	-	-	-	-
00/02-14-011-27W4/0	49.905	-113.582	265	MW	-	407	846	-		407	-	-	-	-
00/09-14-011-27W4/0	49.914	-113.578	365	M	-	-	930	-		388,390	818 - 824	-	-	-
00/07-23-011-27W4/0	49.924	-113.581	350	M	-	-	857	-		379	-	-	-	-
00/12-23-011-27W4/0	49.926	-113.590	-	-	-	-	-	-		-	-	-	-	-
00/03-26-011-27W4/0	49.935	-113.585	-	-	-	-	-	-		-	-	-	-	-
00/12-26-011-27W4/0	49.941	-113.590	336	MW	-	406	945	-		401	-	-	-	-
00/05-35-011-27W4/0	49.950	-113.590	237	M	-	-	930	-		-	-	-	-	-
00/15-03-011-27W4/0	49.885	-113.602	455	MW	-	489	954	-		487,500	-	-	-	-
00/07-10-011-27W4/0	49.893	-113.603	400	MW	-	480	927	-		488	-	-	-	-
00/07-15-011-27W4/0	49.907	-113.606	385	M	-	-	1025	-		402,455	-	-	-	-
00/13-22-011-27W4/0	49.928	-113.614	377	-	-	-	-	-		-	-	-	-	-
00/06-27-011-27W4/0	49.939	-113.608	239	MW	-	445	980	-		439	-	-	-	-
00/11-27-011-27W4/0	49.940	-113.608	277	-	-	-	-	-		-	-	-	-	-
00/10-27-011-27W4/0	49.942	-113.602	377	M	-	-	850	-		-	-	-	-	-
00/09-34-011-27W4/0	49.954	-113.597	466	M	-	-	940	-		-	-	-	-	-
00/14-34-011-27W4/0	49.957	-113.612	-	-	-	-	-	-		-	-	-	-	-
00/07-09-011-27W4/0	49.892	-113.626	351	MW	-	500	1070	-		435,438,505	958 - 967	-	-	-
00/11-09-011-27W4/0	49.899	-113.633	356	MW	-	509	1077	-		536,538,626,848	-	-	-	-
00/06-16-011-27W4/0	49.907	-113.630	400	M	-	-	1065	-		736	-	-	-	-
00/04-21-011-27W4/0	49.918	-113.640	383	MW	-	515	1070	-		501	-	-	-	-
00/10-21-011-27W4/0	49.927	-113.625	400	MW	-	495	942	-		482	-	-	-	-
00/11-28-011-27W4/0	49.940	-113.634	400	MW	-	527	1005	-		460	958 - 967	-	-	-
00/11-33-011-27W4/0	49.956	-113.631	353	M	-	-	900	-		354,438	-	-	-	-
00/14-17-011-27W4/0	49.914	-113.657	-	-	-	-	-	-		-	-	-	-	-
00/05-20-011-27W4/0	49.921	-113.655	384	MW	-	563	1090	-		-	994 - 1010	1028 - 1047	1080 - 1090	-
00/01-29-011-27W4/0	49.933	-113.644	238	MW	-	515	1058	-		-	918 - 925	934 - 956	1041 - 1057	-
00/16-32-011-27W4/5	49.960	-113.642	357	MW	-	472	938	-		373,906	925 - 933	-	-	-
*00/06-19-011-27W4/0	49.921	-113.676	1518	MW	-	2070	3800	-		1548,2038, 3052,3434	3730 - 3762	-	-	-
00/11-19-011-27W4/0	49.928	-113.676	362	MW	-	597	1131	-		462,583	-	-	-	-
00/03-30-011-27W4/0	49.935	-113.677	380	MW	-	620	1044	485	>450	554,1031	-	-	-	-
00/03-31-011-27W4/0	49.950	-113.680	359	M	-	-	1030	-		471	-	-	-	-
00/14-31-011-27W4/2	49.957	-113.676	248	MW	-	575	1101	-		272,463,692,887	-	-	-	-
00/16-01-011-28W4/0	49.887	-113.691	305	MW	-	743	1247	-		-	-	-	-	-
00/16-12-011-28W4/0	49.899	-113.691	419	M	-	-	1222	-		529,568,652,691	-	-	-	-
00/16-24-011-28W4/0	49.929	-113.692	405	MW	-	605	1089	-		-	1046 - 1059	1061 - 1071	-	-
00/06-25-011-28W4/0	49.936	-113.702	308	MW	-	650	1193	-		-	-	-	-	-
00/03-36-011-28W4/0	49.949	-113.699	271	MWP	298	650	1175	-		-	275 - 296	1056 - 1175	-	-

Well_ID	Latitude	Longitude	Casing_Depth	Units_Present	Willow Creek	St. Mary River	Bearpaw	Anomalous Radioactivity	Anomalous_API_Value	High Radioactivity	Sand_A	Sand_B	Sand_C	Sand_D
00/10-36-011-28W4/0	49.957	-113.693	459	MW	-	638	1152	-		625,1101, 1104	1045 - 1056	-	-	-
00/16-23-011-28W4/0	49.929	-113.714	197	M	-	-	1240	-		1025	1133 - 1145	-	-	-
00/08-26-011-28W4/0	49.937	-113.714	-	-	-	-	-	-		-	-	-	-	-
00/06-26-011-28W4/0	49.938	-113.722	-	-	-	-	-	-		-	-	-	-	-
00/16-34-011-28W4/0	49.960	-113.740	488	-	-	715	1272	-		-	-	-	-	-
00/16-28-011-28W4/0	49.945	-113.756	308	MW	-	755	1367	-		536	-	-	-	-
00/06-33-011-28W4/0	49.954	-113.771	325	MW	-	761	1361	-		729	-	-	-	-
00/09-08-011-28W4/0	49.899	-113.783	452	MW	-	935	1552	-		-	1412 - 1424	1464 - 1482	-	-
00/14-29-011-28W4/0	49.944	-113.792	279	MW	-	855	1458	-		509,618,628	1314 - 1329	-	-	-
*00/10-36-011-29W4/0	49.957	-113.830	899	MWP	1842	3283	5146	-		2790	-	-	-	-
00/16-36-011-29W4/0	49.960	-113.828	403	MWP	540	983	1553	-		-	-	-	-	-
00/06-06-012-28W4/0	49.966	-113.816	-	-	-	-	-	-		-	-	-	-	-
00/09-01-012-29W4/0	49.969	-113.825	430	MW	-	960	1518	-		-	507 - 527	628 - 640	1085 - 1095	-
00/06-07-012-28W4/0	49.980	-113.817	331	MW	-	938	1525	-		822	-	-	-	-
00/10-07-012-28W4/0	49.986	-113.807	-	-	-	-	-	-		-	-	-	-	-
00/08-08-012-28W4/0	49.982	-113.783	313	MW	-	824	1402	-		670	-	-	-	-
00/01-20-012-28W4/0	50.002	-113.777	401	MW	-	824	1364	-		1158	-	-	-	-
00/10-32-012-28W4/0	50.052	-113.775	-	-	-	-	-	-		-	-	-	-	-
00/03-04-012-28W4/0	49.965	-113.769	505	MW	-	762	1342	-		1139	-	-	-	-
00/13-16-012-28W4/0	50.002	-113.772	307	MW	-	817	1342	-		1141	1394 - 1208	-	-	-
00/16-16-012-28W4/0	50.002	-113.760	-	-	-	-	-	-		-	-	-	-	-
00/06-21-012-28W4/0	50.009	-113.771	-	-	-	-	-	-		-	-	-	-	-
00/07-21-012-28W4/0	50.010	-113.765	-	-	-	-	-	-		-	-	-	-	-
00/06-10-012-28W4/0	49.980	-113.748	433	MW	-	674	1258	-		1005	-	-	-	-
00/07-10-012-28W4/0	49.981	-113.743	497	MW	-	660	1171	-		648,970	978 - 987	-	-	-
00/11-10-012-28W4/0	49.986	-113.747	482	MW	-	663	1250	-		551,568	-	-	-	-
*00/07-34-012-28W4/0	50.041	-113.740	1303	MW	-	2262	3925	-		-	-	-	-	-
00/04-02-012-28W4/0	49.964	-113.727	-	-	-	-	-	-		-	-	-	-	-
00/11-11-012-28W4/0	49.986	-113.723	473	MW	-	634	1035	-		604	955 - 974	-	-	-
00/04-14-012-28W4/0	49.993	-113.727	182	MW	-	595	1180	-		380,459,578,594,599,605,633,643,672,679,698,815,889,899,910,920,984, 1124	-	-	-	-
00/07-14-012-28W4/0	49.995	-113.716	-	-	-	-	-	-		-	-	-	-	-
00/10-14-012-28W4/0	50.001	-113.716	-	-	-	-	-	-		-	-	-	-	-
00/14-14-012-28W4/0	50.002	-113.723	-	-	-	-	-	-		-	-	-	-	-
00/10-35-012-28W4/0	50.044	-113.717	249	MW	-	849	1105	-		466,858	1025 - 1067	1090 - 1105	-	-
00/02-01-012-28W4/0			-	-	-	-	-	-		-	-	-	-	-
00/09-01-012-28W4/0			-	-	-	-	-	-		-	-	-	-	-
00/15-12-012-28W4/0	49.987	-113.693	431	M	-	-	989	-		-	-	-	-	-
00/02-13-012-28W4/0	49.994	-113.693	-	-	-	-	-	-		-	-	-	-	-
00/06-24-012-28W4/0	50.009	-113.702	455	MW	-	555	1086	-		-	-	-	-	-

