ERCB/AGS Open File Report 2009-12

Sandstone-Hosted Uranium in Southern Alberta: 2007 and 2008 Study Results

Energy Resources Conservation Board

Alberta Geological Survey

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Sandstone-Hosted Uranium in Southern Alberta: 2007 and 2008 Study Results

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Contents

Tables

Figures

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A.T. Lytviak created and customized the software that allowed us to query hundreds of thousands of well logs to identify anomalous values.

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Abstract

Alberta Geological Survey completed field programs in June 2007 and October 2008 near Cardston, Taber and Fort McLeod. We described outcrops of Upper Cretaceous and Tertiary formations in the field, took radioactivity measurements onsite, and collected 122 samples for determination of multiple elements. Representative thin sections were prepared and detailed petrographic descriptions, including point counts, were made. We conducted a radiometric survey along the St. Mary, Waterton and Oldman rivers. The most notable result of the 2007 and 2008 field programs was the discovery of a new radioactive occurrence, consisting of anomalous uranium content (158 ppm) in the siltstones of the Willow Creek Formation along the Oldman River.

An automated evaluation of tens of thousands of digital logs from oil and gas wells, and subsequent detailed analysis of 1800 well logs, outlined areas for future assessment. We selected anomalous gamma-ray intervals in the upper 550 m for determination of rock type and formation. Eighty-two per cent of the high-gamma intervals occur within shaly units with a high organic content (e.g., Base of Fish Scales and Second White Specks formations). Clusters of wells with high gamma readings in sandstone occur in NTS areas 82O, 83G, 84D and 83O. In the Claresholm area, multiple wells with high gamma readings in sandstones of the Willow Creek and St. Mary River formations occur within the upper 500 m.
Testing drill cuttings from oil and gas wells that cover radioactive intervals was unable to confirm the source rocks for the radioactive anomalies but provided insight into the rock types of these intervals.

1 Introduction

This report contains information obtained during studies of the uranium potential of southern Alberta during 2007 and 2008. A preliminary assessment provided in Matveeva and Anderson (2007) recommended expanding three aspects of the uranium-potential studies:

- outcrop studies
- analysis of gamma ray logs, lithologs and cuttings from oil and gas wells
- evaluation of regional geochemical and airborne surveys

Based on these recommendations, Alberta Geological Survey staff conducted outcrop studies in June 2007 and October 2008. Staff also collected lithological data and described alteration patterns related to uranium potential from prospective geological formations, and searched for new radioactive anomalies. In addition, we prepared thin sections from representative samples. Detailed petrographic descriptions are in Stepic and Matveeva (2009).

We identified radioactive anomalies from oil and gas digital geophysical logs using software developed in-house by Alberta Geological Survey. Digital well-log data covering the entire province were queried to generate a dataset containing anomalous gamma readings to a depth of 500 m. Due to the high number of wells thus identified, only selected wells were checked to determine the rock type and formation name of the anomalous interval. We studied cuttings from eight wells at the ERCB Core Research Facility in Calgary to determine the feasibility of using cuttings to explain the source of radioactive anomalies identified on the gamma-ray well logs. Section 3 describes the results of the database analysis and the cuttings study. The relevant datasets are in Digital Data DIG 2009-0016 (Matveeva and Kafle, 2009a), which accompanies this report.

2 Outcrop Sampling Program

An outcrop-sampling program was completed in southern Alberta during June 2007 and October 2008. A previous report (Matveeva and Anderson, 2007) describes the regional geology of the area and a deposit model. The purpose of the 2007 and 2008 field programs was to continue evaluating prospective geological formations for sandstone-hosted uranium potential by identifying favourable alteration patterns (i.e., redox fronts) in outcrop previously identified by Matveeva and Anderson (2007).

Access to outcrops was by boat along the Waterton, St. Mary and Oldman rivers, and by land where boat access was not available. We described each outcrop fully, took spectrometer readings and collected rock samples for geochemical analysis and thin-section petrography.

We conducted a background radiometric survey using a handheld SAIC® GR-135 spectrometer while boating down the rivers, with all measurements taken on board in the middle of the river. Results of the survey are presented in Figure 1 and tabulated in Digital Data DIG 2009-0017 (Matveeva and Kafle, 2009b) , which accompanies this report. The measurements reveal a high radiometric background along the Waterton and St. Mary rivers. Background measurements drop quickly from an average of about 50–60 counts per second (cps) on the outcrop to an average of 20–30 cps 10 m or more from the shore. We observed that the drop in radiometric values was larger in the middle of Oldman River compared to the St. Mary or Waterton rivers, in part because the Oldman River is much wider than the other two. Future ground radiometric surveys—both boat and car borne—must consider the distance to the bedrock outcrop when identifying regional background values and anomaly thresholds.

We collected 109 and 18 rock samples during 2007 and 2008, respectively. All samples were analyzed using inductively coupled plasma (ICP-OES) following HNO_3/HCl partial digestion and $HF/HNO_3/HClO_4$ total digestion. Uranium was also analyzed by the more sensitive fluorimetry method.

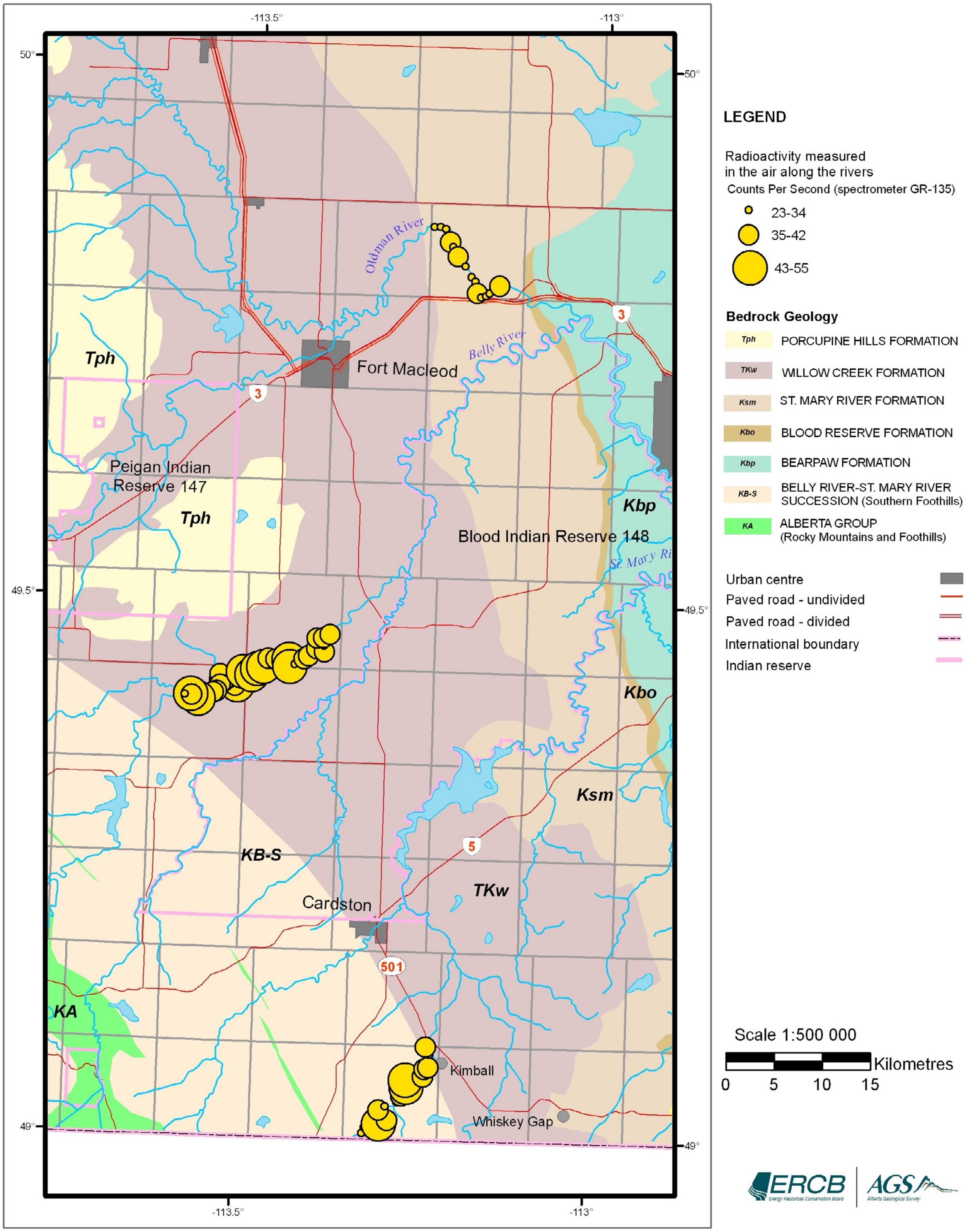


Figure 1. Results of the 2007 radiometric survey.

Samples were prepared using agate grind. The Saskatchewan Research Council Geoanalytical Laboratories carried out all analyses. The description of the analytical method is presented in Saskatchewan Research Council (2009).

Complete results for samples collected during 2006, 2007 and 2008 are in DIG 2009-0017. Figure 2 shows sample locations for 2007 and 2008. Detailed thin-section petrographic descriptions of 25 samples are in Stepic and Matveeva (2009).

2.1 Outcrop Observations

2.1.1 Foremost Formation

We collected 23 samples from the Foremost Formation, including seven samples at the contact between the Foremost and Oldman formations. All uranium (U) values were below 3 ppm (Table 1, DIG 2009-0017). Three coal seams were sampled at stop 070610_02, 03 (Table 2, DIG 2009-0017). The upper coal seam closest to the surface (sample 07USA0042) has the highest U content (2.53 ppm), whereas the underlying second and third coal seams have very low contents (samples 07USA0044 and 07USA0046 with 0.12 and 0.04 ppm U, respectively). Thus, the U concentration gradually decreases with depth below the upper coal. The same pattern was reported for coal seams in the Cypress Hills (Hage, 1968) and in many localities throughout the western United States (Denson, 1959).

2.1.2 Oldman Formation

Seven samples collected from the Oldman Formation have very low U values (less than 2 ppm; Table 1, DIG 2009-0017). One black shale sample (07USA0102) at the contact between the Oldman and Foremost Formations contains 7.5 ppm U.

2.1.3 Bearpaw Formation

Five samples were collected from the Bearpaw Formation, all of which contain <1 ppm U (Table 1, DIG 2009-0017). Samples collected along the St. Mary River are from the Bearpaw Formation, based on the geology map of Lebel and Williams (1994).

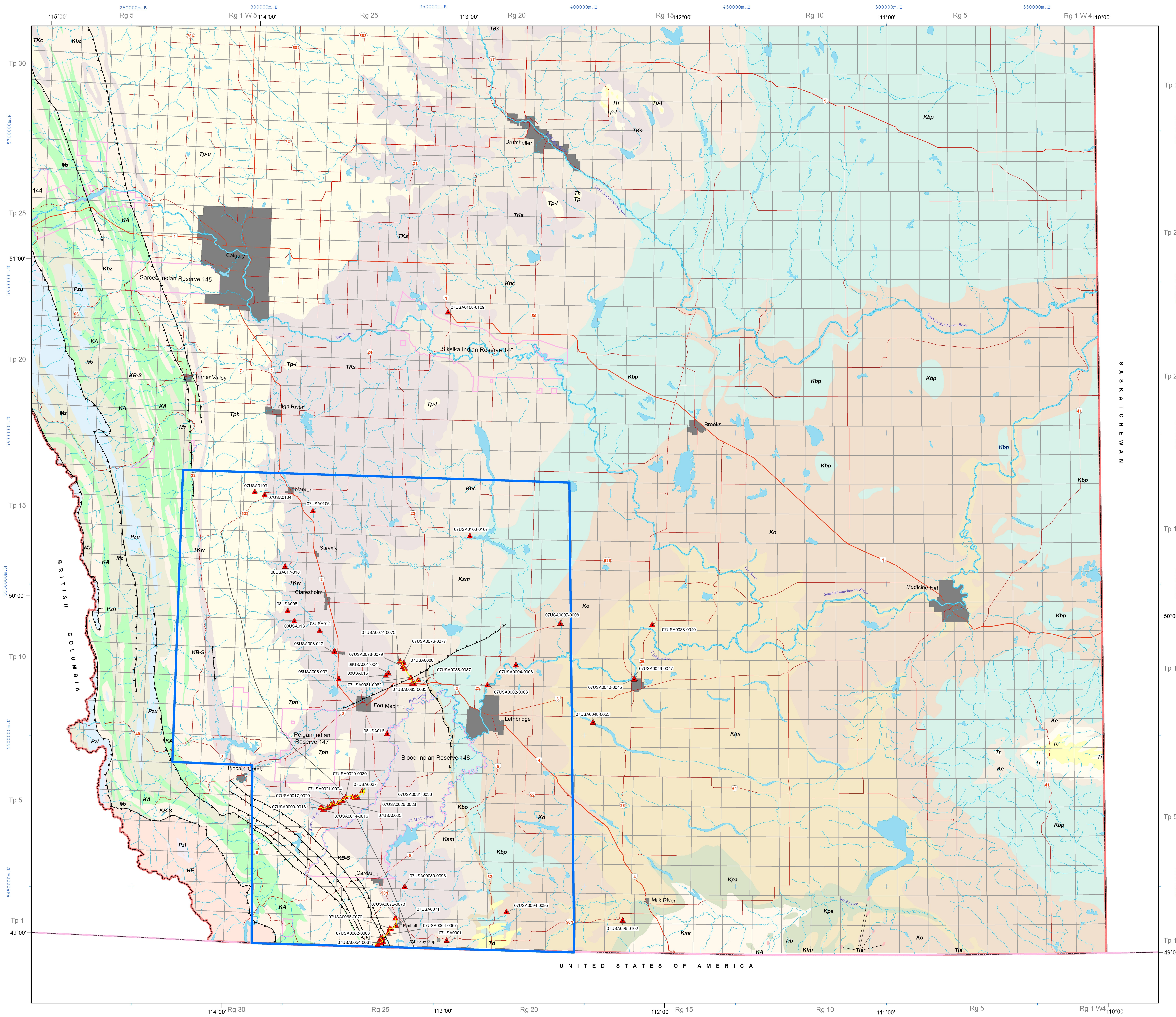
2.1.4 St. Mary River Formation

Three samples of shale from the St. Mary River Formation had elevated U values. Organic-rich shale at the Kimball occurrence (described in Matveeva and Anderson 2007; sample 07USA0071) on St. Mary River contains 27 ppm U and registers 630 cps on the GR-135 spectrometer—the highest reading observed during the 2007 season. Shale samples 07USA0082 and 07USA0085, taken on the Oldman River, contain 13 and 8 ppm U, respectively. A sandstone sample from the banks of the St. Mary River (07USA0069) contains 4.79 ppm U; other sandstone samples contain less than 1 ppm U. For complete results, see Table 1 and DIG 2009-0017.

2.1.5 Willow Creek Formation

We collected 53 samples from the Willow Creek Formation. This formation is of particular interest because the highest U values in southern Alberta (3810 ppm U) were reported from fossilized bone material found in the mudstones of the Willow Creek Formation on the Waterton River (Matveeva and Anderson, 2007). During 2008, we discovered a uranium occurrence in the siltstones of the Willow Creek Formation along the south bank of the Oldman River, northeast of Fort McLeod.

The Oldman radioactive occurrence was discovered during a traverse along an extensive outcrop. Spectrometer readings of over 400 CPS at the surface increased to 1000 CPS at a depth of about 50 cm (Figure 3). The radioactive layer is less than 1 m thick and continues for approximately 3 m along strike (Figure 4). The anomaly occurs within a light grey to whitish siltstone bed (Figure 5). We observed no



Scale: 1: 500 000

Projection: UTM Zone 12
Datum: NAD1983

LEGEND

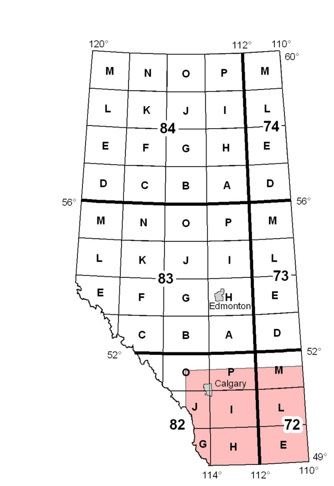
Area covered in oil and gas gamma ray log interpretation in Earth Sciences Report 2007-10

SYMBOL LEGEND

- 2007/2008 rock sample — 08USA017
- Radiometric survey boat route
- Alberta syncline axis
- Fault

Bedrock Geology

Unit	Description
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 coalbeds (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): varicoloured, 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

Figure 2. Locations of study area and samples taken in 2007 and 2008. Southern Alberta Uranium Project (NTS 72E, L, M; 82G, H, I, J, O, P)

T. Matveeva and B. Kafle, 2009

Open File Report 2009-12

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Table 1. Locations, descriptions and summary of analytical results for samples taken during the 2007 and 2008 outcrop sampling program.

Sample No.	UTM Location[1]		Description	Formation	Radio-activity (cps)[2]	U (ppm)	Th (ppm)	K_2O (%)	As (ppm)	Cu (ppm)	Zn (ppm)	Co (ppm)	V (ppm)	CaO (%)
	Easting	Northing												
07USA0001	354387	5432219	Thick, competent, greenish grey, massive, medium-grained sandstone; fizzy calcite cement	St. Mary River	155	0.63	6	1.98	5.6	8.1	32	8	56	3.77
07USA0002	367920	5516786	Reddish orange, burnt shale	Bearpaw	0	0.31	7	2.56	1	17.8	1.2	25	215	0.71
07USA0003	367920	5516786	Black shale (inside clinker)	Bearpaw	220	0.8	6	1.93	2.5	55.4	1.2	16	188	0.86
07USA0004	377298	5523329	3 m thick, massive, very competent, not fizzy, medium-grained sandstone with shale interbedding and rusty root prints visible (80–85 cps on SPP2 scintillometer), and some weak limonite staining in cracks	Oldman	0	1.02	4	1.84	8.9	4.8	27	5	40	11.7
07USA0005	377298	5523329	Very light greenish grey, friable siltstone	Oldman	0	1.03	6	2.86	3.5	23.2	58.1	10	88	8.8
07USA0006	377222	5523340	Friable, medium- to thick-bedded, 2–3 m thick, muscovite- and organic-rich sandstone	Oldman	0	1.67	4	2.46	9	15.5	67.4	10	89	5.31
07USA0007	391999	5537150	1 m thick, rusty, competent, fine-grained, light orange sandstone with calcite cemen	Oldman	90	0.42	5	1.62	4.3	9.7	15.6	5	36	34
07USA0008	391999	5537150	Bentonitic clay siltstone	Oldman	200	0.95	7	3.01	2.4	23.5	58.6	8	79	8.43
07USA0009	312601	5476086	3 m thick, massive, semicompetent, dark greenish grey, somewhat fizzy, medium-grained sandstone with rusty bands in cracks	Willow Creek	0	0.79	3	0.856	6.1	4.6	37	5	58	5.29
07USA0010	313063	5476143	Massive, dark grey with black bands, friable, medium-grained sandstone	Willow Creek	110	1.52	4	1.1	16.7	9.8	43.5	7	68	4.8
07USA0011	313063	5476143	Rusty, organic-rich (black bands) sandstone bed, 10–15 cm thick	Willow Creek	130	5.61	3	1.09	73.7	11	40.7	7	68	4.49
07USA0012	313063	5476143	Light greyish yellow (altered?), medium-grained friable sandstone	Willow Creek	95	1.71	3	0.702	7.9	3.8	31.9	5	53	6.01
07USA0013	313063	5476143	Coarse-grained, organic-rich bed (~20 cm thick) in the upper weathered sandstone channel on north side of river	Willow Creek	95	2.11	2	0.514	18.2	4.7	27.8	3	46	6.92
07USA0014	313533	5475637	1.5–2 m thick, fine-grained, light grey-brown, massive, competent sandstone	Willow Creek	110	0.99	4	1.51	2.1	10.8	49.7	6	76	12.3
07USA0015	313741	5475543	Light yellowish grey, blocky shale with limonite staining along fractures	Willow Creek	170	2.53	6	2.09	2.6	26.6	88.7	9	121	6.84
07USA0016	313741	5475543	Light grey-yellow, medium-grained, massive, consolidated sandstone; calcite cement with some gravelite beds (weakly fizzy)	Willow Creek	120	1.39	4	0.511	16.9	3.8	46.3	6	52	6.65
07USA0017	314937	5476193	2 m thick, greenish grey, massive, medium- to fine-grained, competent sandstone with calcite cement	Willow Creek	100	0.65	3	0.63	2	6.9	33.1	4	54	5.06
07USA0018	315707	5476368	Bright pink-purple, crumbly shale (~1 m thick)	Willow Creek	130	0.59	8	3	3.3	12.4	54.6	10	163	1.04
07USA0019	315707	5476368	Light greenish grey, crumbly shale	Willow Creek	100	0.5	4	1.22	0.6	6.5	30.8	4	69	0.75
07USA0020	315707	5476368	Black shale (bands)	Willow Creek	125	2.8	10	1.97	0.9	59.4	76.2	11	112	1.08
07USA0021	316068	5477096	1.5 m thick, fine-grained, consolidated grey sandstone bed	Willow Creek	70	0.54	4	0.885	1.1	8.8	42.9	5	66	5.86
07USA0022	316327	5477325	Very light yellowish grey, massive, calcite-cemented sandstone	Willow Creek	80	0.46	4	0.837	2.8	5.3	36.5	5	59	6.1
07USA0023	316951	5477551	1 m thick, organic-rich, rusty sandstone layer	Willow Creek	180	7	2	0.717	510	9.4	34	5	65	3.34
07USA0024	316951	5477551	5 m thick, fine- to medium-grained, massive, light yellowish grey sandstone with calcite cement	Willow Creek	135	2.33	3	0.81	7.6	3.7	31.4	5	51	6.73
07USA0025	318504	5477784	8 m thick, light grey, fine- medium-grained sandstone with calcite cement and layers of organic material	Willow Creek	145	2.92	3	0.766	141	9.1	41.1	6	60	9.98

Sample No.	UTM Location[1] Easting	Northing	Description	Formation	Radio-activity (cps)[2]	U (ppm)	Th (ppm)	K_2O (%)	As (ppm)	Cu (ppm)	Zn (ppm)	Co (ppm)	V (ppm)	CaO (%)
07USA0026	319798	5478374	~2.5 m thick, dark grey shale	Willow Creek	55	0.86	7	1.85	0.9	16.1	38.9	8	82	2.02
07USA0027	319917	5478626	Black organic- or mud-patched sandstone; possible plant prints	Willow Creek	230	16.2	6	2.14	311	27.1	47.3	9	190	0.76
07USA0028	319917	5478626	~3 m thick, very light grey, fine-grained, massive sandstone with calcite cement	Willow Creek	160	3.71	4	0.708	5.2	5.2	34.8	6	58	11.6
07USA0029	320968	5479675	Black crumbly shale (first dark layer beneath the till)	Willow Creek	130	2.02	8	3.01	1.3	35.2	46.7	10	146	1.44
07USA0030	320968	5479675	Very light grey sandstone, with massive bottom (~6 m), friable top (3 m) and bands of organic material	Willow Creek	212	5.66	3	0.778	14.8	5.7	38.8	14	56	9.48
07USA0032	324074	5479526	~1 m thick, red, fine-grained, massive sandstone bed with calcite cement	Willow Creek	90	0.47	3	1.3	3.2	4.5	32.3	5	56	15.6
07USA0033	324024	5479520	Crumbly black shale bed immediately below 1 m thick sandstone bed (possible hematization in shale?)	Willow Creek	160	4.64	7	2.83	4	30.7	41.6	9	137	0.92
07USA0034	324241	5479457	Black shale	Willow Creek	145	1.86	8	2.77	3.6	23.3	24.9	8	145	0.98
07USA0035	324241	5479457	2.5 m thick, massive, light grey, fine-grained sandstone; friable with greenish surface and calcite cement	Willow Creek	85	0.61	4	1.14	2.2	6.9	34.5	7	65	6.42
07USA0036	324831	5479617	8–10 m thick, massive, light yellowish grey, medium-grained sandstone with calcite cement, organic-rich bands and evident trough-crossbedding	Willow Creek	110	1.3	3	1.51	2	6.7	38.4	8	64	13.7
07USA0037	326442	5481710	Thin (~50 cm), grey fine- to medium-grained, friable sandstone with calcite cement	Willow Creek	70	0.5	3	0.764	0.7	2.8	27.2	5	55	6.78
07USA0038	422385	5536659	Very friable, medium-grained, grey sandstone with brown limonite staining; weakly fizzy	Foremost	95	0.65	3	1.85	3.3	11.5	62.8	11	104	1.62
07USA0039	422385	5536659	More competent, grey, medium-grained sandstone bed (~35 cm thick) with calcite cement	Foremost	85	0.39	3	1.66	5.7	8.1	33	7	69	9.78
07USA0040	422385	5536659	Brown ironstone concretions	Foremost	90	2.96	3	0.753	5.3	14.3	48.9	16	197	1.47
07USA0042	416468	5518889	~70 cm thick coal bed	Foremost	140	2.53	6	1.94	10.8	58.7	81.4	11	231	0.64
07USA0043	416468	5518889	Grey-brown crumbly siltstone with beds of ironstone concretions below coal	Foremost	80	0.57	4	1.66	3.1	14.2	52.5	16	90	4.48
07USA0044	416468	5518889	Good-quality, black blocky coal	Foremost	45	0.12	1	0.028	4.4	6.8	3.2	4	19	0.6
07USA0045	416468	5518889	Organic-rich, black mud/siltstone below coal	Foremost	100	0.95	7	1.8	3.3	28.6	74.5	6	123	0.33
07USA0046	416332	5518618	1.5 m thick coal seam	Foremost	80	0.04	1	0.083	5.2	6.3	7.9	3	21	0.47
07USA0047	416332	5518618	Black mudstone below coal	Foremost	130	0.54	6	1.73	33.3	22.2	46.7	6	131	0.62
07USA0048	402797	5504380	2–3 m thick, massive, very competent (hoodoo forming), dark yellow-brown, medium-grained sandstone bed with calcite cement	Foremost	80	0.52	2	1.55	4.7	6.3	31	8	80	0.6
07USA0049	402797	5504380	Very light yellowish grey shale/mudstone	Foremost	145	0.88	6	2.2	4	6.4	27.6	7	43	6.24
07USA0050	402797	5504380	Dark purplish grey shale with rusty film on fractures (slaty)	Foremost	165	1.81	10	3.02	5.6	16.4	59.2	6	102	0.51
07USA0051	402797	5504380	Very light grey (almost white) shale	Foremost	165	0.88	8	2.76	3.8	18.6	54.9	7	76	6.51
07USA0052	402797	5504380	Greenish grey shale	Foremost	180	0.9	7	2.58	3.2	16.4	49	5	73	6.93
07USA0053	402797	5504380	Dark grey-black shale	Foremost	210	2.98	9	3.06	10.6	26.7	76.4	23	114	1.4
07USA0054	331506	5430935	Greenish purple, crumbly shale with beds dipping at 30° (Lundbreck Formation)	Belly River	160	0.33	8	3.02	1.8	12	14.3	7	81	6.41
07USA0055	332197	5431478	Greenish shale below sandstone (Connelly Creek Formation)	Belly River	130	0.68	8	3.37	0.9	24.5	91.4	7	110	1.34
07USA0056	332197	5431478	Rusty concretions with black organic core (Connelly Creek Formation)	Belly River	160	0.57	5	1.28	126	7.4	50	7	111	2.74

Sample No.	UTM Location[1] Easting	Northing	Description	Formation	Radio-activity (cps)[2]	U (ppm)	Th (ppm)	K_2O (%)	As (ppm)	Cu (ppm)	Zn (ppm)	Co (ppm)	V (ppm)	CaO (%)
07USA0057	332197	5431478	Grey, medium-grained, consolidated, massive sandstone with weak calcite cement (Connelly Creek Formation)	Belly River	130	0.39	5	1.07	7.2	3.4	45.4	6	61	9.47
07USA0058	332505	5431382	Medium-grained, light grey sandstone with ironstone concretions occuring in lower section; weakly fizzy (Connelly Creek Formation)	Belly River	120	0.26	4	0.761	7.5	2.3	44.8	8	52	6.22
07USA0059	332505	5431382	Fine-grained, dark grey, massive slate, with calcite cement below concretions (Connelly Creek Formation)	Belly River	140	0.83	6	1.83	1.2	16.3	92.6	9	71	10.6
07USA0060	333344	5431794	Limestone with ~20 cm thick shell bed	Bearpaw	80	0.33	2	0.254	10	2.7	5.9	3	12	45.8
07USA0061	333344	5431794	Brown-grey limestone	Bearpaw	80	0.37	2	0.251	5.4	1.9	3.3	1	10	46.8
07USA0062	332484	5432857	Massive, grey, fine-grained sandstone with thin (2 cm) layer of coal, surrounded by rusty zone (Connelly Creek Formation)	Belly River	90	0.55	4	1.38	5.3	3.2	30.2	5	54	6.84
07USA0063	333065	5433204	Black shale near water surface	Bearpaw	140	0.75	8	2.91	9	30.9	102	13	173	1.68
07USA0064	334986	5434585	Shale (Lundbreck Formation)	Belly River	155	0.74	7	2.74	9.6	50.7	118	18	167	1.78
07USA0065	334986	5434585	Coaly shale (Lundbreck Formation)	Belly River	160	1.84	8	2.88	16.3	30.2	72.6	7	131	0.43
07USA0066	334986	5434585	Sandstone (Lundbreck Formation)	Belly River	115	0.51	6	1.39	4	9.9	38.3	5	53	12.1
07USA0067	334986	5434585	Coaly, crumbly black shale; rusty with sulphur (Lundbreck Formation)	Belly River	240	3.48	9	2.99	19.3	23.2	73.6	7	131	1.04
07USA0068	335532	5436172	Green siltstone with white calcite film on outcrop	St. Mary River	115	0.41	5	1.69	4.6	4.9	33.2	6	50	9.21
07USA0069	335965	5436059	Greenish grey, fine-grained sandstone with calcite cement	St. Mary River	150	4.79	9	3.75	5.6	16	28	8	69	0.79
07USA0070	335965	5436059	Dark grey-black crumbly shale	St. Mary River	250	0.61	9	2.76	1.3	23.4	52.8	9	67	4.59
07USA0071	337555	5437218	Kimball occurrence: black shale below sandstone	St. Mary River	630	27.1	11	3.97	106	15.8	52.2	7	64	0.39
07USA0072	337393	5439581	Red shale below sandstone	Willow Creek	145	1.14	9	3.98	4.6	19.5	61.9	11	107	4.16
07USA0073	337393	5439581	Friable grey-green sandstone	Willow Creek	105	0.44	6	1.65	0.9	5.3	26.3	5	52	5.17
07USA0074	338928	5524612	Greenish grey-black shale with calcite cement (fizzy) and light brown weathering surfaces	St. Mary River	220	1.4	11	4.24	3	30	76.9	17	103	6.49
07USA0075	338928	5524612	Light greenish grey, fine-grained, competent sandstone with calcite cement (fizzy)	St. Mary River	130	0.94	7	1.96	8.2	13.6	32.1	5	46	10.8
07USA0076	340144	5524075	Very dark grey shale with brown on fractures and calcite film (fizzy)	St. Mary River	210	1.17	10	3.67	7	22.9	62.6	8	85	4.3
07USA0077	340144	5524075	Very competent, dark brownish grey sandstone; fizzy	St. Mary River	130	0.61	5	2.13	6.4	4.9	25.9	5	46	13
07USA0078	339994	5522913	Fine- to medium-grained, grey-green, consolidated micaceous sandstone	St. Mary River	150	0.81	8	3.34	3.2	22.3	62.6	8	80	5.36
07USA0079	339994	5522913	1 m thick, greenish, consolidated shale with ironstone concretions	St. Mary River	180	0.8	7	2.63	2.4	15.4	43.6	11	58	4.56
07USA0080	340544	5522175	Massive, greenish grey-brown, fine-grained sandstone with crossbedding and trough-crossbedding; weakly fizzy	St. Mary River	130	0.86	6	2.33	4.2	5.8	37.3	5	64	4.66
07USA0081	342495	5519092	2 m thick, massive, light yellowish-grey sandstone; very weakly fizzy	St. Mary River	130	0.94	6	2.49	12.5	7.6	37.9	6	59	5.09
07USA0082	342495	5519092	Black and brown clay-like shale	St. Mary River	210	13	11	2.15	27.8	30.6	68.6	6	67	1.35
07USA0083	342918	5517265	Dark grey, crumbly shale	St. Mary River	200	1.26	9	3.65	10.6	20.7	62.5	11	93	0.68
07USA0084	342918	5517265	Very fine grained, light grey-brown, consolidated siltstone/sandstone with calcite film on outcrop (fizzy)	St. Mary River	115	0.83	7	2.11	3.1	14.6	37.2	7	51	8.57
07USA0085	343561	5517234	~1 m thick, black coaly/shaly bed with yellow staining along the middle of the bed	St. Mary River	250	8.03	8	3.06	91	25.1	69.6	7	97	0.65
07USA0086	344950	5518437	Thin layer of dark brown shaly clay	St. Mary River	160	2.12	8	3.49	19.9	26.8	90.3	12	126	4.24