Well_ID	Latitude	Longitude	Casing_Depth	Units_Present	Willow Creek	St. Mary River	Bearpaw	Anomalous Radioactivity	Anomalous_API_Value	High Radioactivity	Sand_A	Sand_B	Sand_C	Sand_D
00/16-24-012-28W4/0	50.016	-113.692	-	-	-	-	-	-		-	-	-	-	-
00/16-25-012-28W4/0	50.031	-113.692	188	MWP	-	490	1032	-		528	1021 - 1031	-	-	-
00/16-36-012-28W4/0	50.045	-113.692	233	M	-	-	950	-		428,802	-	-	-	-
00/07-06-012-27W4/0	49.966	-113.670	430	MW	-	525	1030	-		442	910 - 929	-	-	-
00/11-07-012-27W4/0	49.986	-113.676	495	MW	-	500	1070	-		535,659,835,858	-	-	-	-
00/05-18-012-27W4/0	49.994	-113.681	-	-	-	-	-	-		-	-	-	-	-
00/16-19-012-27W4/0	50.016	-113.669	226	MW	-	462	1021	-		-	-	-	-	-
00/07-30-012-27W4/0	50.024	-113.673	404	MW	-	488	1000	-		813	780 - 792	872 - 882	915 - 931	941 - 987
00/11-31-012-27W4/0	50.042	-113.676	237	MW	-	467	1033	-		593,788	-	-	-	-
00/16-31-012-27W4/0	50.045	-113.669	202	MW	-	455	915	-		341,343,345,756,758	-	-	-	-
02/16-31-012-27W4/0	50.045	-113.668	238	MW	-	454	1014	-		384,448	-	-	-	-
00/10-05-012-27W4/0	49.968	-113.645	256	MW	-	497	929	-		390,399,420,486,607	-	-	-	-
00/09-05-012-27W4/0	49.969	-113.643	185	MW	-	456	926	-		222,227	-	-	-	-
00/07-08-012-27W4/0	49.979	-113.648	405	MW	-	470	1009	-		-	-	-	-	-
00/16-08-012-27W4/0	49.987	-113.646	405	MW	-	490	1006	-		437	-	-	-	-
00/10-17-012-27W4/0	49.999	-113.650	240	M	-	-	1007	-		-	887 - 904	-	-	-
00/11-20-012-27W4/0	50.012	-113.657	231	MW	-	468	1004	-		-	-	-	-	-
00/16-20-012-27W4/0	50.016	-113.646	185	MW	-	445	980	-		265,371	-	-	-	-
00/05-29-012-27W4/0	50.023	-113.659	247	MW	-	453	970	-		341,349	-	-	-	-
00/14-29-012-27W4/0	50.031	-113.658	184	M	-	-	998	-		757,780,792	883 - 895	-	-	-
02/14-29-012-27W4/0			-	-	-	-	-	-		-	-	-	-	-
00/07-32-012-27W4/0	50.041	-113.650	202	MW	-	433	930	-		363,368,819,846	-	-	-	-
00/06-04-012-27W4/0	49.968	-113.623	307	M	-	-	1000	-		-	-	-	-	-
00/16-04-012-27W4/0	49.975	-113.617	-	-	-	-	-	-		-	-	-	-	-
00/01-09-012-27W4/0	49.979	-113.623	496	M	-	-	925	-		-	-	-	-	-
00/13-09-012-27W4/0	49.987	-113.636	225	MW	-	425	899	338	320	-	-	-	-	-
00/06-16-012-27W4/0	49.996	-113.634	315	MW	-	461	980	-		329,390,449	-	-	-	-
00/09-21-012-27W4/0	50.015	-113.623	275	MW	-	410	872	-		-	-	-	-	-
00/10-28-012-27W4/0	50.028	-113.624	196	MW	-	396	975	-		699	-	-	-	-
00/04-33-012-27W4/0	50.037	-113.636	181	MW	-	399	917	310	>300	238,296,316,372,737,739	-	-	-	-
00/04-03-012-27W4/0	49.964	-113.614	242	MW	-	427	960	-		304,347,704,856	-	-	-	-
00/01-03-012-27W4/0	49.964	-113.601	307	MW	-	360	955	-		-	929 - 943	-	-	-
00/04-10-012-27W4/0	49.979	-113.613	401	M	-	-	869	-		847	-	-	-	-
00/07-10-012-27W4/0	49.981	-113.604	421	M	-	-	855	-		697,830	-	-	-	-
00/08-15-012-27W4/0	49.994	-113.600	278	MW	-	409	935	-		-	-	-	-	-
00/16-15-012-27W4/0	50.001	-113.601	273	MW	-	350	976	-		-	-	-	-	-
00/10-22-012-27W4/0	50.014	-113.602	389	M	-	-	922	-		-	802 - 815	-	-	-
00/06-27-012-27W4/0	50.023	-113.608	182	MW	-	380	925	-		294,413	793 - 812	-	-	-
00/06-34-012-27W4/0	50.038	-113.612	330	M	-	-	949	-		688	-	-	-	-
00/09-34-012-27W4/0	50.043	-113.600	270	M	-	-	920	-		-	754 - 770	-	-	-