Sample No.	UTM Location[1] Easting	Northing	Description	Formation	Radio-activity (cps)[2]	U (ppm)	Th (ppm)	K_2O (%)	As (ppm)	Cu (ppm)	Zn (ppm)	Co (ppm)	V (ppm)	CaO (%)
07USA0087	344950	5518437	~1.5 m thick, dark grey, fine-grained sandstone with calcite cement	St. Mary River	130	0.98	5	2.17	9	8.6	36.8	7	59	7.14
07USA0088	340399	5449934	Dark grey mudstone	Willow Creek	165	1.79	7	2.3	3.4	5.7	13.1	8	132	10.5
07USA0089	340399	5449934	Red-purple mudstone	Willow Creek	135	1.2	5	1.43	3.4	4.5	16.3	8	90	23.9
07USA0090	340399	5449934	Friable, light grey, medium-grained sandstone with calcite cement (fizzy)	Willow Creek	100	0.43	3	0.938	1.5	0.8	13.9	7	70	6.37
07USA0091	340399	5449934	30 cm thick, competent very fine grained sandstone with reddish brown-yellow staining; fizzy	Willow Creek	115	0.66	5	1.06	2.7	1.5	12.1	6	68	18.3
07USA0093	340515	5449903	Dark grey crumbly mudstone	Willow Creek	185	6.65	6	2.18	4.8	12.6	8.6	6	96	18.3
07USA0094	374173	5441694	~0.7 m thick, fine-grained sandstone with calcite cement; light yellow on weathered surface,	Oldman	105	0.66	7	1.43	3.5	7.8	37.4	5	61	13.1
07USA0095	374173	5441694	Light grey crumbly shale below sandstone	Oldman	150	0.69	7	3.28	4.3	19.4	65.9	8	108	5.1
07USA0096	412647	5438822	Fine-grained grey sandstone, bedding highlighted by darker bands with calcite cement	Oldman/Foremost	95	0.64	4	1.22	2.1	4.2	23	4	44	17.8
07USA0099	412647	5438822	~2 m thick, rusty light brown-grey crumbly shale	Oldman/Foremost	120	1.74	5	1.98	2.7	42	97.3	17	149	1.68
07USA0100	412647	5438822	20 cm thick coal- and organic-rich shale	Oldman/Foremost	120	5.54	4	1.84	16.2	33.8	24.2	8	165	1.33
07USA0101	412647	5438822	Grey crumbly shale with sand interbedding; white weathering	Oldman/Foremost	155	1.48	8	2.37	1.9	18.6	67.9	8	93	9.5
07USA0102	412647	5438822	Black, organic-rich shale at bottom of outcrop	Oldman/Foremost	175	7.48	4	1.41	41.5	37.6	55	8	138	0.34
07USA0103	290832	5580667	Massive, light grey, fine- to medium-grained sandstone with calcite cement	Porcupine Hills	90	0.59	3	0.938	10.3	4.6	34.8	5	58	8.06
07USA0104	294141	5579712	Massive, thick crossbedded sandstone; light yellow weathered surfaces, lighter yellowish grey-brown fresh surfaces	Porcupine Hills	75	0.25	2	0.583	21.5	4.1	22.4	3	45	3.19
07USA0105	310152	5574328	Dark grey mudstone	Willow Creek	140	0.3	8	2.66	2.6	17.7	63.2	13	149	0.9
07USA0106	362074	5566085	Black-brown shale	Edmonton Group	130	1.21	5	1.78	4.3	20.4	64.1	8	126	0.74
07USA0107	362074	5566085	Light grey shale with rusty limonite bands and ironstone	Edmonton Group	150	2.97	9	1.26	3.3	21.7	61	7	96	1.59
07USA0108	354846	5640116	2 m thick, dark brown shale	Battle	80	0.69	11	0.106	1.1	8	3.4	3	52	0.91
07USA0109	354846	5640116	~20 cm thick, dark grey siliceous Kneehills tuff	Kneehills Tuff	100	2.05	6	0.2	0.2	4.2	1.4	1	27	0.39
08USA001	335055	5520653	~50 cm thick, dark grey mudstone bed	Willow Creek	426	6.67	8	2.08	6	14	34	12	101	3.72
08USA002	335055	5520653	Siltstone	Willow Creek	700	158	4	1.14	2	3	1	6	52	24.4
08USA003	335055	5520653	Competent massive light grey siltstone, about 50 cm below 08USA002; rust and black film in crevasses	Willow Creek	800	79.1	5	1.18	1	3	1	4	54	21.9
08USA004	335055	5520653	Light grey massive siltstone	Willow Creek	700	106	4	1.27	2	2	1	5	52	21.5
08USA005	301757	5541329	Massive, competent, light yellowish grey, fine-grained sandstone	Porcupine Hills	0	1.17	3	1.06	4	3	1	5	43	12.2
08USA006	318677	5518758	Dark purple mudstone	Willow Creek	0	1.24	6	1.88	4	27	82	16	144	0.81
08USA007	318677	5518758	Bioturbated, dark grey mudstone	Willow Creek	0	1.09	5	1.13	4	6	1	5	60	33.8
08USA008	317181	5528004	Friable, 'salt and pepper'-coloured sandstone	Willow Creek	115	1.19	5	1.53	5	13	26	12	95	9.14
08USA009	317181	5528004	Dark grey mudstone with rust along cracks	Willow Creek	130	1.7	7	2.46	2	49	86	10	127	0.9
08USA010	317181	5528004	Reddish dark grey mudstone	Willow Creek	140	1.02	8	2.53	3	6	46	4	123	0.38
08USA011	317181	5528004	Massive, light grey sandstone; light brown weathering	Willow Creek	100	0.87	4	0.6	5	3	1	8	48	12.1

Sample No.	UTM Location[1]		Description	Formation	Radio-activity (cps)[2]	U (ppm)	Th (ppm)	K_2O (%)	As (ppm)	Cu (ppm)	Zn (ppm)	Co (ppm)	V (ppm)	CaO (%)
	Easting	Northing												
08USA012	317214	5527725	Dark-brown–weathering sandstone beds, up to 1.2 m thick, with cross-bedding, light-grey 'salt-and-pepper' on fresh surface	Willow Creek	95	1.91	4	1.58	2	14	3	7	87	14.4
08USA013	303970	5537934	Light grey friable sandstone	Willow Creek	105	1.92	5	1.09	1	8	1	6	65	9.77
08USA014	312371	5534770	Light grey sandstone with horizontal fracturing; light yellow weathering	Willow Creek	87	0.82	3	0.76	1	2	1	5	40	19.7
08USA015	334315	5519996	Dark grey mudstone	Willow Creek	340	13.8	9	3.04	1	31	32	6	150	2.97
08USA016	334671	5500663	Dark grey mudstone	Willow Creek	130	1.07	9	2.54	1	32	68	13	156	1.82
08USA017	300891	5556002	Dark grey shale	Willow Creek	163	1.42	10	2.92	1	41	120	8	173	0.81
08USA018	300891	5556002	Light grey sandstone	Willow Creek	90	1.02	6	0.52	2	8	6	3	60	7.32

[1] UTM Zone 12, NAD83

[2] determined using a GR-135 spectrometer

Table 2. Locations and descriptions of outcrops visited during the 2007 and 2008 sampling program.

Stop No.	UTM Location[1]		Description	Formation
	Easting	Northing		
070606_01	354387	5432219	Competent, greenish grey, massive, medium-grained sandstone bed (~ 3 m thick); fizzy (calcite cement)	St. Mary River/Willow Creek
070607_01	367920	5516786	Burnt shale and coal beds in steep banks; thick, light brown till (>50 m thick) with well-sorted gravel beds on top	Bearpaw
070607_02	377298	5523329	Interlayered sandstone bodies (3 m thick) and shale/siltstone beds (1–3 m thick) with light brown till (>20 m thick) on top; sandstone is massive, medium grained and non-fizzy	Oldman
070607_03	377222	5523340	Friable, moderately thick bedded, fine-grained sandstone with muscovite and organics (2–3 m thick)	Oldman
070607_04	391999	5537150	Rusty, competent sandstone bed with calcite cement (~1 m thick) above bentonitic clay siltstone	Oldman
070608_01	312601	5476086	3 m thick, massive, semicompetent, dark greenish grey, medium-grained sandstone with weak fizzing and rusty bands in fractures, south shore of river	Willow Creek
070608_02	312360	5476249	Greenish grey sandstone channel (~2 m thick) with rusty spotting on surface	Willow Creek
070608_03	313063	5476143	Massive, greenish grey sandstone body; thick trough-crossbeds, alteration along top of body, limonite staining in fractures; beds rich in organics and log prints	Willow Creek
070608_04	313533	5475637	3 m thick, massive grey sandstone channel with 20 m thick mudstone above	Willow Creek
070608_05	313653	5475537	1.5–2 m thick, fine-grained, light grey-brown, massive, competent sandstone	Willow Creek
070608_06	313741	5475543	Contact between upper light grey-yellow, medium-grained massive sandstone (fizzy) and light yellowish grey blocky shale with limonite staining along fractures	Willow Creek
070608_07	314937	5476193	~2 m thick, greenish grey, massive, medium- to fine-grained, competent sandstone (~ 25 m wide); fizzy	Willow Creek
070608_08	315707	5476368	Contact between bright pink-purple, crumbly shale (1 m thick) and light greeenish grey, crumbly shale and bands of black shale (~30 cm thick), south shore of river	Willow Creek
070608_09	316068	5477096	1.5 m thick, fine-grained, consolidated, grey sandstone bed	Willow Creek
070608_10	316511	5477254	~3 m thick grey sandstone	Willow Creek
070608_11	316327	5477325	~4 m thick, friable, very light grey, massive sandstone with calcite cement and horizontal fractures with limonite staining	Willow Creek
070608_12	316951	5477551	Massive, light yellowish grey sandstone with calcite cement, interbedded with organic-rich rusty layers and organic bands, north shore of river; ~5m thick sandstone channel	Willow Creek
070608_13	318410	5477381	2.5 m thick, 30 m wide sandstone channel	Willow Creek
070608_14	318504	5477784	~8 m thick, light grey, fine- to medium-grained sandstone channel with calcite cement and organic-rich layers; also contains large limonite nodules; calcite+ankerite (?) along fractures	Willow Creek
070609_01	319798	5478374	Dark grey shale below sandstone (~2.5 m thick)	Willow Creek
070609_02	319917	5478626	Very light grey, fine grained, massive sandstone with black, muddy, possibly plant prints and calcite cement	Willow Creek
070609_03	320968	5479675	Black crumbly shale (first dark layer below the till); light grey sandstone channel (~ 6 m thick), massive at the bottom and friable in upper 3 m, interbedded with organic-rich layers and black shales; weak limonite staining	Willow Creek
070609_04	323275	5479644	White calcite concretions in mudstones	Willow Creek
070609_05	324074	5479526	~1 m thick, red, fine-grained, massive sandstone bed with calcite cement	Willow Creek
070609_06	324024	5479520	Crumbly black shale bed immediately below a 1 m thick sandstone bed (reddish hematite in shale bed?)	Willow Creek
070609_07	324241	5479457	2.5 m thick, massive, friable, light grey, fine-grained sandstone channel with calcite cement overlying shale beds; little limonite staining on surface, greenish on fresh surface	Willow Creek
070609_08	324831	5479617	8–10 m thick sandstone: lower part (2 m) is light grey and upper part is light grey yellowish with limonite staining in fractures, massive, medium-grained sandstone with calcite cement, trough-crossbedding and organic-rich bands up to 2 mm thick	Willow Creek
070609_09	326442	5481710	Thin (~50 cm), grey, friable, fizzy, fine- to medium-grained.sandstone bed	Willow Creek

Stop No.	UTM Location[1]		Description	Formation
	Easting	Northing		
070610_01	422385	5536659	Light grey to brown, medium-grained sandstone with calcite cement and ironstone concretions, ranging rom friable at the top to competent at the bottom	Foremost
070610_02	416468	5518889	Interbedded coal, organic-rich layers and siltstones; siltstones are light grey and contain small ironstone concretions; 30 cm thick bed of Coquina shell above upper coal seam	Foremost
070610_03	416332	5518618	1.5 m thick coal seam with black mudstone below	Foremost
070610_04	402797	5504380	Dark yellow-brown, hoodoo forming, competent, medium-grained sandstone with calcite cement and interbedded from white, purple, grey and black shales	Foremost
070611_01	331506	5430935	Greenish purple crumbly shale, beds dipping at 30°	Belly River
070611_02	332197	5431478	Massive, light yellowish grey sandstone (5 m thick, oriented 350°/20°W) with shale beds above; sandstone has good trough-crossbeds and contains ironstone concretions	Belly River
070611_03	332505	5431382	Medium-grained, light grey sandstone with iron-calcite concretions below the bed; sandstone is slightly fizzy	Belly River
070611_04	333344	5431794	Brown-grey limestone body with shell bed	Bearpaw
070611_05	332484	5432857	3 m thick channel of massive, grey, fine grained sandstone with thin coal interbed; massive calcite infilling fractures	Belly River
070611_06	333065	5433204	Black shale, right bank of river	Bearpaw
070611_07	334986	5434585	Shale, coaly shale and sandstone; shale is crumbly black and rusty with some sulphur(?) staining	Belly River
070611_08	335532	5436172	Green siltstone with white calcite film on the outcrops	St. Mary River
070611_09	335965	5436059	Interbedded grey, fine-grained sandstone with calcite cement (0.5–1 m thick) and dark grey to grey, crumbly shale (0.5–1 m thick)	St. Mary River
070611_10	337555	5437218	Kimball occurrence: radioactive black shale below sandstone	St. Mary River
070611_11	337393	5439581	Red shale below grey-green friable sandstone body	Willow Creek
070612_01	338928	5524612	Interbedded fine-grained, competent, grey sandstone (0.5–2.5 m thick) and dark grey-brown shale (0.5–1.5 m thick); shale beds have ironstone concretions	St. Mary River
070612_02	340144	5524075	Interbedded grey sandstone (0.5–3 m thick) and light grey to dark grey shale; calcite film on rocks makes them looked bleached from a distance	St. Mary River
070612_03	339994	5522913	Thick (~2.5 m), massive, fine- to medium-grained, grey-green sandstone underlain by 1 m thick shale with ironstone concretions	St. Mary River
070612_04	340544	5522175	Massive, thick (5 m), light greenish grey-brown, fine-grained sandstone (weakly fizzy) with crossbedding and trough-crossbedding, and limonite on fractures	St. Mary River
070612_05	342495	5519092	2 m thick, massive, light yellowish grey sandstone (weakly fizzy) overlying black to brown clay-like shale	St. Mary River
070612_06	342918	5517265	Dark grey, crumbly shale above a very fine grained, light grey-brown, consolidated siltstone/sandstone (fizzy)	St. Mary River
070612_07	343561	5517234	Thrust zone: thick, massive sandstone body thrusted over thinly interbedded sandstone and grey shale, dip ~20°; black coal-like shale (0.5–1 m thick) located below thick sandstone unit	St. Mary River
070612_08	344950	5518437	Thin layer of dark brown shale-like clay overlying dark grey, fine-grained sandstone with calcite cement; till is ~1.5m thick at this stop	St. Mary River
070613_01	340399	5449934	Interlayered dark-grey, purple, purple-orange and light grey mudstone with white caliche concretions and layers of pure calcite (~2 mm thick); friable sandstone beds up to 30cm thick	Willow Creek
070613_02	340515	5449903	Dark grey crumbly mudstone	Willow Creek
070613_03	374173	5441694	Light yellow, fine-grained sandstone bed (0.7 m thick) with calcite cement overlying light grey crumbly shale	Oldman
070613_04	412647	5438822	Fine-grained grey sandstone with calcite cement located above shale layers with colour ranging from light brown-grey to black; some shale layers are organic rich, whereas others contain ironstone concretions with shells	Oldman/Foremost
070614_01	290832	5580667	7 m thick, massive, light grey, fine- to medium-grained sandstone with calcite cement	Porcupine Hills
070614_02	294141	5579712	Massive, thick, yellowish grey-brown, crossbeddded sandstone >4m thick	Porcupine Hills
070614_03	310152	5574328	Dark to light grey mudstone	Willow Creek