Well_ID	Latitude	Longitude	Casing_Depth	Units_Present	Willow Creek	St. Mary River	Bearpaw	Anomalous Radioactivity	Anomalous_API_Value	High Radioactivity	Sand_A	Sand_B	Sand_C	Sand_D
00/16-02-012-27W4/0	49.972	-113.578	407	M	-	-	905	-		629	762 - 787	-	-	-
00/06-11-012-27W4/0	49.980	-113.585	386	M	-	-	909	790	>>450	-	776 - 810	-	-	-
00/01-14-012-27W4/0			391	M	-	-	900	-		779	-	-	-	-
00/06-23-012-27W4/0	50.009	-113.587	0	M	-	330	895	-		-	772 - 783	-	-	-
00/16-35-012-27W4/0	50.045	-113.578	210	MW	-	345	880	-		340	-	-	-	-
00/03-01-012-27W4/0	49.964	-113.562	392	M	-	-	885	-		-	746 - 767	785 - 800	-	-
00/05-12-012-27W4/0	49.980	-113.568	415	M	-	-	890	-		-	-	-	-	-
00/04-13-012-27W4/0	49.993	-113.568	283	M	-	-	870	-		-	-	-	-	-
00/13-13-012-27W4/0	50.002	-113.568	512	M	-	-	882	-		779,742	-	-	-	-
00/04-24-012-27W4/0	50.008	-113.568	384	M	-	-	853	-		-	-	-	-	-
00/16-25-012-27W4/0	50.031	-113.555	211	M	-	-	840	-		-	-	-	-	-
00/08-36-012-27W4/0	50.041	-113.555	242	MW	-	315	840	-		275,598	-	-	-	-
00/16-36-012-27W4/0	50.045	-113.555	152	MW	-	349	828	-		596	-	-	-	-
00/11-01-013-27W4/0	50.057	-113.566	185	MW	-	332	860	-		321	-	-	-	-
00/09-02-013-27W4/0	50.059	-113.578	304	MW	-	354	793	-		343,351	750 - 780	776 - 793	-	-
00/04-02-013-27W4/0	50.052	-113.590	451	M	-	-	905	-		665	-	-	-	-
00/06-03-013-27W4/0	50.055	-113.608	236	MW	-	410	840	-		324,340,401,698	-	-	-	-
00/16-03-013-27W4/0	50.060	-113.600	213	MW	-	396	840	-		289,400,681	-	-	-	-
00/08-10-013-27W4/0	50.067	-113.600	-	-	-	-	-	-		-	-	-	-	-
00/14-10-013-27W4/0	50.074	-113.607	386	MW	-	440	947	-		420	-	-	-	-
00/04-04-013-27W4/0	50.052	-113.636	308	MW	-	500	976	-		-	-	-	-	-
00/11-04-013-27W4/0	50.056	-113.634	207	MW	-	408	920	-		-	872 - 897	-	-	-
00/03-09-013-27W4/0	50.066	-113.633	257	MW	-	440	970	-		737	-	-	-	-
00/16-09-013-27W4/0	50.074	-113.623	213	MW	-	408	976	-		426,729	790 - 800	-	-	-
00/08-16-013-27W4/0	50.083	-113.619	242	MW	-	410	896	-		722	-	-	-	-
00/14-16-013-27W4/0	50.089	-113.631	395	M	-	424	985	-		404,420,528,731,939	-	-	-	-
00/04-05-013-27W4/0	50.052	-113.659	306	MW	-	440	988	-		-	-	-	-	-
00/10-05-013-27W4/0	50.058	-113.651	370	M	-	-	940	-		752	-	-	-	-
00/04-08-013-27W4/0	50.065	-113.661	635	-	-	-	-	-		-	-	-	-	-
00/02-08-013-27W4/0	50.066	-113.649	225	MW	-	434	936	-		433,738	926 - 936	-	-	-
00/01-17-013-27W4/0	50.081	-113.647	219	MW	-	445	1018	-		720	330 - 344	-	-	-
00/14-17-013-27W4/0	50.091	-113.656	365	MW	-	445	1042	-		553,739	-	-	-	-
00/07-20-013-27W4/0	50.099	-113.651	256	MW	-	447	1035	-		400,738	909-921	934-946	-	-
00/11-20-013-27W4/0	50.100	-113.656	221	MW	-	390	961	-		751	-	-	-	-
00/15-06-013-27W4/0	50.060	-113.674	-	-	-	-	-	-		-	-	-	-	-
02/03-07-013-27W4/0	50.065	-113.678	621	-	-	-	-	-		-	-	-	-	-
00/07-07-013-27W4/0	50.069	-113.672	613	-	-	-	-	-		-	-	-	-	-
00/06-18-013-27W4/0	50.084	-113.677	-	-	-	-	-	-		-	-	-	-	-
00/10-19-013-27W4/0	50.102	-113.674	225	MW	-	478	1020	461	300	759-764	-	-	-	-
00/14-19-013-27W4/0	50.105	-113.678	360	MW	-	474	992	-		393,415,441,774,778	-	-	-	-