Stop No.	UTM Location[1]		Description	Formation
	Easting	Northing		
070615_01	362074	5566085	Black-brown to light grey shale with rusty staining and limonite bands	Edmonton Group
070615_02	354846	5640116	Battle Formation: dark brown, 2 m thick shale and 20 cm thick, dark grey, siliceous Kneehills tuff	Battle/Kneehills Tuff
081015_01	333686	5520589	Willow Creek beds across the Oldman River, near Riverside Bed & Breakfas	Willow Creek
081015_02	335055	5520653	Dark grey and reddish brown mudstone with thin interbeds of light grey sandstone; up to 1072 cps spectrometer count on sandstone bed (0.5 m thick, >2 m along strike); no reason for anomaly discovered	Willow Creek
081015_03	334230	5519900	Light grey siltstone	Willow Creek
081015_04	335770	5521325	Mudstones, purple and grey	Willow Creek
081016_01	301757	5541329	Massive, competent, light grey-yellowish finegrained sandstone	Porcupine Hills
081016_02	318677	5518758	Dark grey and dark purple mudstones	Willow Creek
081016_03	317181	5528004	Interbedded sandstone and mudstone	Willow Creek
081016_04	317214	5527725	Layered dark brown–weathering sandstone beds, up to 1.2 m thick, with crossbedding, lith-grey 'salt-and-pepper' on fresh surface	Willow Creek
081016_05	303970	5537934	Light grey friable sandstone, interbedded with siltstone	Willow Creek
081016_06	312371	5534770	Flat outcrop in the riverbed of light grey sandstone with horizontal fracturing, light yellow weathering surface and carbonate cement	Willow Creek
081017_01	334278	5520112	Interlayered light grey, red and dark grey mudstones; till thickness ~3 m	Willow Creek
081017_02	334315	5519996	Dark grey mudstone layers, thin (<1 m), friable, 'salt-and-pepper', very light grey sandstone bed	Willow Creek
081017_03	334424	5519862	Light grey and light red mudstones with abundant gypsum roses	Willow Creek
081017_04	334456	5519643	Interlayered light grey, red and dark grey mudstones with abundant white calcite concretions	Willow Creek
081017_05	334671	5500663	Dark grey mudstone	Willow Creek
081017_06	300891	5556002	Interlayered massive sandstone, siltstone and mudstone	Willow Creek

[1] UTM Zone 12, NAD83

obvious alteration. Uranium concentrations in three samples, 08USA002, 08USA003 and 08USA004, are 79, 106 and 158 ppm, respectively. These samples do not contain anomalous amounts of other metals; the only anomaly observed is an elevated CaO content of 21%–24% (Table 1 and DIG 2009-0017). The importance of the uranium occurrence lies not in its high U content but in the fact that it is not related to the high organic content and thus represents a different type of uranium hostrock. We will use thin sections from this occurrence to explain the nature of the uranium anomaly.

Organic-rich sandstone from the banks of the Waterton River (sample 07USA0027) returned a value of 16.2 ppm U. Four sandstone samples (07USA0011, 07USA23, 07USA27 and 07USA30) from the bank of the Waterton River and one sample of mudstone (07USA0093) from east of Cardston returned values of 5–14 ppm U (Table 1, DIG 2009-0017).

Massive, thick (>3 m) sandstone beds of the Upper Willow Creek Formation outcrop along the Waterton River. The upper 2–4 m of sandstone are often light yellow, with limonite developing along fracture planes. Grey and greenish sandstone prevails below this level (Figures 6, 7). East of Cardston, the lower Willow Creek Formation (samples 07USA0088 to 07USA0093) is composed of interlayered mudstone and sandstone that exhibit characteristic purple, orange, brown and grey colours (Figure 8).

2.1.6 Porcupine Hills Formation

Two samples of massive sandstone from the Porcupine Hills Formation contained less than 1 ppm U (samples 07USA0103 and 07USA0104). Sample 08USA005, collected from a small sandstone outcrop, contains 1.18 ppm U (Table 1, DIG 2009-0017).

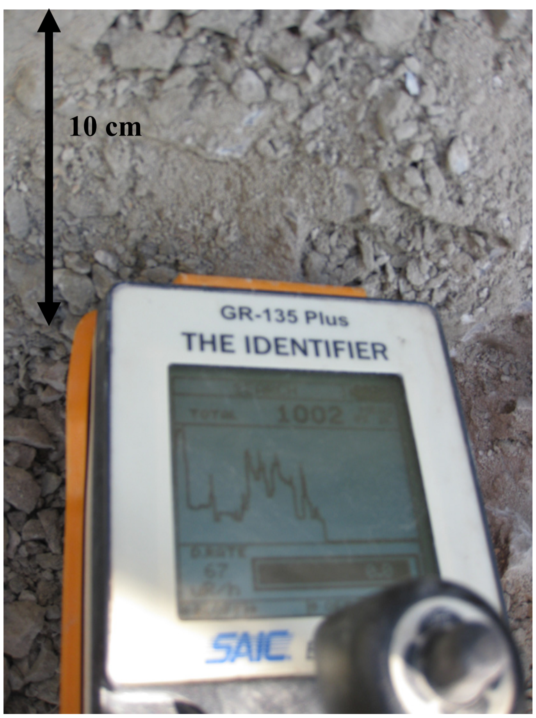


Figure 3. Oldman radioactive anomaly showing 1002 cps on the GR-135 spectrometer, stop 081115_02 (for co-ordinates, refer to Table 2).

Figure 4. Outcrop at the Oldman radioactive occurrence, stop 081115_02 (for co-ordinates, refer to Table 2).

Figure 5. Detail of outcrop at the Oldman radioactive occurrence, stop 081115_02 (for co-ordinates, refer to Table 2).

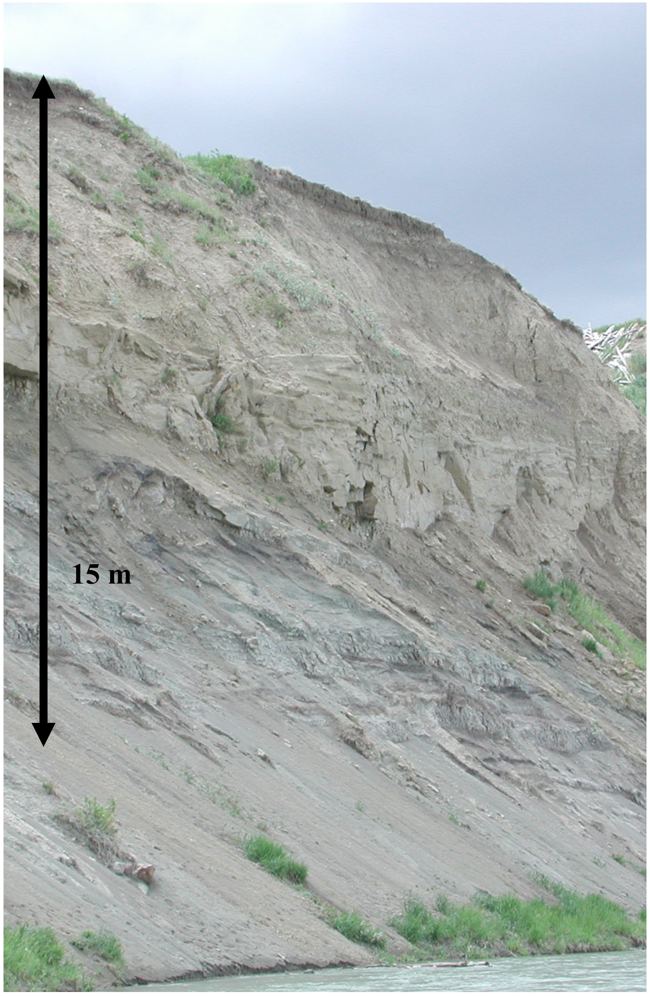


Figure 6. Outcrops of the Upper Willow Creek Formation along the Waterton River, stop 070608_06 (for co-ordinates, refer to Table 2).

Figure 7. Limonite staining in outcrop of the Upper Willow Creek Formation along the Waterton River, stop 070608_06 (for co-ordinates, refer to Table 2). Geological hammer for scale.

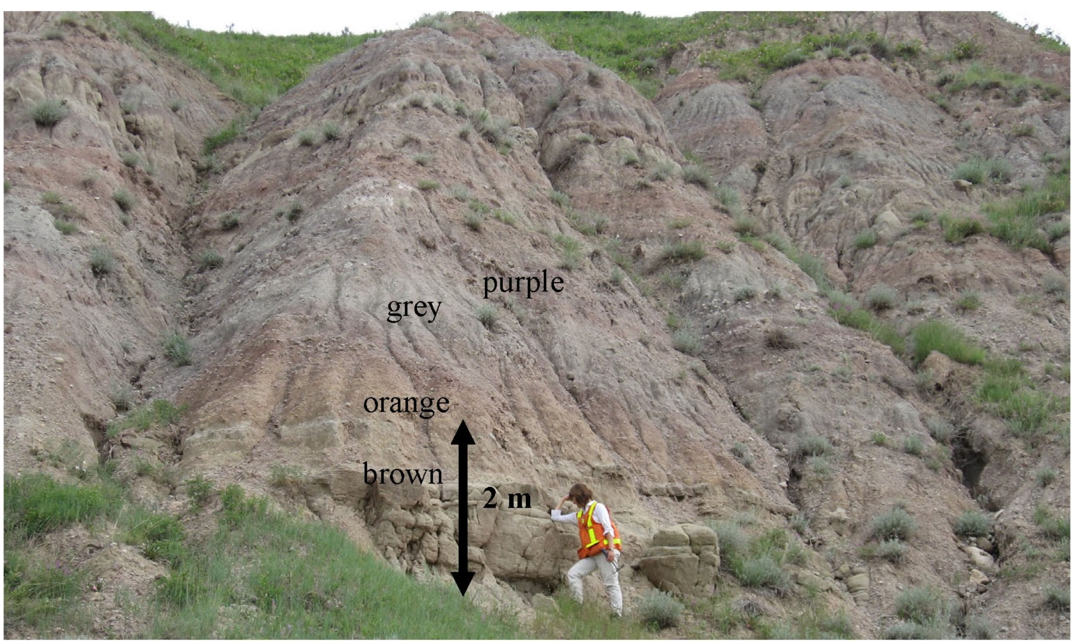


Figure 8. Grey, purple, brown and orange colouration of the Willow Creek Formation, stop 070613_01 (for co-ordinates, refer to Table 2).

2.1.7 Edmonton Group

Two shale samples from this formation (07USA0106 and 07USA0107) both contained less than 3 ppm U (Table 1, DIG 2009-0017). This was the northernmost outcrop sampled during this study, and this area has not been targeted by companies exploring for uranium.

2.2 Assay Results

Figure 11 is a plot of the U and V concentrations in outcrop samples collected during 2006, 2007 and 2008. We excluded anomalous values from the plot so it would show only background values for the various formations. The results reinforce the observation, made in 2006, that background values of U gradually decrease upsection from the St. Mary River Formation. These results correlate with those from the thin-section study, which shows that the amount of volcanic fragments and feldspars decrease upsection. Mack and Jerzykiewicz (1989) reported similar observations. The highest U value (27 ppm) during the 2007 sampling trip came from the Kimball occurrence, which occurs in organic-rich shale within deformed beds of the St. Mary River Formation (sample 07USA0071). An elevated U value (16 ppm) was found in an organic-rich sandstone of the Willow Creek Formation along the Waterton River (sample 07USA0027), and a light grey siltstone bed of the Willow Creek Formation had the highest concentration of all samples (158 ppm U).

Table 1 presents a summary of the results and all analytical results are tabulated in Digital Data DIG 2009-0017 (Matveeva and Kafle, 2009b).

2.3 Alteration Observations

A pronounced alteration front is apparent in many geological provinces with sandstone-hosted uranium deposits. The front separates the yellow, red and whitish oxidized sandstones that occur updip from uranium bodies from grey and green reduced ‘fresh ground’ that occurs downdip from the mineralization. Matveeva and Anderson (2007) have described the alteration scheme is described in detail in Matveeva and Anderson (2007). Using the oxidation-reduction–front model, we had hoped to observe differences in colour within a formation and locate the alteration front. However, the outcrops observed did not display a consistent change in colour, so an alteration front could not be located.

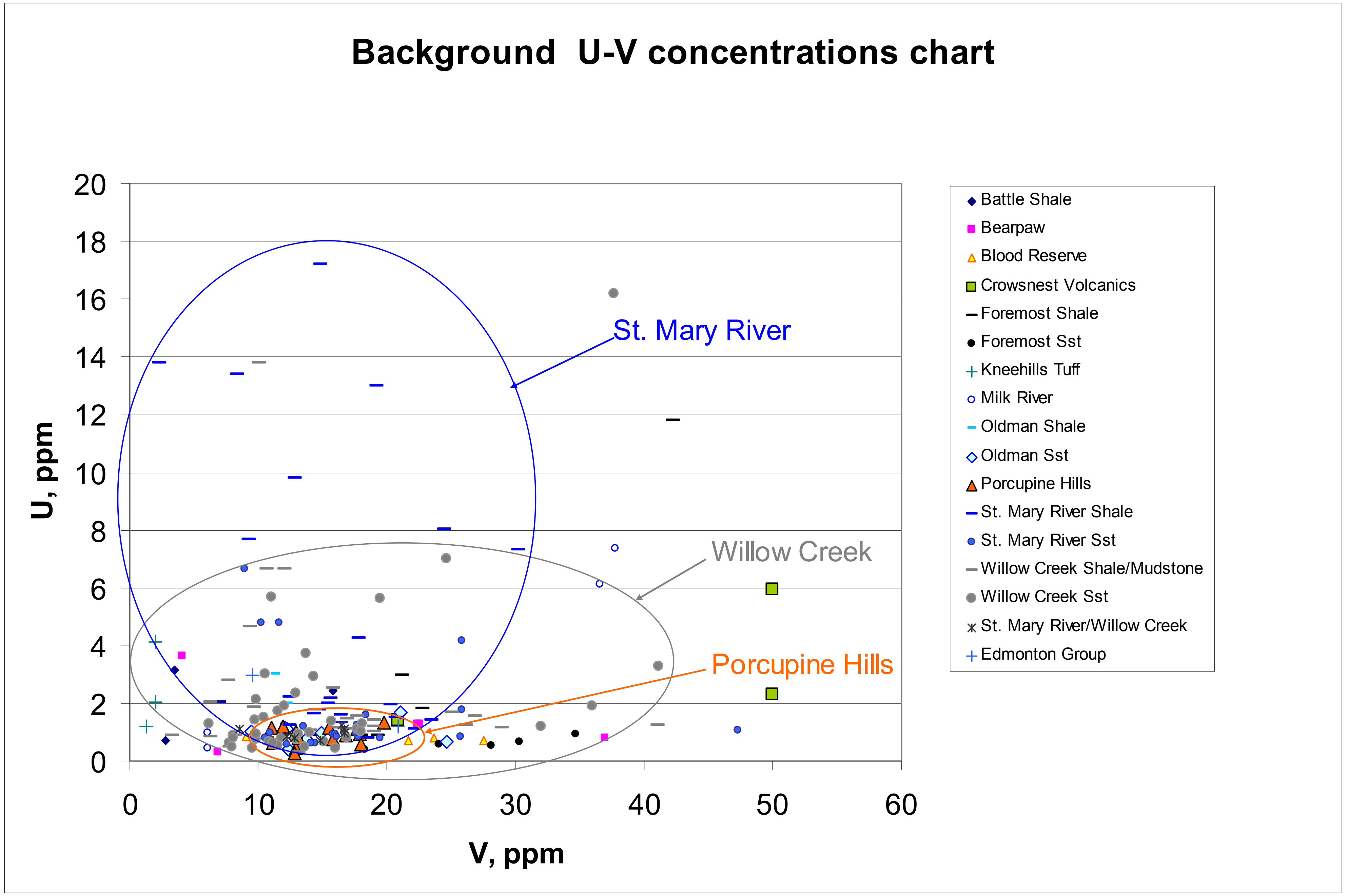
As can be seen in Figures 6, 9 and 10, a repeated scheme observed beneath till in different bedrock formations is a 2–5 m thick, light yellow upper layer underlain by a light grey to grey lower layer. Rusty films or manganese dendrites often form on open fracture surfaces (Figure 7). We attribute this to the oxidation of the near-surface beds, related to the current erosion level, rather than alteration by moving oxidizing ground waters in confined aquifers. No strong differences in colour within any single formation have been found in southern Alberta, relative to colour schemes described for fresh and altered grounds in areas hosting uranium deposits elsewhere in the world (Davis, 1969; Sanford, 1985; Kochenov et al., 1995; Grushevoi and Pechenkin, 2003).