Well_ID	Latitude	Longitude	Casing_Depth	Units_Present	Willow Creek	St. Mary River	Bearpaw	Anomalous Radioactivity	Anomalous_API_Value	High Radioactivity	Sand_A	Sand_B	Sand_C	Sand_D
00/04-30-013-27W4/0	50.110	-113.681	360	M	-	-	1060	-		780	-	-	-	-
02/06-30-013-27W4/0	50.111	-113.680	391	M	-	-	1055	-		781	867-883	-	-	-
00/06-30-013-27W4/0	50.111	-113.679	1030	-	-	-	-	-		-	-	-	-	-
00/08-30-013-27W4/0	50.111	-113.667	298	MW	-	470	1045	-		-	368-382	-	-	-
00/10-30-013-27W4/0	50.116	-113.673	297	MW	-	464	1047	-		760	-	-	-	-
00/07-01-013-28W4/0	50.055	-113.695	231	MW	-	489	1027	-		291,361,416,430,804	-	-	-	-
00/05/12/013/28W4/0	50.067	-113.703	215	MW	-	502	1025	-		551,636	222-239	288-298	-	-
00/11-13-013-28W4/0	50.087	-113.700	232	MW	-	530	1033	-		842	-	-	-	-
00/08-24-013-28W4/0	50.096	-113.691	350	MW	-	477	1094	-		818	-	-	-	-
00/16-24-013-28W4/0	50.103	-113.691	231	MW	-	487	1114	-		466,491,791,813	282 - 293	-	-	-
00/13-24-013-28W4/0	50.103	-113.704	286	MW	-	560	1070	-		557,871	5058 - 1068	-	-	-
00/10-25-013-28W4/0	50.115	-113.694	230	MW	-	500	1029	-		488,495,805	275-292	-	-	-
00/04-36-013-28W4/0	50.124	-113.698	260	MW	-	487	1024	-		378,482,529,534,748,790-795	-	-	-	-
00/02-36-013-28W4/0	50.124	-113.697	244	MW	-	496	1025	-		-	-	-	-	-
00/07-02-013-28W4/0	50.055	-113.718	239	MW	-	533	1073	-		438,452,488,687,883	-	-	-	-
00/10-11-013-28W4/0	50.071	-113.720	220	MW	-	556	1071	-		903	291-315	-	-	-
00/07-05-013-28W4/0	50.052	-113.775	-	-	-	-	-	-		-	-	-	-	-
00/05-04-013-28W4	50.052	-113.774	-	-	-	-	-	-		-	-	-	-	-
00/07-24-013-29W4/0	50.098	-113.833	612	MWP	684	913	1384	-		828,861,913	665-681	-	-	-
*00/07-20-013-29W4/0	50.097	-113.921	1230	MWP	2750	3920	5890	-		-	-	-	-	-
00/14-29-013-29W4/0	50.118	-113.929	462	MWP	752	1078	1610	-		-	651-664	672-690	695-705	731-752
00/09-32-013-29W4/2	50.129	-113.916	442	MWP	692	1085	1539	-		860,877, 1037,1422	567-579	665-692	-	-
*00/05-12-014-30W4/0	50.155	-113.980	804	MWP	?	?	5770	-		-	-	-	-	-
00/04-04-014-29W4/0	50.138	-113.915	605	MWP	737	1009	1519	-		1056,1384, 1397	643-660	715-731	-	-
00/06-11-014-29W4/0	50.155	-113.861	353	MWP	824	1075	1625	-		1405	707-725	747-773	807-823	945-958
00/04-06-014-28W4/0	50.139	-113.818	305	MWP	692	824	1316	-		366,718,799	410-427	484-513	545-564	-
00/07-32-013-28W4/0	50.129	-113.781	459	MW	-	703	1175	-		478,1027	-	-	-	-
00/06-33-013-28W4/0	50.125	-113.770	375	MWP	458	674	1207	-		641,673,717,798,989	375-406	440-457	1130-1143	-
00/02-28-013-28W4/0	50.110	-113.765	305	MWP	418	694	1149	-		-	351-366	385-418	575-593	-
*00/07-21-013-28W4/0	50.097	-113.763	1050	MWP	-	-	-	-		-	-	-	-	-
00/16-15-013-28W4/0	50.089	-113.737	207	MWP	394	655	1090	538	325	408,533	283-316	362-394	-	-
00/08-03-013-28W4/0	50.055	-113.737	449	MW	-	660	1197	-		510	-	-	-	-
00/14-22-013-28W4/0	50.103	-113.748	458	MW	-	651	1100	-		600,986	-	-	-	-
00/12-23-013-28W4/2	50.102	-113.727	589	MW	-	615	1115	-		927	-	-	-	-
00/02-14-013-28W4/0	50.077	-113.715	455	MW	-	565	1059	-		555,695,886	-	-	-	-

Appendix 3 – 2006 Water Sampling Results

Sample Number	Easting, NAD83 UTMZ12	Northing, NAD83 UTMZ12	As, ugL	Cu, mgL	Iron, mgL	Se, mgL	U, mgL	V, mgL
06USAM021	36422	5478152	0.7	0.006	0.46	0.000	5.9	0.000
06USAM022	316588	5477966	0.2	0.001	0.005	0.001	2.6	0.000
06USAM023	316390	5479295	0.8	0.022	0.014	0.000	3.5	0.000
06USAM024	315517	5477642	5.1	0.044	0.002	0.001	5.1	0.000
06USAM025	314348	5476385	0.6	0.002	0.013	0.001	8	0.000
06USAM026	319189	5477286	0.2	0.004	0.051	0.001	10	0.000
06USAM027	322624	5479193	0.4	0.009	0.015	0.007	9.9	0.000
06USAM028	326930	5476383	20	0.027	0.038	0.002	2.8	0.000
06USAM029	325855	5475408	0.3	0.1	0.008	0.099	17	0.000
06USAM030	324742	5486327	0.8	0.005	0.001	0.017	8.9	0.000
Samples were collected in 100 ml plastic bottles, charged with 20% nitric acid solution and analysed in SRC laboratory using ISP-Mass Spectrometry Scan.								

Appendix 4 – Photographs

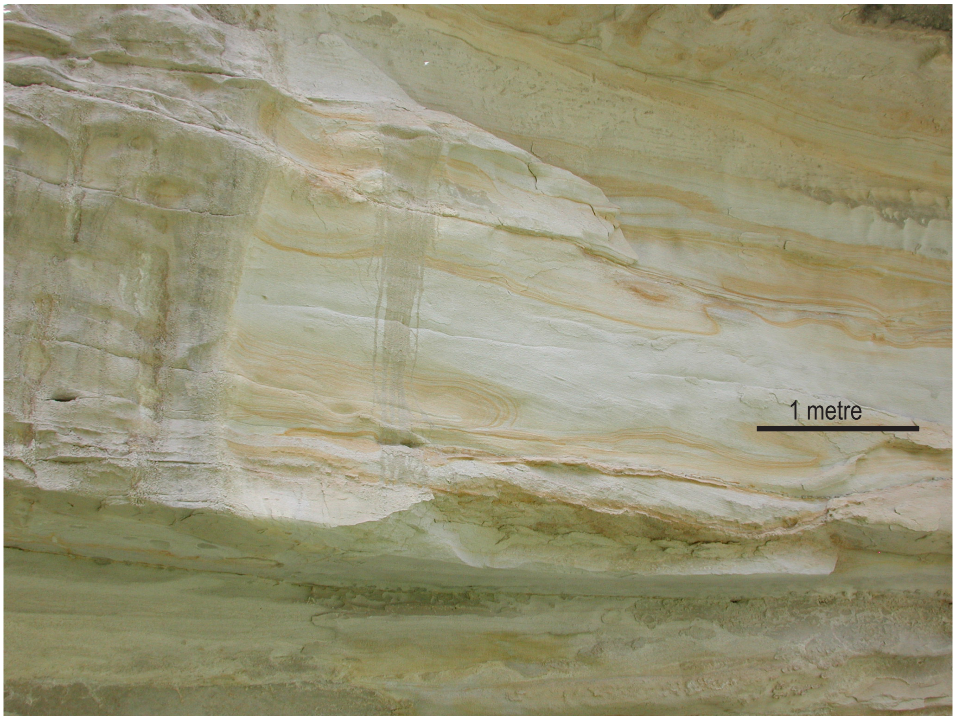


Photo 1. Alteration zones, lower section of Police Creek Canyon.

Photo 2. Sandstones of Oldman River Formation.