The various formations do have different lithologies and colours. Mineral exploration companies have described extensive beds of reddish and light orange colour, often found in the Willow Creek Formation (Figure 8), as alteration related to oxidizing groundwater. However, the red-coloured beds are typically very extensive and lie conformably with other layers. The purple, reddish and orange colours of the Willow Creek Formation could be due to surface oxidation at the time of deposition rather than later alteration by oxidizing groundwater, although the latter is also possible.

It is important to note, however, that the colours of fresh and altered ground vary significantly in different uranium provinces (Davis, 1969; Sanford, 1985; Kochenov et al., 1995; Grushevoi and Pechenkin, 2003). If an alteration front exists in southern Alberta, the rock-colour schemes may be unique to this area. It is also noteworthy that differences between fresh and altered ground are usually discovered during the advanced stages of exploration, when the location of at least one uranium orebody is already known. Our observations of colour variations in outcrop should therefore be viewed in the context of the initial stages of a resource assessment.

Figure 9. Outcrop of the Oldman Formation along the Oldman River, north of Lethbridge, stop 070607_02 (for co-ordinates, refer to Table 2).

Figure 10. Outcrop of the St. Mary River Formation along the Oldman River west of Lethbridge, stop 070612_08 (for co-ordinates, refer to Table 2).



Anomalous samples:

Sample No.	Occurrence	Lithology	Formation	U (ppm)
06USA0019	Kimball	shale	St. Mary River	26.7
07USA0071	Kimball	shale	St. Mary River	27.1
06USA0018	Kimball	shale	St. Mary River	29.7
06USA0024	Kimball	shale	St. Mary River	66.9
06USA0105	Ubone	bone	Willow Creek	3810
08USA003	Rivervalley	siltstone	Willow Creek	79.1
08USA004	Rivervalley	siltstone	Willow Creek	106
08USA002	Rivervalley	siltstone	Willow Creek	158

Figure 11. Background values of uranium and vanadium from the 2006, 2007 and 2008 outcrop-sampling program.

3 Log Studies from Oil and Gas Wells

Similar to the 2006 study, gamma values less than 150 API units were considered 'background,' whereas values greater than 150 and less than 300 API were ranked 'high' and those greater than 300 API were considered 'anomalous.'

This work is an expansion of a study carried out during 2006 (Matveeva and Anderson, 2007), specifically well log interpretation for sandstone-hosted uranium potential in southern Alberta. The main goal of the 2006 study was to assess the identification of sandstone bodies with anomalous radioactivity using geophysical well logs within 500 m of the surface. The initial study included more than 200 wells in the Claresholm area. The results from the 2006 study were encouraging, so we expanded the project to cover the entire province. Alberta Geological Survey has access to a large digital oil and gas well-log database that we queried for the evaluation of uranium potential.

The oil and gas industry routinely uses gamma-ray logs in to interpret rock type. Resistivity, neutron porosity and bulk density logs complement the gamma-ray log interpretations. The natural gamma-ray log, measured in API (American Petroleum Institute) units, records the natural radiation from all radioactive elements present in the rock. It is not possible to convert the API units into a quantitative assessment of uranium content. In general, a high gamma value corresponds to a clay-mineral–rich rock or other rock type with radioactive minerals (e.g., sandstone), whereas a low gamma value corresponds to a rock low in clay minerals or radioactive elements. In the presence of a high gamma interval, the neutron-density separation can be used to aid in identification of lithology. A large separation between density and neutron logs indicates shale, whereas sandstone will show a narrow separation (Figure 12; Rider, 2002). We have not considered other rock types (e.g., limestone) here because of a paucity of these rocks in the stratigraphic interval of this investigation. Gas-bearing organic matter in shale can cause a higher resistivity than background, as can gas-filled sandstone, but the neutron-density response in sandstone should be unique. Some types of drilling mud can also cause high gamma-ray values, but these usually affect the entire log.

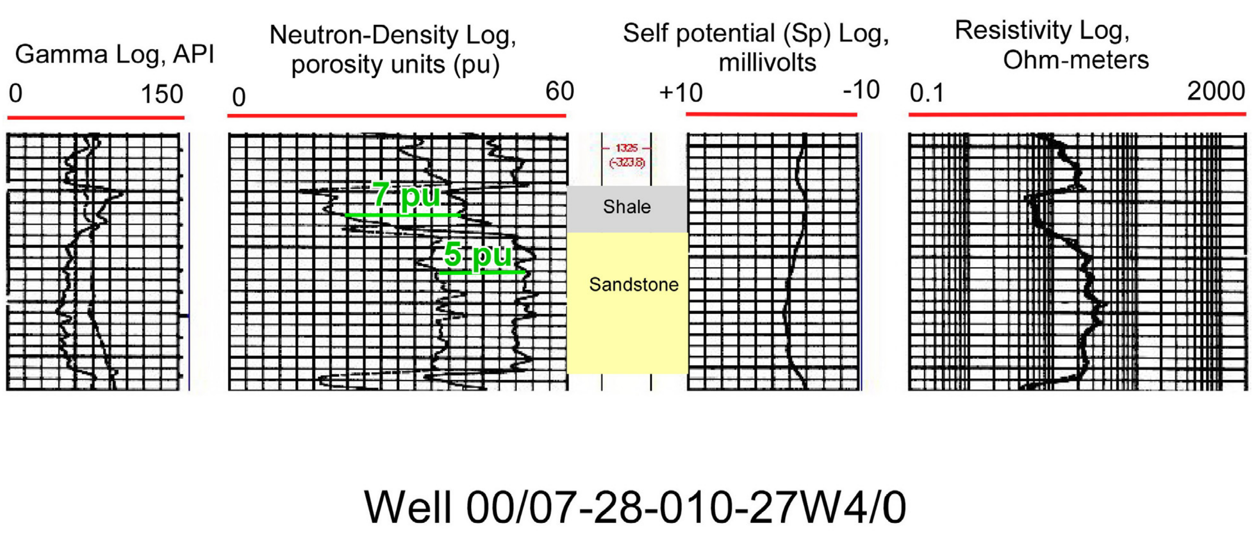


Figure 12. Interpretation of geophysical logs to derive rock type. The larger separation between neutron-density logs (7pu) and lower resistivity is an example of shale, whereas smaller separation (5pu) and higher resistivity is an example of sandstone.

3.1 Province-Wide Well-Log Study

We used two databases in this study: 1) digital log ASCII standard (LAS) logs held by ERCB/AGS, and 2) raster well logs from the commercial software AccuMap®.

The digital database of gamma logs from oil and gas wells was queried to identify wells with gamma values >300 API, regardless of thickness of the zone of gamma readings. An algorithm written for this analysis queried more than 48 000 gamma ray logs from more than 22 000 oil and gas wells and found more than 35 835 gamma readings >300 API. Of these, 11 476 readings >300 API within the upper 500 m were found in 6176 wells (Figure 13). Due to the large number of wells with anomalous readings, we selected only one or two wells from a cluster to be checked individually in AccuMap for identification of rock type and formation. In total, 1318 wells were selected and checked to verify the anomaly and determine rock type using a combination of gamma, density and resistivity logs. Matveeva and Kafle (2009a) contains the results of this check, including well identification number, NTS area, location co-ordinates (latitude and longitude), maximum gamma value, depth to the first anomalous gamma reading, depth to the second anomalous gamma reading, formation name for first anomalous gamma reading, formation name for second anomalous gamma reading, and probable rock type within first anomalous gamma reading.

Of the 1318 wells, 1080 have an anomalous gamma reading in shale (Figure 14), mostly within the Base of Fish Scales Formation (BFSC) or Second White Specks Formation (formation names used are informal and followed AccuMap picks). These are predominantly shaly units with abundant organic matter within the Colorado Group shale (Figure 15).

Anomalous gamma values within the BFSC are mostly from wells located in the northern half of the province. Anomalous gamma readings within the Second White Specks occur in wells from the east-central part of the province, particularly in NTS areas 73D, 73E, 73L, 73M and 74D. Table 3 (*from* Dufresne et al., 2001) provides the values for uranium content of these two units.

Dufresne et al. (2001) noted that the pronounced U enrichment in the bone beds is the reason for the distinct radiometric anomaly often seen on downhole geophysical logs at or near the Base of Fish Scales Formation and in the Second White Specks Formation (Table 3). The BFSC Formation bone beds tend to contain higher P and lower Ca than the Second White Specks Formation bone bed. This likely reflects a greater concentration of fish bone matter in the Fish Scale Formation bone beds than shell material in the Second White Specks formation bone beds.

There are 177 wells (prior to lithological interpretation) with multiple gamma values >300 API within 500 m of the surface. The majority of the first anomalous gamma values are within the BFSC, Second White Specks and Colorado Shale, whereas the second peak falls within the Peace River, BFSC and Second White Specks.

Anomalous gamma readings within the Colorado Formation are in wells located in the east-central part of the province. Anomalous readings in the Bearpaw Formation occur in the southwestern part of the province (Figure 15).

We observed anomalous gamma readings in rock interpreted as sandstone in 77 wells within NTS areas 73L and 83I; the high gamma value occurs midway between the Second White Specks and the BFSC. A trend of multiple wells with radioactive anomalies in sandstones lies north of Calgary and west of Edmonton, and can be traced north of Grande Prairie.

Digital Data DIG 2009-0016 (Matveeva and Kafle, 2009a) contains complete datasets for this study.

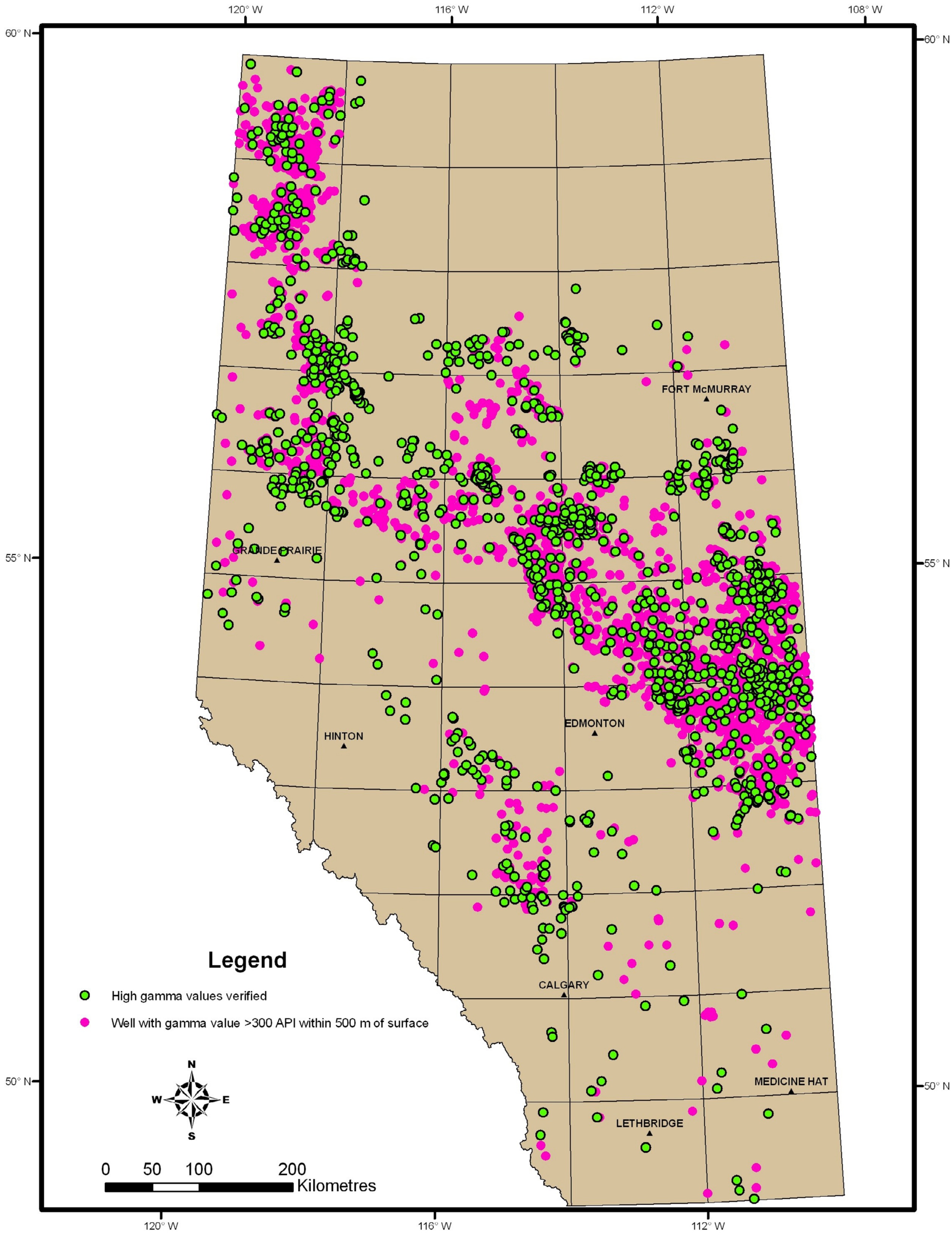


Figure 13. Wells with anomalous gamma values (from AGS digital logs) in the upper 500 m are in pink. Wells for which the logs have been verified and lithology identified are in green.

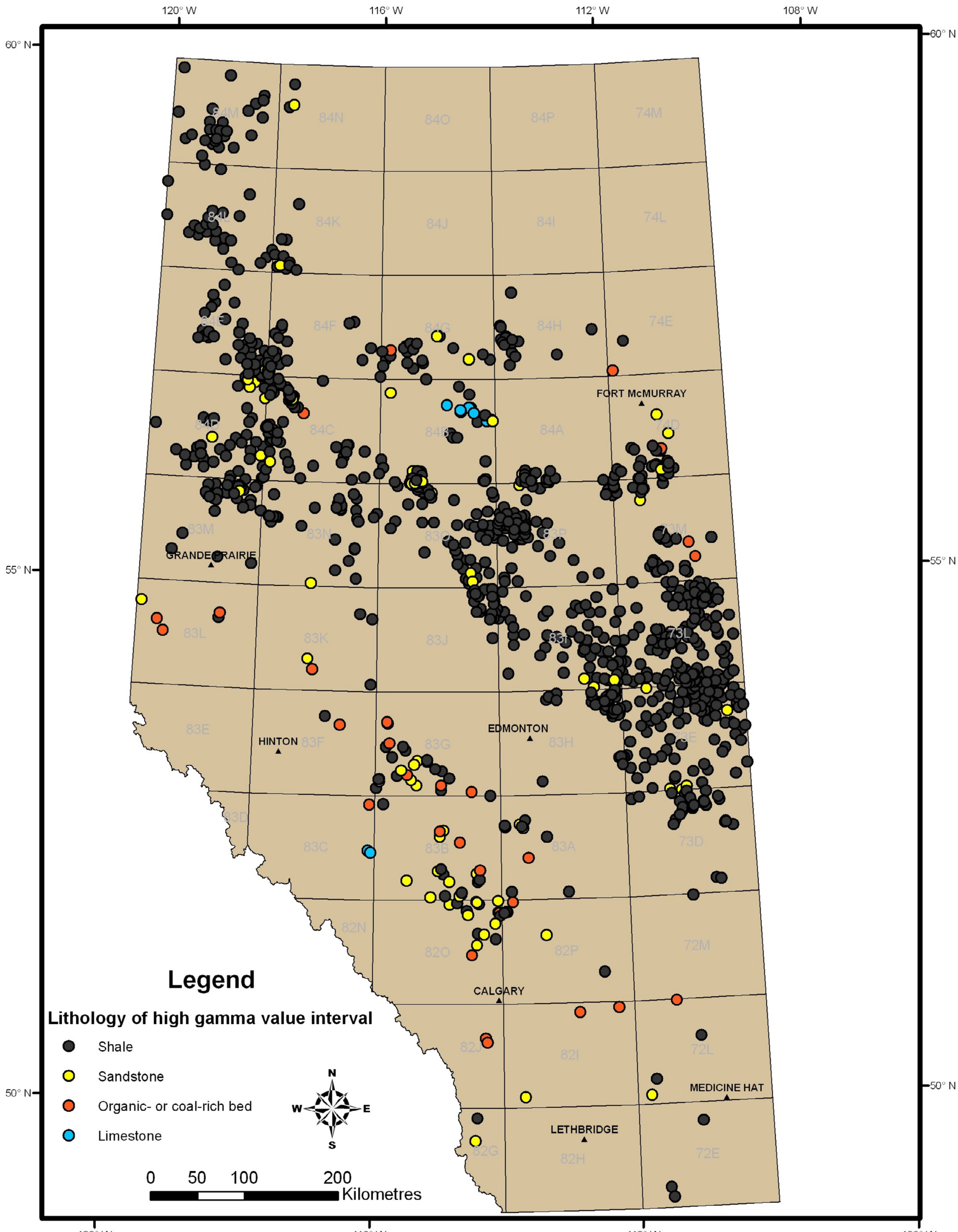


Figure 14. Lithology of the anomalous gamma intervals (rock type interpreted using combination of gamma, resistivity and density-porosity logs).

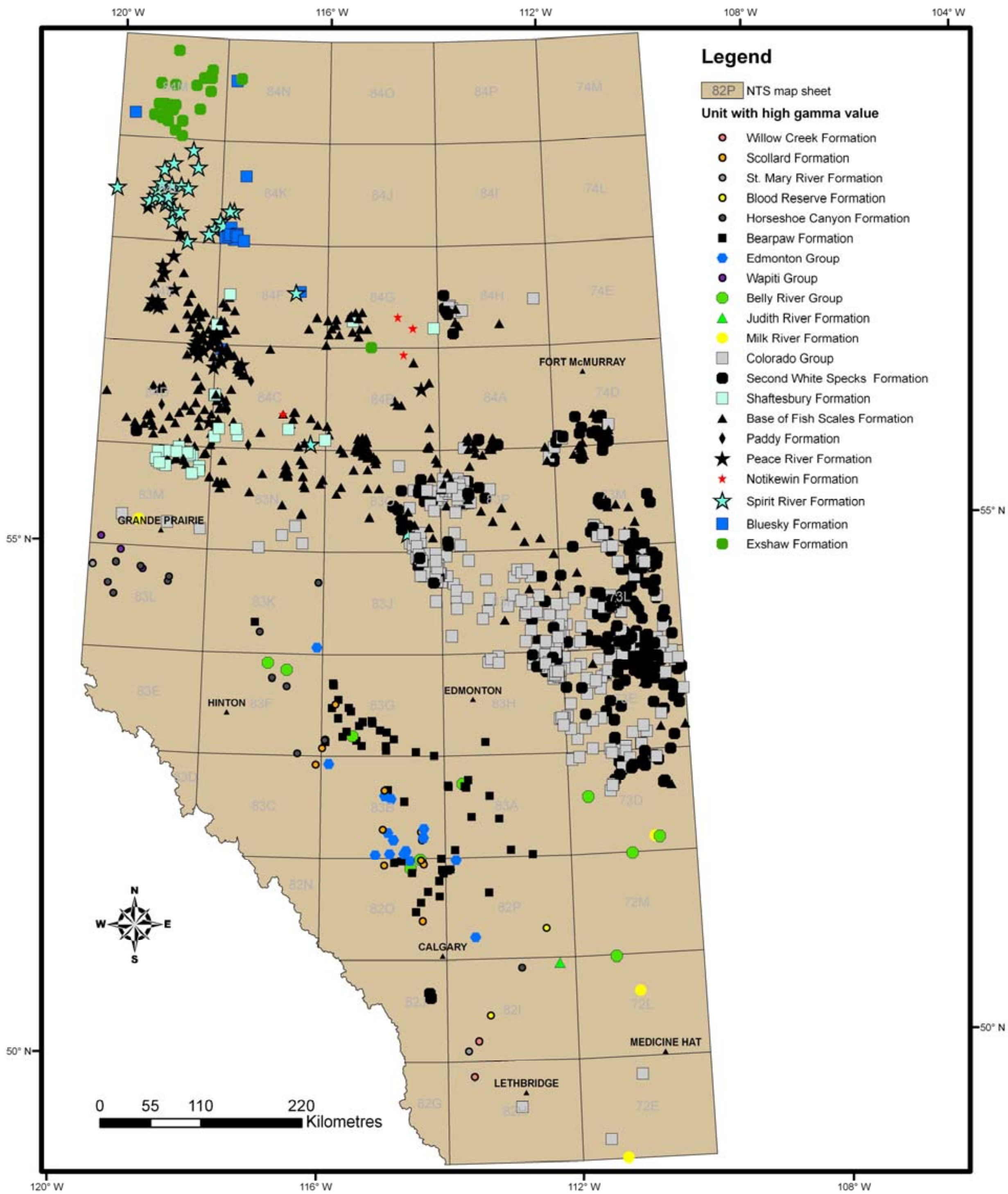


Figure 15. Distribution of anomalous gamma values by formation.

Table 3. Examples of uranium content in anomalously radioactive formations of Alberta.

Sample No.	Formation and Lithology	U (ppm)
95SH50-005	Base of Fish Scales Formation black shale	28.6
95SH40-003	Base of Fish Scales Formation bone bed	352
95SH50-004	Base of Fish Scales Formation bone bed	129
95DB07-001	Base of Fish Scales Formation bone bed	28
95SH07-005	Base of Fish Scales Formation bone bed	220
95SH10-003	Base of Fish Scales Formation sandy shale	11
95SH32-003	Base of Fish Scales Formation shale	4.1
95SH50-011	Base of Fish Scales Formation shale	15
95MD07-002	Base of Fish Scales Formation shale	5.1
95SH10-007	Base of Fish Scales Formation shale	48.4
95DL03-006	Second White Specks bone bed	170
95SH57-001	Second White Specks shale	3.6
95DB01-001	Second White Specks shale	16

3.2 Claresholm-Lethbridge Area Well-Log Study

We carried out detailed well-log interpretation in the southwestern part of the province to study the spatial distribution of wells with high gamma values. The area selected for the study extends from Township 1 to 16 and from Range 19W4 to 2W5.

The main goals were to

- expand the area of the 2006 study;
- identify the wells with high gamma values within 550 m of surface; and
- examine the spatial distribution of high and anomalous gamma values and possibly the spatial association between wells with anomalously high gamma values.

We used AGS in-house software to query the AGS digital well-log database within the study area by applying the following criteria: gamma value greater than 300 API with a thickness of more than 0.5 m within 550 m of the surface.

The AGS digital well-log database does not include all drilled oil and gas wells. Hence, we used the queried wells from the AGS database as 'master' wells, and all wells containing gamma logs within a 3 km radius from these 'master' wells were selected in AccuMap. The gamma-ray logs from these selected wells were checked to locate anomalous (>300 API) and/or high gamma values (>150 API) within a depth from the surface similar to that in the master well (note that these values are different from those used for the province-wide study).

In the study area, we identified 30 master wells (Figure 16) with high and anomalous gamma values. Thirteen wells have anomalous gamma values (>300 API) and 17 wells have high values (>150 API). Table 4 presents the data from all the wells. The depth to the gamma peaks ranges from 176 to 545 m from surface (Figure 17).

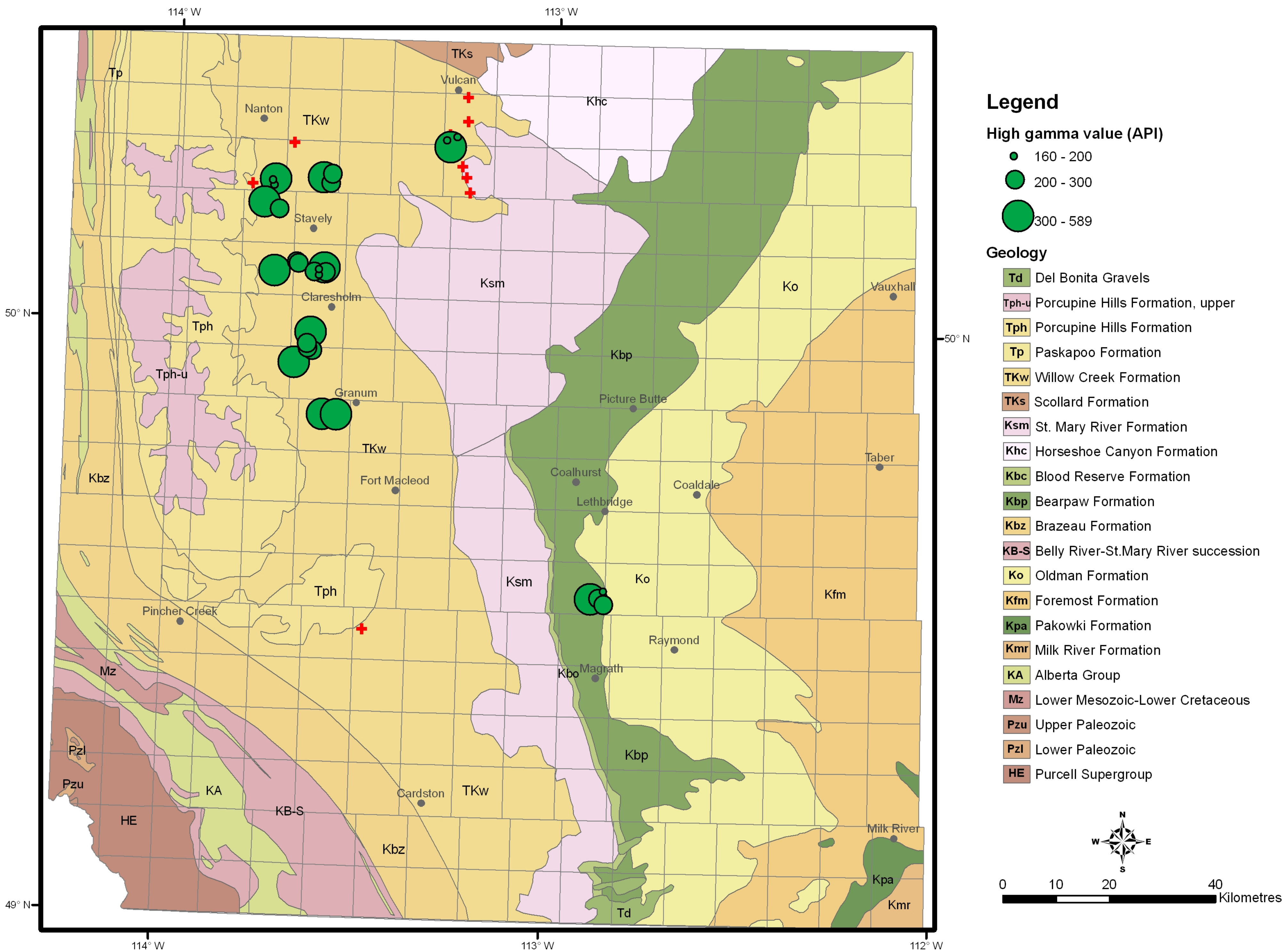


Figure 16. Distribution of wells with anomalous radioactivity in the Claresholm area.

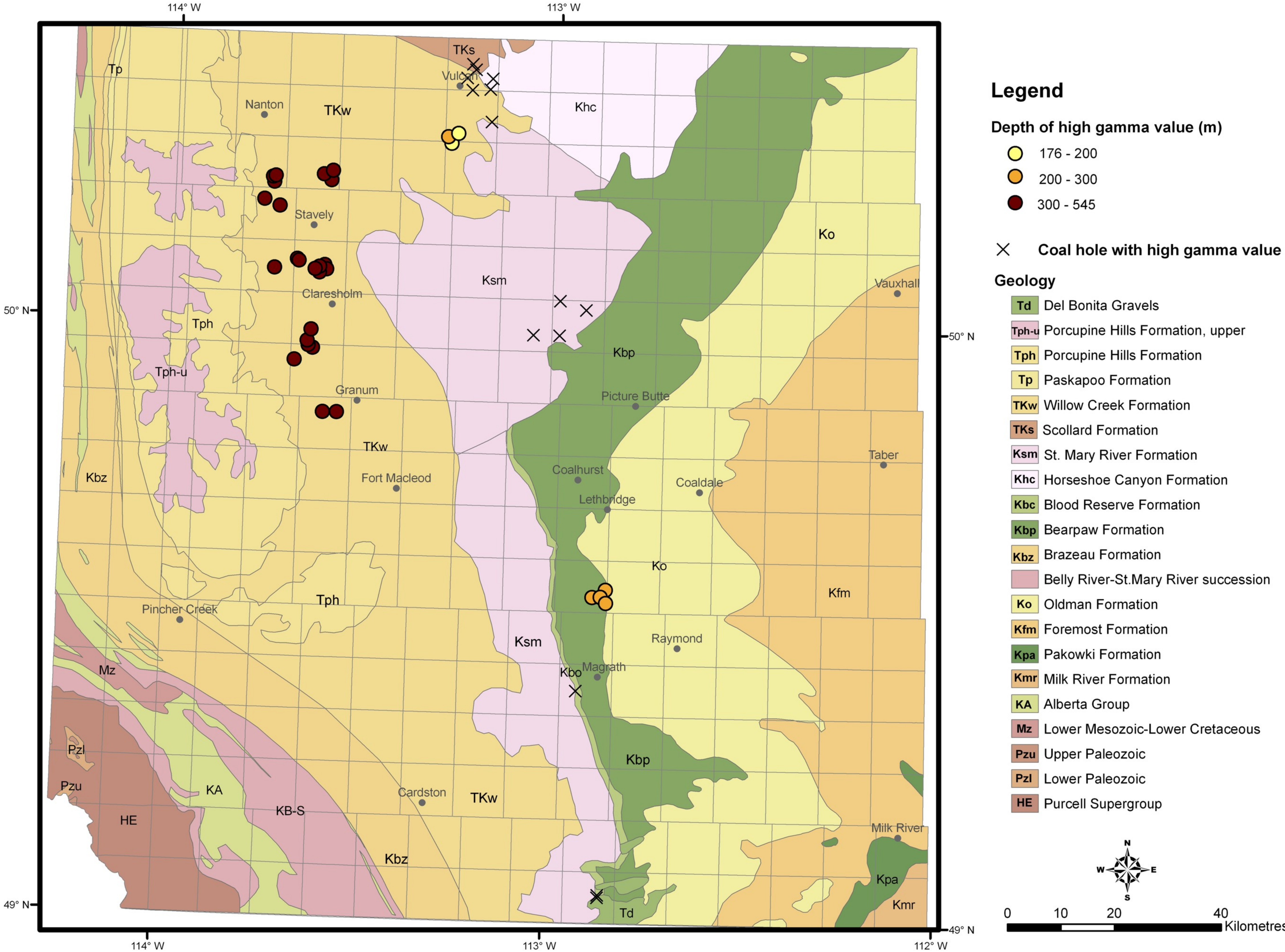


Figure 17. Depth of radioactive intervals in the Claresholm area.

Table 4. Claresholm-Lethbridge area well-log study.