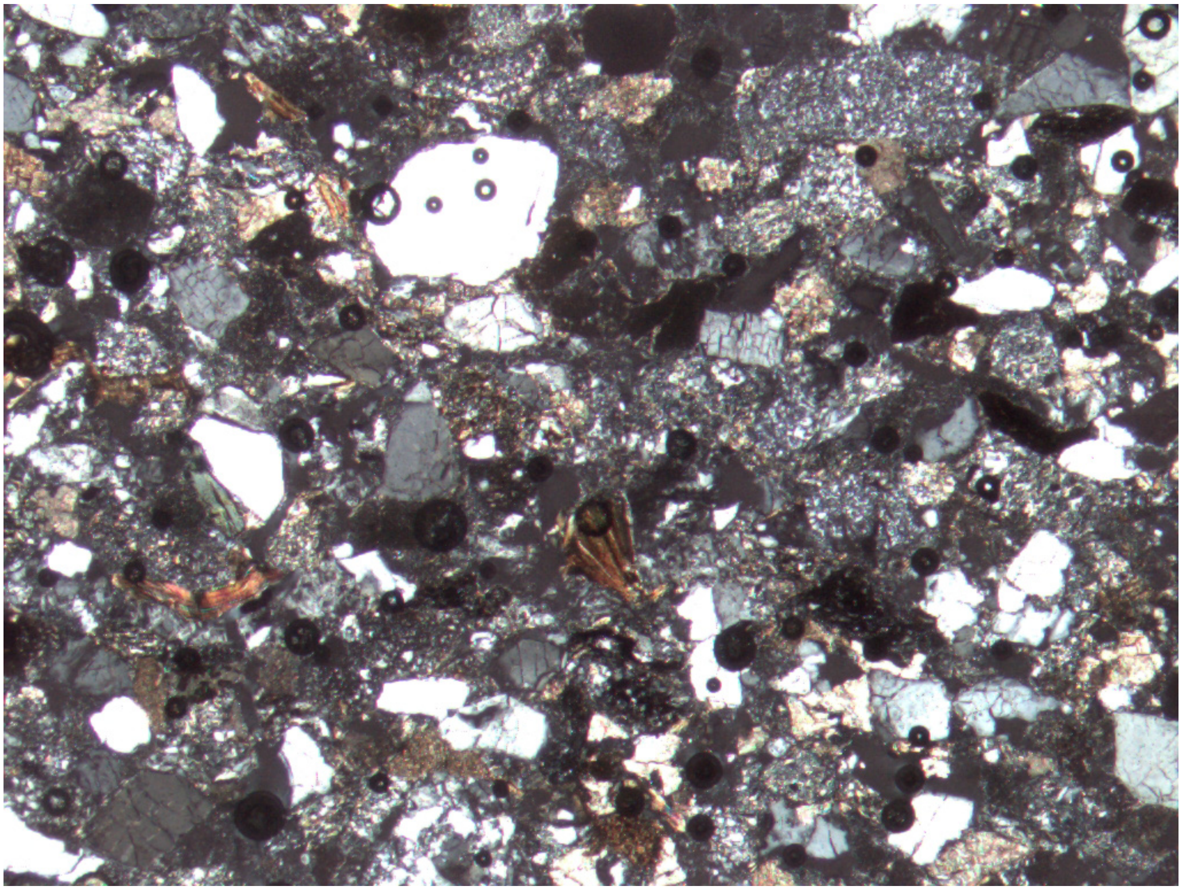


Photo 3. Thin section of a sample 06USA0065, magnification 400, crossed polars.

Photo 4. Blood Reserve Formation on Milk River.

Photo 5. Blood Reserve Formation, plant imprints in green sandstone.

Photo 6. Blood Reserve Formation, McIntyre Ranch.

Photo 7. Blood Reserve Formation, shrimp burrow, McIntyre Ranch.

Photo 8. Blood Reserve Formation, Macronichnus trace fossil, McIntyre Ranch.

Photo 9. Blood Reserve Formation, alteration bands in sandstone, McIntyre Ranch.

Photo 10. Blood Reserve Formation, carbonate concretion in sandstone, McIntyre Ranch.

Photo 11. St. Mary River Formation, radioactive zone 1, central part, Kimball occurrence.

Photo 12. Anticline fold, St. Mary River Formation near Kimball.

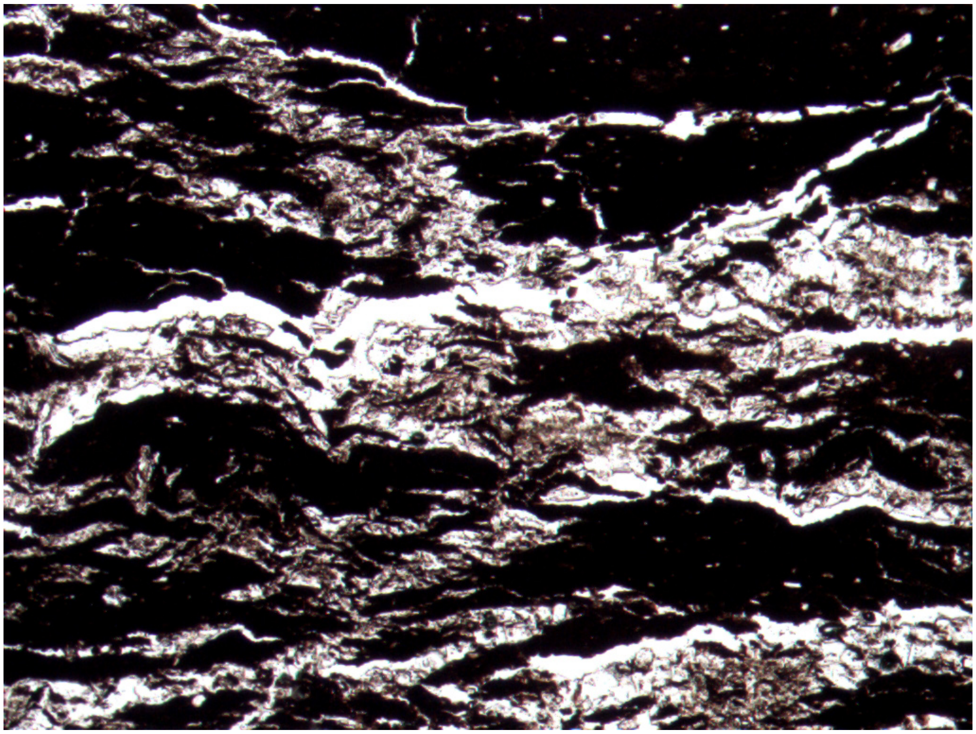


Photo 13. Thin section of the sample 06USA0024, plain polarized light, magnification 400.

Photo 14. Whitemud-Battle-Willow Creek contact, Oldman River.

Photo 15. Rootlets in Whitemud Formation sandstones.

Photo 16. Burrow, highlighted by development of iron oxides, Whitemud Formation.

Photo 17. Battle Formation, Oldman River.

Photo 18. Red paleosol, Willow Creek Formation.

Photo 19. Caliche carbonate concretions, Willow Creek Formation.