Well ID	Location[1]		KB Elevation (m)	Maximum Gamma Value (API)	Maximum Gamma Depth(m)	Formation	Comments	Data Source
	Longitude	Latitude						
00/10-02-015-28W4	-113.744944	50.233221	1101.70	200.00	515.00	Willow Creek	Background GR 90 API	Accumap
00/06-11-015-28W4	-113.748658	50.241837	1099.80	165.00	516.00	Willow Creek	Background GR 90 API	Accumap
00/08-11-015-28W4	-113.741463	50.243769	1105.60	589.99	505.20	Willow Creek	Background GR 90 API; peak GR value corresponds to higher resistivity	LAS
00/04-12-015-27W4	-113.595411	50.238918	1008.50		359.00	Willow Creek	GR value given as 17.1 micro-Roentgens/hr.	Accumap
00/14-11-015-27W4	-113.615155	50.248502	1024.70	349.15	384.37	St. Mary River	Background GR 90 API	LAS
00/03-13-015-27W4	-113.591992	50.254879	1009.10	205.00	332.00	St. Mary River	Background GR 90 API; peak GR value corresponds to higher resistivity	Accumap
00/07-22-013-27W4	-113.606026	50.095831	1037.70	361.52	344.80	Willow Creek	Background GR 90 API; low resitivity	LAS
00/16-15-013-27W4	-113.600633	50.088712	1040.40	225.00	368.00	Willow Creek	Background GR 75 API	Accumap
00/08-16-013-27W4	-113.619103	50.083007	1047.10	160.00	411.00	St. Mary River	Background GR 100 API	Accumap
00/01-21-013-27W4	-113.619386	50.092874	1043.20	160.00	413.00	St. Mary River	Background GR 100 API	Accumap
00/14-16-013-27W4	-113.630566	50.088800	1049.00	250.00	420.00	St. Mary River	Background GR 100 API	Accumap
00/11-33-011-27W4	-113.630748	49.956114	993.30	250.00	437.00	St. Mary River	Background GR 90 API	Accumap
00/16-32-011-27W4	-113.641945	49.960306	995.60	250.00	372.00	Willow Creek	Background GR 75 API	Accumap
00/10-05-012-27W4	-113.645407	49.967693	998.50	225.00	394.00	Willow Creek	Background GR 90 API; multiple peak GRs at 390 and 394 m	Accumap
00/16-31-015-24W4	-113.283627	50.306850	1001.70	310.29	195.68	St. Mary River	Background GR 75 API	LAS
00/11-06-016-24W4	-113.292870	50.317705	1008.20	165.00	218.00	St. Mary River	Peak GR has negative(smaller) separation of neutron porosity and density porosity, and high resitivity	Accumap
00/15-05-016-24W4	-113.266627	50.323837	1039.30	165.00	176.00	St. Mary River	Background GR 120 API	Accumap
00/11-11-007-22W4	-112.886293	49.548491	952.70	409.00	224.60	Belly River	Background GR 90 API	LAS
00/09-13-007-22W4	-112.852012	49.561290	937.30	200.00	212.00	Belly River	Background GR 120 API; Peak GR corresponds to higher resitivity	Accumap
00/13-12-007-22W4	-112.864961	49.549223	949.70	220.00	213.00	Belly River	Background GR 120API; peak GR corresponds to higher resitivity	Accumap
00/01-12-007-22W4	-112.850516	49.539200	946.10	220.00	208.00	Belly River	Background GR 120 API	Accumap
00/07-28-010-27W4	-113.599088	49.848568	1001.20	341.70	384.60	Willow Creek	Background GR 90 API; peak GR corresponds to higher resitivity	LAS
00/06-26-010-27W4	-113.562779	49.848874	999.90	302.45	319.80	Willow Creek	Peak GR corresponds to higher resistivity	Accumap
02/11-28-014-28W4	-113.768685	50.203813	1098.70	331.50	495.70	Willow Creek	Background GR 90 API; peak GR has negative(smaller) separation of neutron porosity and density porosity, and high resitivity	LAS
00/16-22-014-28W4	-113.728429	50.193258	1075.50	220.00	545.00	Willow Creek	Backgound GR 90 API	Accumap
00/03-30-011-27W4	-113.677373	49.935060	1010.90	350.00	485.00	Willow Creek	Background GR 90 API; peak GR has large neutron porosity and density porosity separation, and lower resistivity	Accumap
00/13-09-012-27W4	-113.636096	49.986792	1006.00	320.00	338.00	Willow Creek	Background GR 100 API; peak GR has large neutron porosity and density porosity separation, and lower resistivity.	Accumap
00/14-19-013-27W4	-113.678114	50.104674	1046.10	300.00	393.50	Willow Creek	Background GR 80 API	Accumap

Well ID	Location[1]		KB Elevation (m)	Maximum Gamma Value (API)	Maximum Gamma Depth(m)	Formation	Comments	Data Source
	Longitude	Latitude						
00/10-19-013-27W4	-113.673670	50.101952	1046.80	300.00	461.00	Willow Creek	Background GR 100 API; peak GR has negative(smaller) separation of neutron porosity and density porosity	Accumap
00/16-15-013-28W4	-113.737086	50.088711	1057.60	325.00	538.00	Willow Creek	Backgound GR 90 API	Accumap

[1] NAD83

Abbreviation: GR, gamma ray

The thickness of anomalous gamma intervals ranges from 0.5 to 1.5 m, whereas that of intervals with high gamma readings varies between 0.9 and 5.0 m.

Geologists often attribute anomalous gamma intervals within the Upper Cretaceous and Tertiary formations to bentonite beds. Bentonite is an alteration product of volcanic ash and often contains more uranium and thorium than surrounding sedimentary rocks. A sample of Dorothy bentonite near Drumheller (Matveeva and Kafle, 2009b, sample 06USA0107) contains 6 ppm U and 12 ppm Th. We have not attempted to differentiate bentonite beds during this study, as we believe it would be very difficult to do so without studying core samples, which were not available for these wells.

We observed intervals of anomalous and high gamma values in the following formations: 17 in the Willow Creek Formation, 9 in the St. Mary River Formation and 4 in the Belly River Formation (Figure 18). Most of these anomalous and high-gamma intervals are surrounded by thick intervals reading less than 90 API on the gamma log, a typical background value for sandstone in the study area. The resistivity logs in most of the high-gamma intervals have resistivity values one or two orders of magnitude higher than background. These observations can be interpreted as a radioactive zone within a sandstone package.

We constructed five cross-sections to illustrate a spatial association between wells with anomalous and high gamma values within several clusters of wells in the Claresholm-Lethbridge area (Figures 19–23). Ground surface was chosen as the datum for the cross-sections because there is little variation in the topographic relief in the immediate area. In section A (Figure 19), gamma logs from well 00/08-11-015-28W4 show anomalous gamma readings of 590 API at a depth of 505 m. Wells 00/06-11-015-28W4 and 00/10/02-015-28W4, at distances of 0.5 and 1.1 km from the ‘master’ well, show high gamma values of 165 and 200 API at depths of 516 and 515 m, respectively. In all three wells, the high gamma value corresponds to a high resistivity value, which we interpret as a radioactive interval within a sandstone package. Likewise, in sections B, C, D and E (Figures 20–23), the gamma peaks are clearly traceable in the surrounding wells at a similar depth in either the Willow Creek, St. Mary River or Belly River formations.

3.3 Coal-Hole Microfiche Study

Gamma logs from coal holes were studied to evaluate shallow depths where oil and gas wells have either no logs or poor-quality logs (Matveeva and Anderson, 2007). Microfiche of logs from coal holes in AGS holdings were searched to identify holes where gamma values >150 API occur within the upper 550 m. Using 93 microfiche available for the Claresholm-Lethbridge area, 14 coal holes (Table 5) met the criteria (Figure 17). In most of these holes, a high gamma signature occurs within shale and bentonite. Rock type is described in the accompanying lithologs. Two holes, numbers 1979 and 1779 (Figure 24), show a high gamma value at a depth of 11 m from the ground surface in an area east of Whiskey Gap. Water-well samples from this area, collected by AGS (Olson and Anderson, 2007), indicate anomalous values of radon (up to 222 Bq/L) and uranium (up to 160 ppb).

3.4 Cuttings from Oil and Gas Wells

We studied well cuttings from eight oil and gas wells in the ERCB Core Research Centre in Calgary to see if the high gamma peaks identified on well logs is also reflected in the cuttings when they are analyzed with the GR-135 hand-held spectrometer. In each case, the high gamma value on the gamma log did not correspond to a high gamma count in the cuttings. This could be due to 1) small sample volume (most likely reason), 2) dilution of radioactive rock unit (sample was collected from a 5 m interval), 3) uphole contamination in drill cuttings; 4) abundant cavings, and 5) clay particles being washed out from

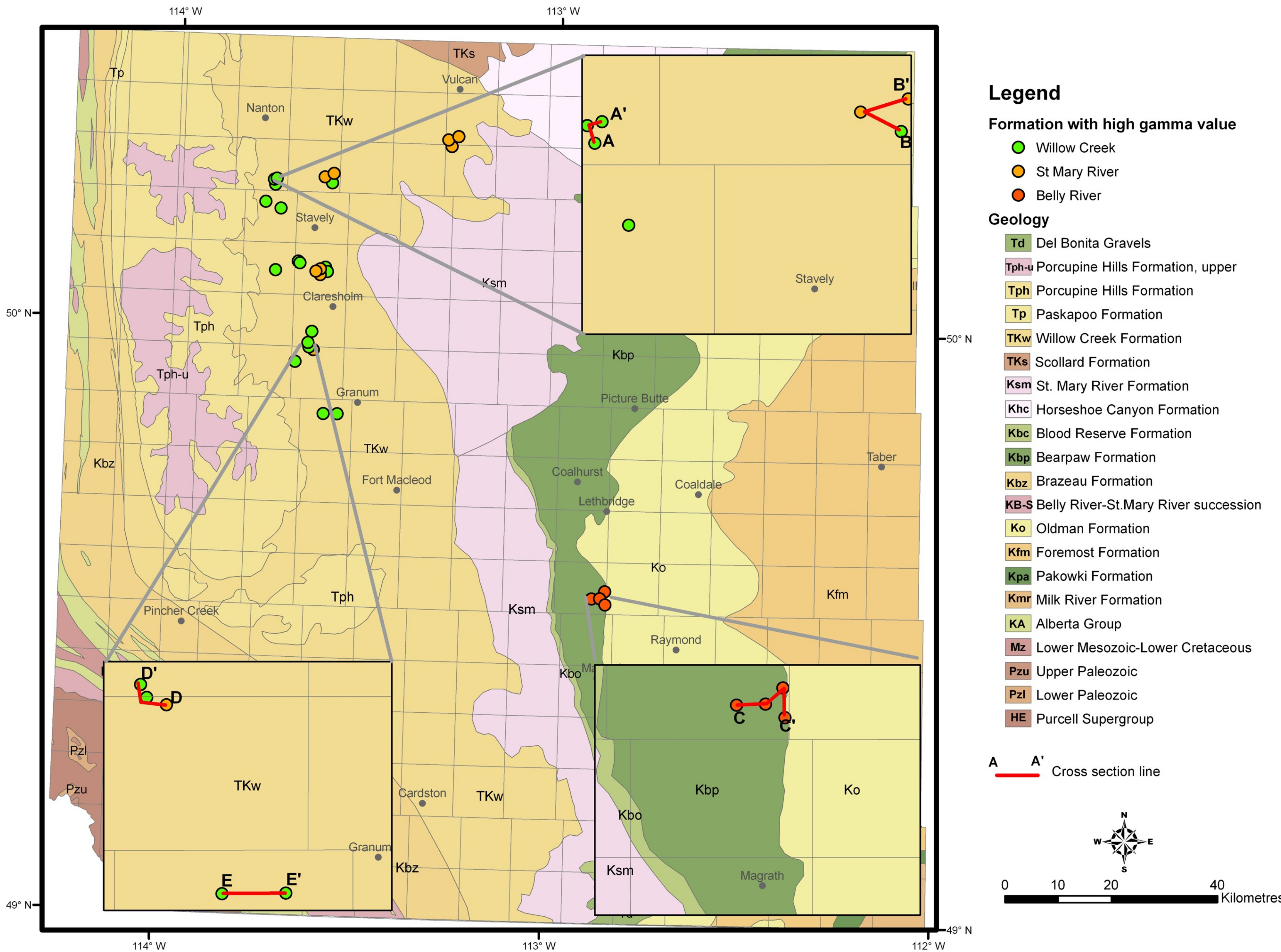


Figure 18. Formations hosting radioactive intervals in the Claresholm area, showing locations of cross-sections in Figures 19–23.

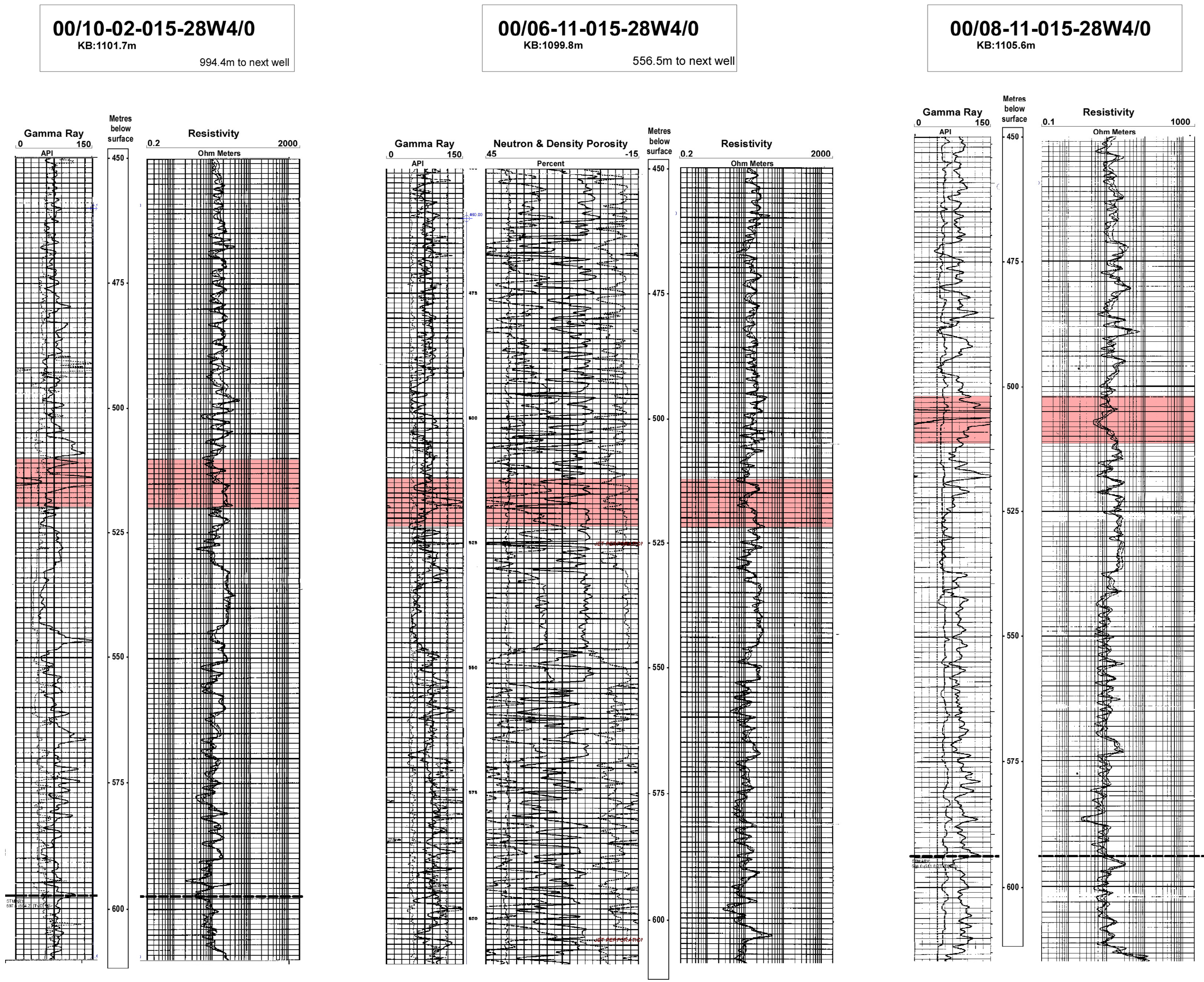


Figure 19. Anomalously radioactive intervals, cross-section A, Claresholm-Lethbridge area. See Figure 18 for location of section.

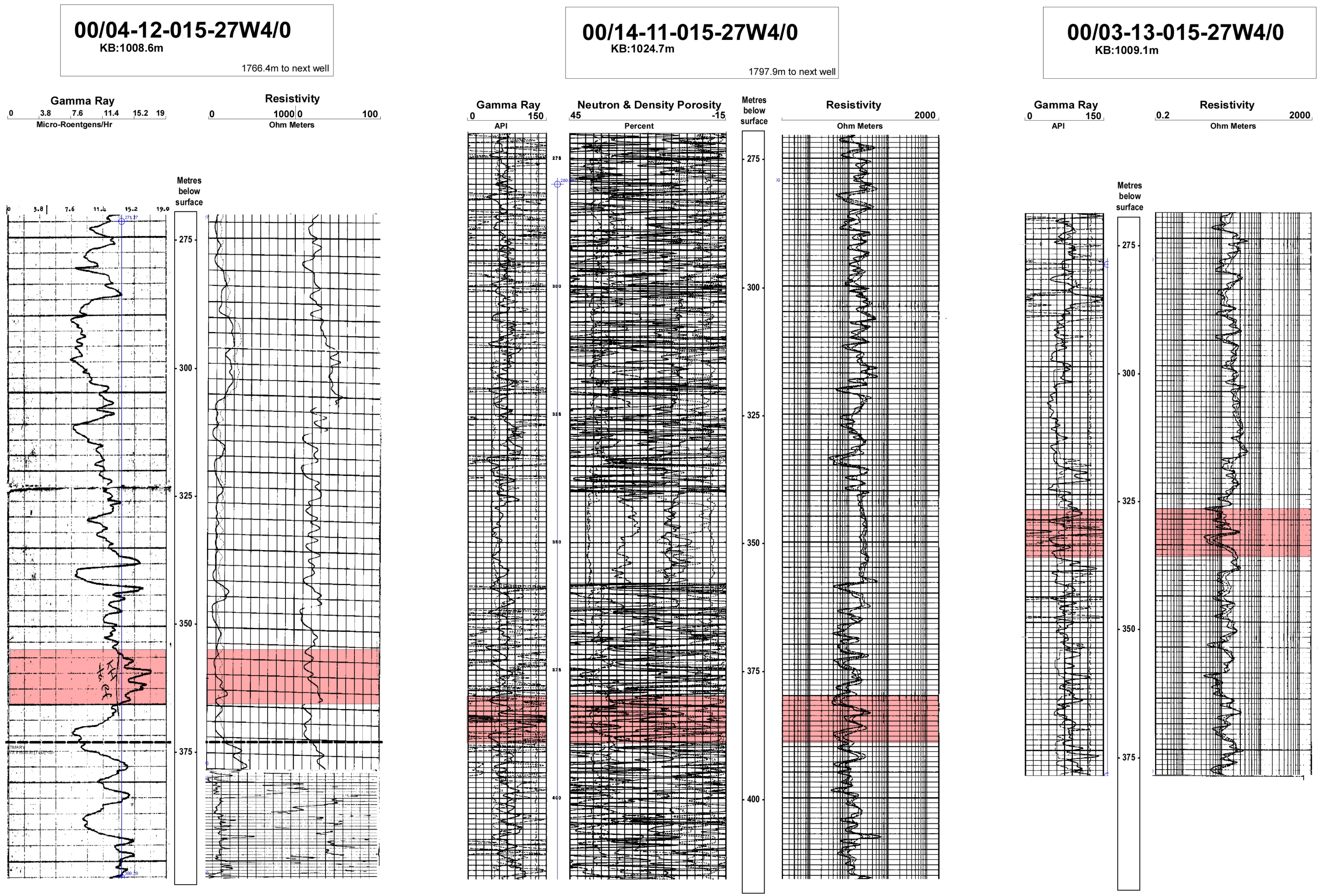


Figure 20. Anomalously radioactive intervals, cross-section B, Claresholm-Lethbridge area. See Figure 18 for location of section.