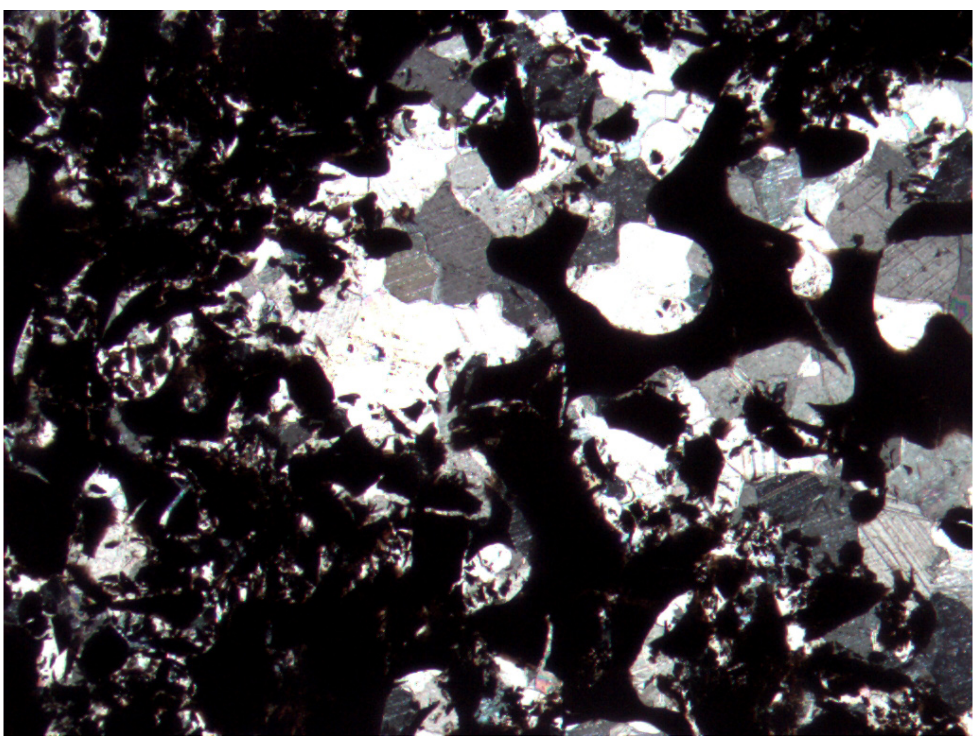


Photo 20. Monazite grain in sample 06USA0045, thin section magnification 100, crossed polars.

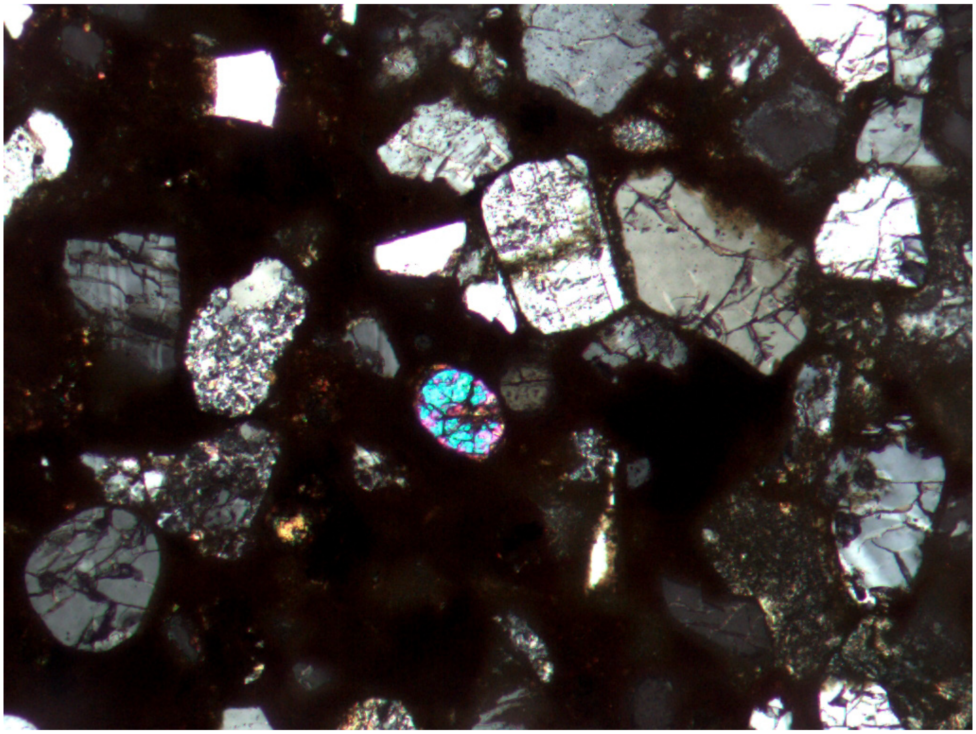


Photo 21. Monazite grain in sample 06USA0045, thin section magnification 100, crossed polars.

Photo. 22. Massive sandstone channels with trough crossbeds, Waterton River.

Photo 23. Sandstone channel 6 m thick 40 m wide, Waterton River.

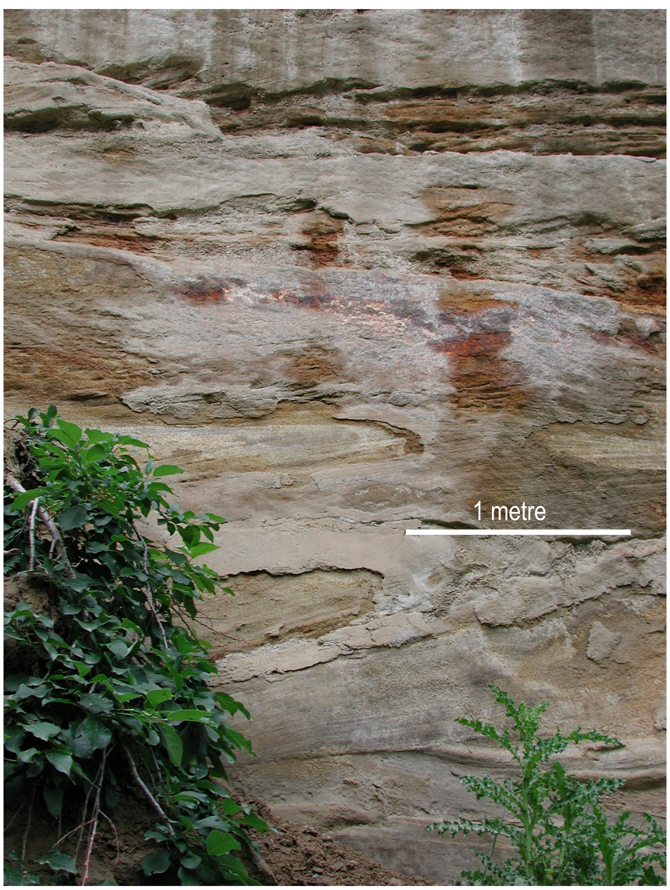


Photo 24. Rusty zone in massive sandstone outcrop.

Photo 25. Organic imprints in massive sandstone bodies on Waterton River.

Photo 26. Manganese dendrites on the surface of sandstone outcrop, Porcupine HIlls Formation.

Photo 27. Porcupine Hills Formation outcrop.

Photo 28. Development of iron oxide film on the crack surface in sandstone–Porcupine Hills Formation.

Photo 29. Monarch fault zone.

Photo 30. Faulting in Willow Creek Formation, Waterton River near Ewelme colony.

Appendix 5 – Drift Thickness Map Description

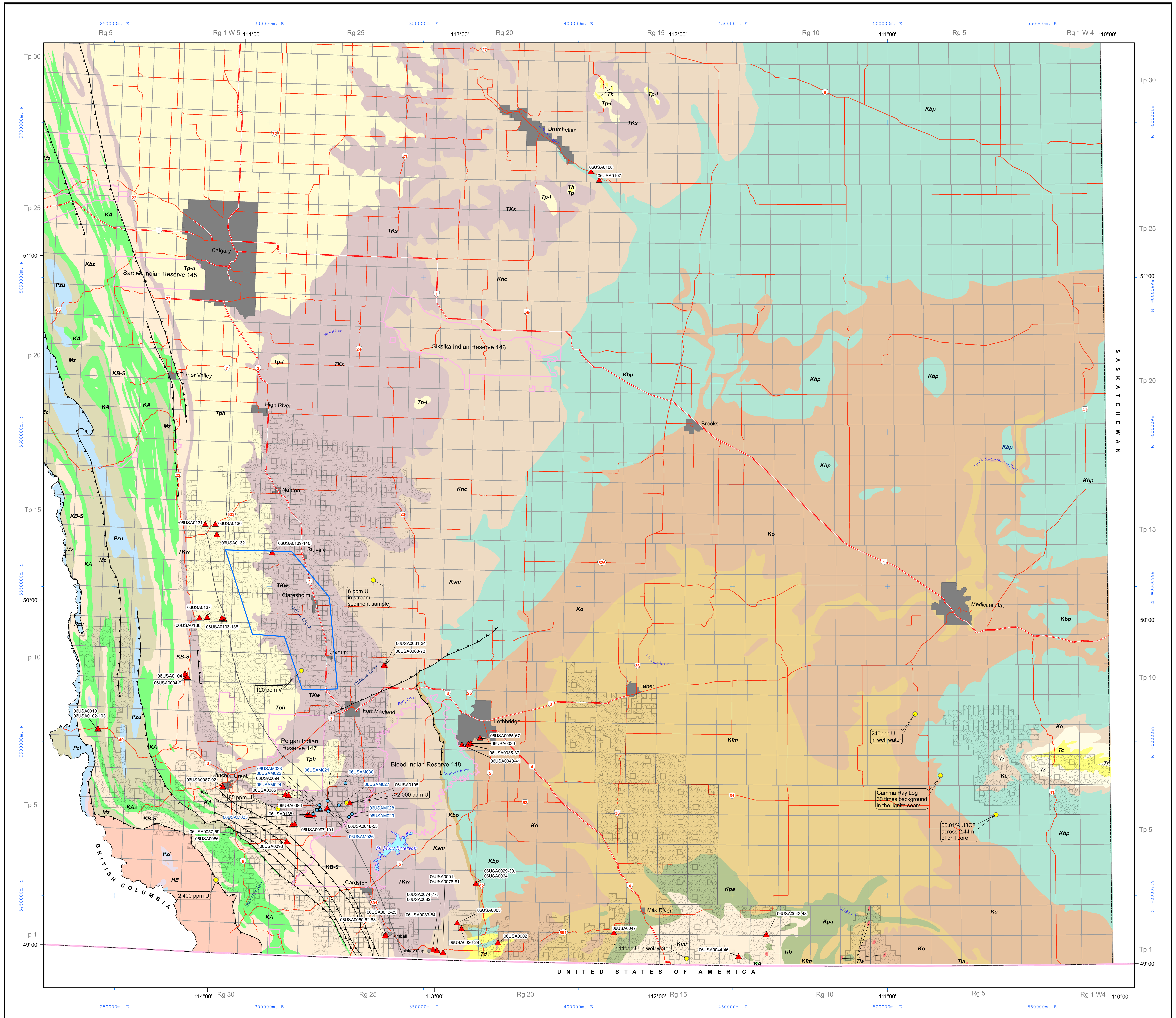
For this project a drift thickness map (Figure 20) was generated at Alberta Geological Survey. In 1994 all the bedrock maps generated by the ARC's Groundwater Division over the previous 3 decades were digitized and tagged with their elevation values. In early 2002 these were supplemented with metadata in preparation to pre-processing with the in-house Erdna software.

Erdna was then used to
- convert most of the digitization from British measure (ft AMSL) to MAMSL;
- reformat additional bedrock topography received as vectors from more recent AGS
- mapping in east-central Alberta to the same format as the legacy digitizations;
- reformat all of the data to 3-D polylines and
- project the 3-D polyline to 1:2 000 000 scale engineering coordinates.

CPS3 (Radian Corporation) gridding software was ported from VMS to MSWindows NT and used to model the 3-D polylines as a regular grid. The gird spacing chosen was 0.025 cm. This spacing was chosen as it represented a reasonable compromise between grid size, digitization resolution, scales of original maps and goodness of overlay of grid-based contours with the original digitization. At the chosen scale this spacing represents a resolution of about 500 m on the ground.

Towards the end of 2003 several bedrock maps generated by AGS were reformatted from shapefile to Erdna and then CPS3 formats. The legacy digitization was then clipped to remove those portions of it that had been supplanted by the new maps. The result was re-gridded using CPS3 and clipped to remove extrapolation into unmapped areas.

In February of 2007 this grid was used as the basis of a drift thickness map for the area between longitudes 111.379197 - 113.878587 West and 48.999792 - 50.571806 North.



Scale: 1: 500 000

0 5 10 20 30 40 kilometres

0 5 10 20 30 miles

Projection: UTM Zone 12
Datum: NAD1983

LEGEND

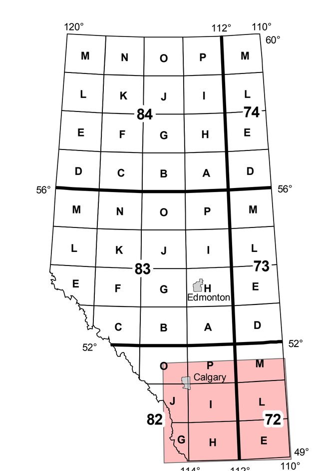
(blue outline)	Area covered in oil and gas gamma ray log interpretation in Earth Science Report 2007-10
(stipple)	Mineral agreements (information compiled from Alberta Department of Energy as of February 2007)

SYMBOL LEGEND

2006 rock sample	06USA0047
Well water sample	06USAM028
Previously known occurrence related to uranium mineralization	
Alberta syncline axis	
Fault	

Bedrock Geology

Tia	Sweetgrass Hills Minette Intrusives: dark basic (minette) dykes/plugs/vents
Tib	Sweetgrass Hills Diorite Intrusives: pale-greenish-grey diorite porphyry plug
Tr	RAVENSCRAG FORMATION: pale-grey, fine-grained, feldspathic sandstone, argillaceous and silty in part; grey to brownish-grey clay and mudstone; lignitic coal and thin bentonite beds, minor ironstone; nonmarine. Note: in Alberta the Ravenscrag Formation includes in its lower part strata that are mapped separately as 'Frenchman Formation' in Saskatchewan
Tc	CYPRESS HILLS FORMATION: conglomerate; minor calcareous sandstone; nonmarine
Td	DEL BONITA GRAVELS: gravel, minor thin beds and lenses of sand; nonmarine
Th	HAND HILLS FORMATION: conglomerate, gravel,sandstone; minor shale, marl (Hand Hills and Wintering Hills); nonmarine
Tph	PORCUPINE HILLS FORMATION: pale-grey, thick-bedded, cherty, calcareous sandstone; pale-grey calcareous mudstone; nonmarine. Tph-u: upper Porcupine Hills member; Tph-l: lower Porcupine Hills member. Note: division of Porcupine Hills Formation into upper and lower members is tentative, subject to verification as formal sub-units
Tp	PASKAPOO FORMATION (Rocky Mountains and Foothills): light-grey or yellowish, medium to fine-grained, crossbedded, brownish weathering sandstone; olive-green siltstone/mudstone interbedded with thin sandstone lenses and minor lenses of carbonaceous shale; nonmarine
Tp-u	Paskapoo Formation, upper: light-grey or yellowish, medium to fine-grained, crossbedded, brownish weathering sandstone; olive-green siltstone/mudstone interbedded with thin sandstone lenses and minor lenses of carbonaceous shale; nonmarine
Tp-l	Paskapoo Formation, lower: light-grey or yellowish, medium to fine-grained, crossbedded, brownish weathering sandstone; olive-green siltstone/mudstone interbedded with thin sandstone lenses and minor lenses of carbonaceous shale; nonmarine
TKc	COALSPUR FORMATION (Rocky Mountains and Foothills): light grey, brownish weathering, argillaceous sandstone; grey and greenish grey siltstone/mudstone; coal, thinly interbedded with claystone in upper part; minor volcanic tuff in lower part; light grey, locally conglomeratic sandstone of the Entrance Member (25-30 m thick) forms the base of the formation; nonmarine
TKw	WILLOW CREEK FORMATION: pale-grey, fine-grained, calcareous sandstone, thick-bedded and coarse-grained in upper part; grey, green and pink bentonitic mudstone with abundant white-weathering calcareous concretions; scattered thin limestone beds; nonmarine
TKs	SCOLLARD FORMATION: grey feldspathic sandstone; dark-grey bentonitic mudstone; thick coal beds; nonmarine
Mz	LOWER MESOZOIC-LOWER CRETACEOUS (Rocky Mountains and Foothills): dark-grey to black siltstone; dolomitic siltstone and limestone; silty dolomite, limestone, breccia and gypsum (Triassic); dark-grey to black fissile shale and siltstone; black cherty and phosphatic dolomite and limestone; green glauconitic shale and sandstone (Jurassic); thick-bedded, fine to coarse-grained, cherty sandstone interbedded with dark-grey shale, siltstone and coal (Nikanassin and Kootenay Formations); grey, siliceous, calcareous sandstone; green chloritic and feldspathic sandstone; dark grey carbonaceous and calcareous shale; grey, green and red shale and silty shale; some conglomerate; coal in central and northern Foothills (Luscar Group), no major coal in southern Foothills (Blairmore Group); trachytic tuff and agglomerate at top of map unit in southern Foothills (Crowsnest Volcanics)
Ksm	ST. MARY RIVER FORMATION: pale-green and grey, fine to medium-grained, calcareous sandstone; green and grey siltstone and mudstone; thin coal beds; coquinoid limestone in basal part; nonmarine
Ke	EASTEND FORMATION: grey, fine to medium-grained, feldspathic, clayey sandstone; grey to dark-green silty shale and siltstone, black carbonaceous shale; coal beds; shoreline complex
Khc	HORSESHOE CANYON FORMATION: grey, feldspathic, clayey sandstone; grey bentonitic mudstone and carbonaceous shale; concretionary ironstone beds, scattered coal and bentonite beds of variable thickness, minor limestone beds; mainly nonmarine
Kbo	BLOOD RESERVE FORMATION: grey and greenish-grey, thick-bedded, feldspathic sandstone; shoreline complex
Kbp	BEARPAW FORMATION: dark-grey blocky shale and silty shale; greenish glauconitic and grey clayey sandstone; thin concretionary ironstone and bentonitic beds; marine
Kbz	BRAZEAU FORMATION (Central and Northern Foothills): greenish-grey, thick-bedded, chloritic and feldspathic sandstone and blocky grey mudstone; some tuff and thin coal beds; nonmarine
KB-S	BELLY RIVER-ST. MARY RIVER SUCCESSION (Southern Foothills): includes Belly River Group and Bearpaw, Blood Reserve and St. Mary River formations (stratigraphic equivalents of Brazeau Formation)
Ko	OLDMAN FORMATION: pale-grey, thick-bedded, medium to coarse-grained, feldspathic sandstone; grey clayey siltstone; green and grey mudstone; dark grey and brown carbonaceous shale; ironstone concretionary beds; nonmarine
Kfm	FOREMOST FORMATION: pale-grey feldspathic sandstone, grey and green siltstone; greenish-grey mudstone and dark-grey carbonaceous shale; concretionary ironstone beds; thin coal beds; nonmarine
Kpa	PAKOWKI FORMATION: dark-grey shale and silty shale; minor sandstone; thin chert-pebble conglomerate or pebble bed at base; marine
KA	ALBERTA GROUP (Rocky Mountains and Foothills): dark-grey, fissile, silty shale; some thin-bedded, fine to medium-grained, cherty sandstone (Blackstone Formation); thick-bedded, well-sorted, quartzose sandstone; dark-grey shale and carbonaceous shale; siltstone and thin coal beds (Cardium Formation); dark-grey fissile shale and siltstone; thin-bedded, fine-grained, glauconitic sandstone; thin beds of concretionary ironstone (Wapiabi Formation). NOTE: North of Athabasca River, areas designated as KA include Smoky Group, and Dunvegan and Shaftesbury formations (stratigraphic equivalents of Alberta Group)
Kmr	MILK RIVER FORMATION: pale-grey, thick-bedded, feldspathic sandstone with hard calcareous beds; pale to dark-grey shale and silty shale; ironstone concretions; marine and nonmarine
Pzu	UPPER PALEOZOIC (Rocky Mountains and Foothills): grey argillaceous limestone and dolomite, in part cherty and stromatoporoidal, in part coarsely biostromal; black nodular and calcareous shale; grey to brown aphanitic to finely crystalline limestone, dolomite-mottled limestone, and dolomite; black bituminous shale (Upper Devonian); dark-grey fissile shale, siltstone, argillaceous limestone and cherty limestone; medium to coarse-grained crinoidal limestone, cherty and dolomitic limestone; dolomite, cherty dolomite, anhydrite, red shale and sandstone (Mississippian); thin and thick-bedded quartzose sandstone, phosphatic quartzose siltstone, silty and cherty dolomite, chert and cherty carbonate (Pennsylvanian-Permian)
Pzl	LOWER PALEOZOIC (Rocky Mountains and Foothills): thick-bedded, grey, pink and purple quartzite and quartzose sandstone, with shale and limestone lenses (Lower Cambrian Gog Group); pale-grey thick-bedded dolomiite and limestone; dark-grey, fine-grained, thick to thin-bedded limestone and dolomite; maroon, buff and green, calcareous and siliceous shales; local intraformational conglomerates (Middle and Upper Cambrian); grey to grey-green limestone, shaly limestone and shale, local intraformational conglomerate; pale-grey to pale-brown, medium-bedded, siliceous dolomite; clean, white quartzite (Ordovician); pale-grey and yellowish-grey, medium-bedded, fine-grained dolomite (Silurian)
HE	PURCELL SUPERGROUP (Rocky Mountains and Foothills): varicolored laminated and stromatolitic limestone and dolomite; conglomerate with quartzite and dolomite pebbles (Waterton and Altyn formations); red and green argillite and quartzite, channel-filled and ripple-marked (Appekunny and Grinnell Formations); dark-grey limestone and dolomite, stromatolitic and oolitic, interbedded with dolomitic and calcareous shale and siltstone (Siyeh Formation); dark-green to purple amygdaloidal basalt (Purcell Formation); argillaceous and silty dolomite; green, grey, purple and red argillite and quartzite (Kintla Formation)



BASEMAP LEGEND

- Urban centres
- Paved road - undivided
- Paved road - divided
- International boundary
- Provincial and territorial boundaries
- Indian reserve
- UTM grid Zone 12 — 500000m. E

Appendix 6. 2006 Study Area, Mineral Claims and Bedrock Geology Southern Alberta Uranium Project (NTS 72E,L,M; 82G,H,I,J,O,P)

T. Matveeva and S. Anderson, 2007

Earth Sciences Report 2007-10

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