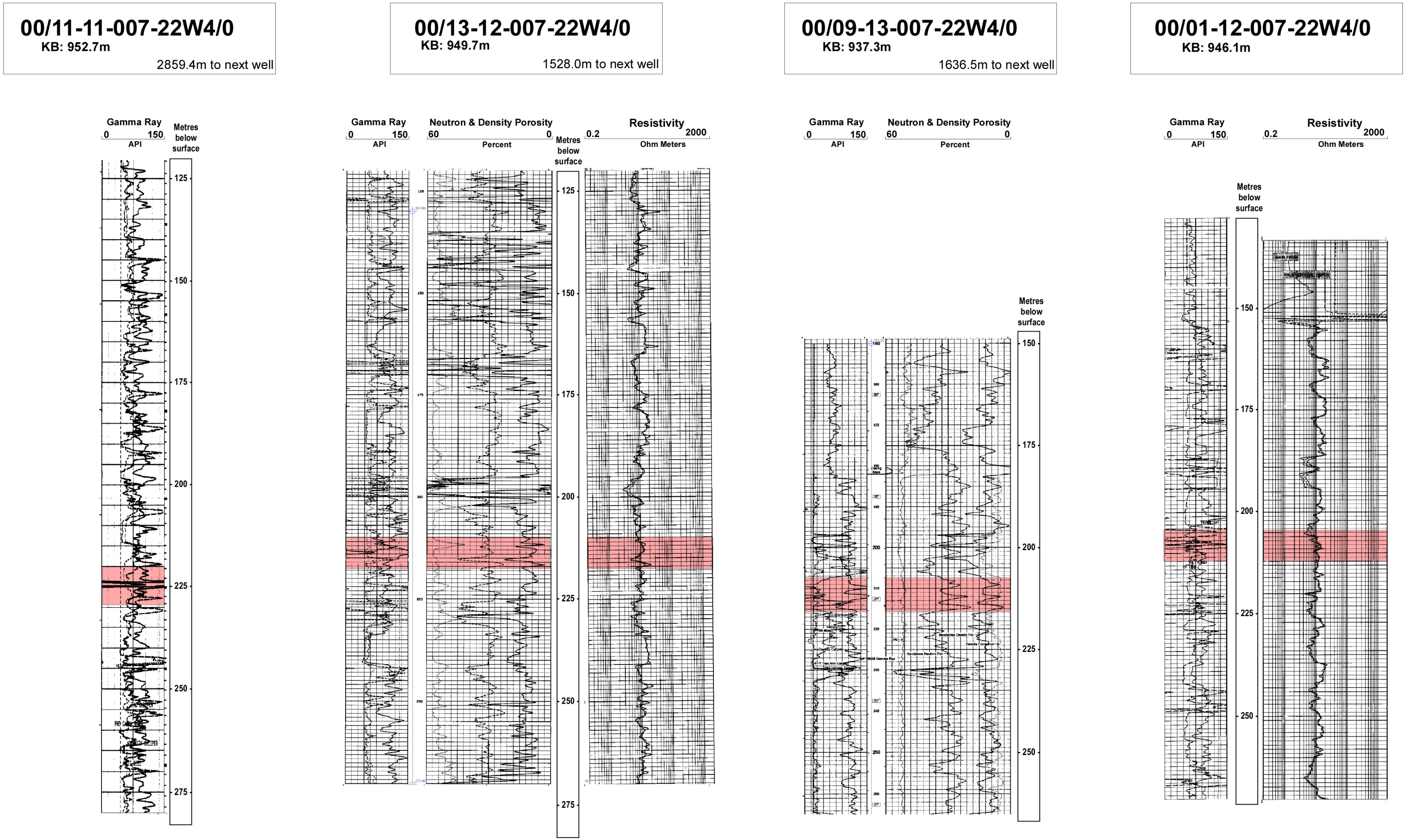


Figure 21. Anomalously radioactive intervals, cross-section C, Claresholm-Lethbridge area. See Figure 18 for location of section.

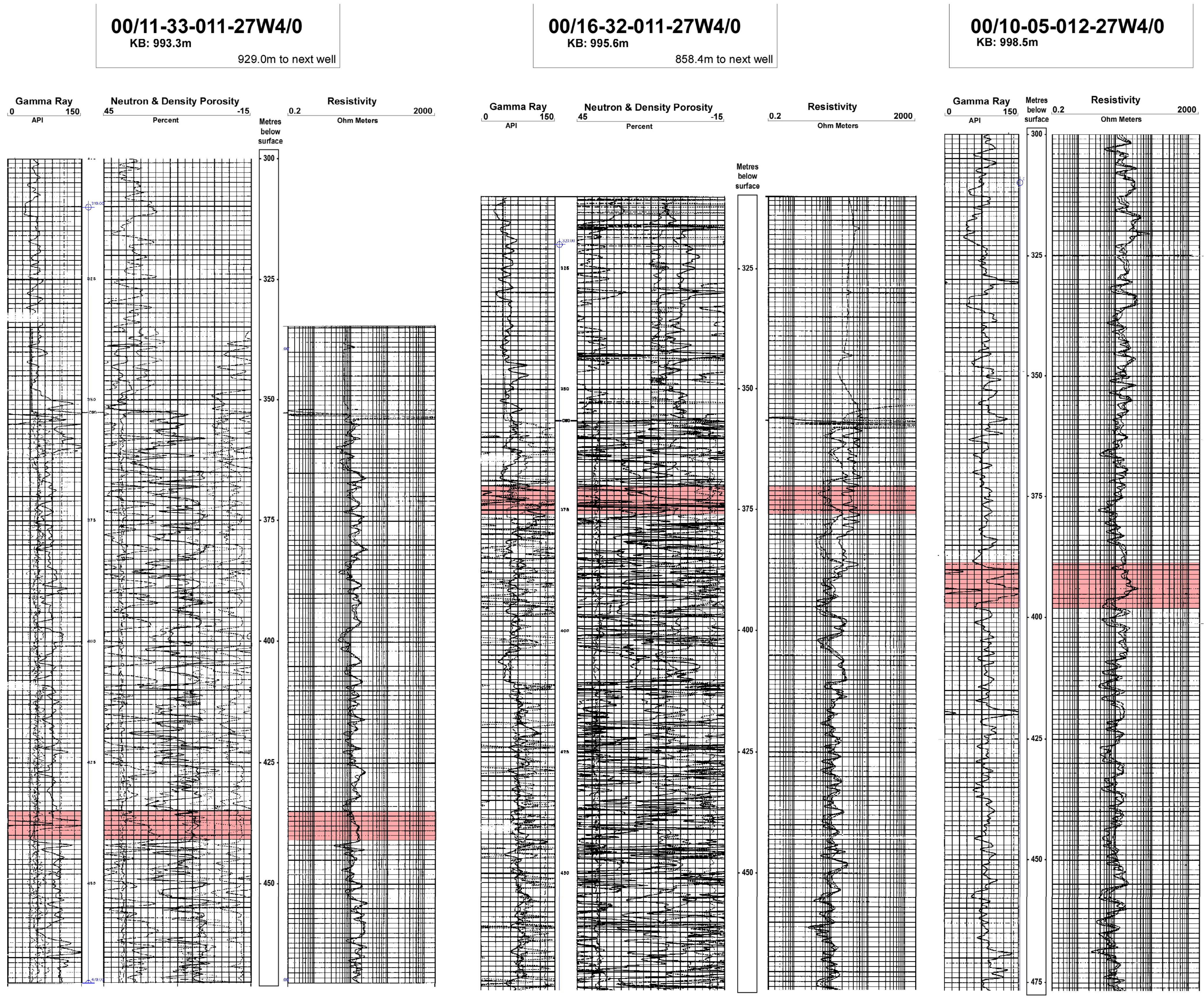


Figure 22. Anomalously radioactive intervals, cross-section D, Claresholm-Lethbridge area. See Figure 18 for location of section.

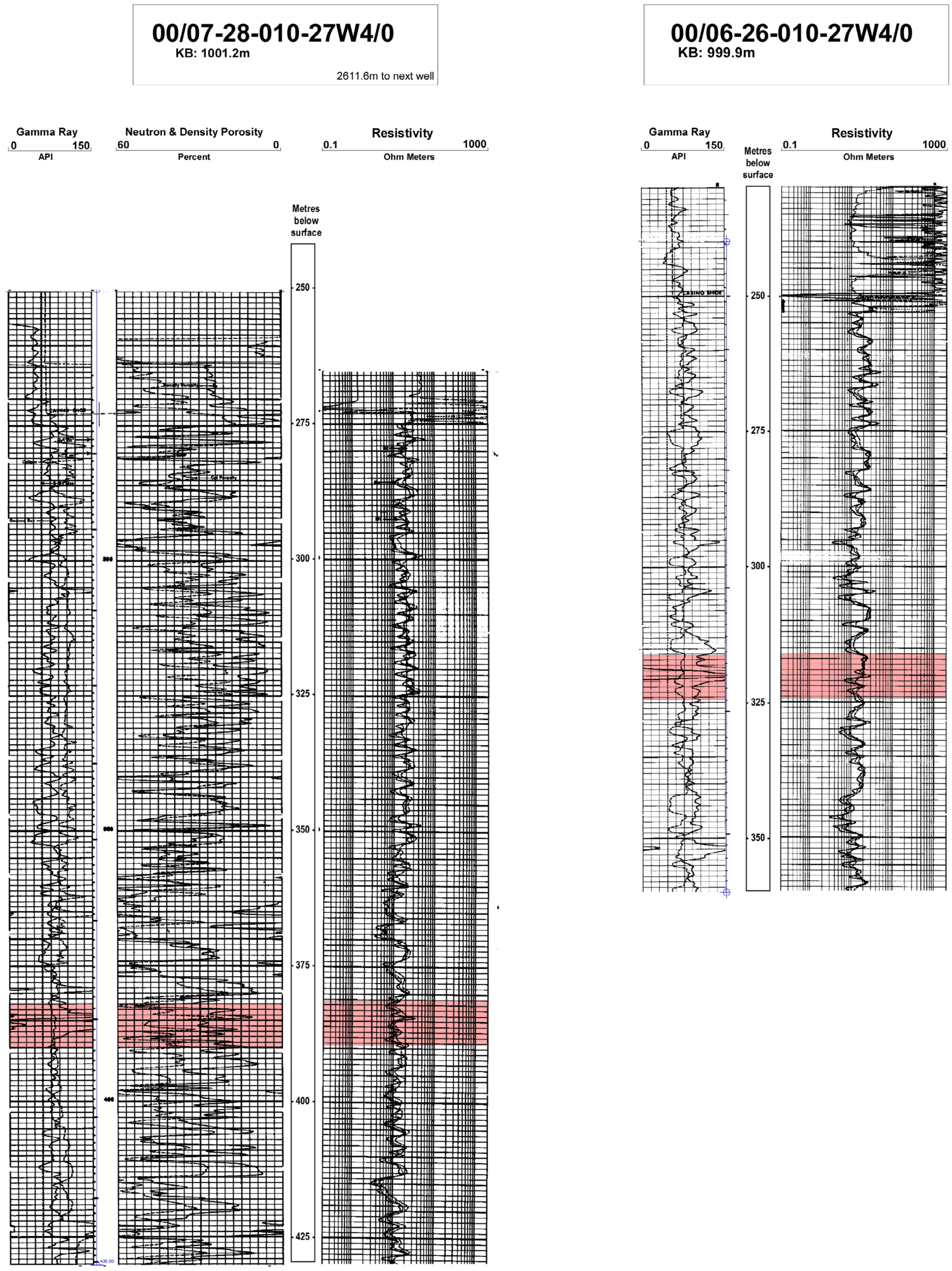


Figure 23. Anomalously radioactive intervals, cross-section E, Claresholm-Lethbridge area. See Figure 18 for location of section.

Table 5. Anomalous gamma intervals from coal-hole microfiche study.

Location	Coal Hole ID	Location		1st Gamma Peak		2nd Gamma Peak		Comments
		Longitude	Latitude	Value (API)	Depth (m)	Value (API)	Depth (m)	
13-16-24W4	SH1181	-113.18018	50.34464	150	115.5	180	328.3	
01-17-24W4	SH781	-113.18576	50.39917	300	237.0			
03-17-24W4	26-82	-113.23326	50.39727	400	10.0		55.0	Erratic high value (high value above water level at 61.0 m)
09-17-24W4	SH681	-113.24725	50.41732	225	322.0			
12-17-24W4	VUO382	-113.18016	50.41740	300	201.0			
15-17-24W4	34-82	-113.22487	50.43188	275	69.0	260	290.0	
15-17-24W5	24-82	-113.23327	50.44103	300	299.0			
15-01-22W4	1979	-112.85548	49.04296	166	11.0	165	12.5	Dark brown, carbonaceous shale interbedded with grey-yellow siltstone and possibly bentonite shale and siltstone; low gamma value above and below probable sandstone
15-01-22W4	1779	-112.85519	49.04712	175	11.7			Shale with bentonite
17-05-22W4	1976	-112.92280	49.39034	155	294.0	165	308.0	
10-12-23W4	2579	-113.05599	49.98782	150	40.0			Mix of sandstone, shale and bentonite
07-12-22W4	1179	-112.98772	49.98778	187	53.0			Thickly interbedded shale, sandstone and siltstone
27-12-22W4	2279	-112.91944	50.03153	150	14.0			Background gamma value 60 API
31-12-22W4	2379	-112.98766	50.04600	220	38.0			Interbedded shale, silty shale with bentonite stringers, and hard fine-grained sandstone; background gamma value 120 API

cuttings. We also examined and photographed the cuttings under binocular microscope (Figures 25–28). The cuttings proved helpful in defining some of the lithologies of the interval (sandstone, shale, quartz fragments, calcite films). Table 6 provides descriptions of the cuttings.

4 Conclusions

The intent of this report is to provide data and observations from the 2007 and 2008 work.

The most notable result of the field program was the discovery of a new radioactive occurrence and anomalous uranium value (158 ppm) in siltstone of the Willow Creek Formation along the Oldman River. Studies of outcrops did not reveal a regional redox boundary between oxidized and reduced formations. The variety of colours encountered seemed to relate more to the current erosion level, with more oxidized layers in the first few metres underlain by more reduced beds. Organic-rich shale of the St. Mary River Formation also yielded anomalously high uranium values. Uranium enrichment in shale can be attributed to the affinity between uranium and organic matter. However, the nature of uranium enrichment in seemingly unaltered and organic-poor clastic sediments of Willow Creek Formation remains unexplained at this time.

The extensive study of oil and gas well logs showed that gamma logs are adequate for identifying anomalously radioactive intervals and that resistivity, neutron and density logs could be used to determine rock types in and around the radioactive unit. The study showed that anomalous gamma intervals in 82% of the verified logs occur within shaly units with a high organic content (e.g., Base of Fish Scales and Second White Specks). Of the 1318 wells verified, 1080 wells have high gamma values within shale and

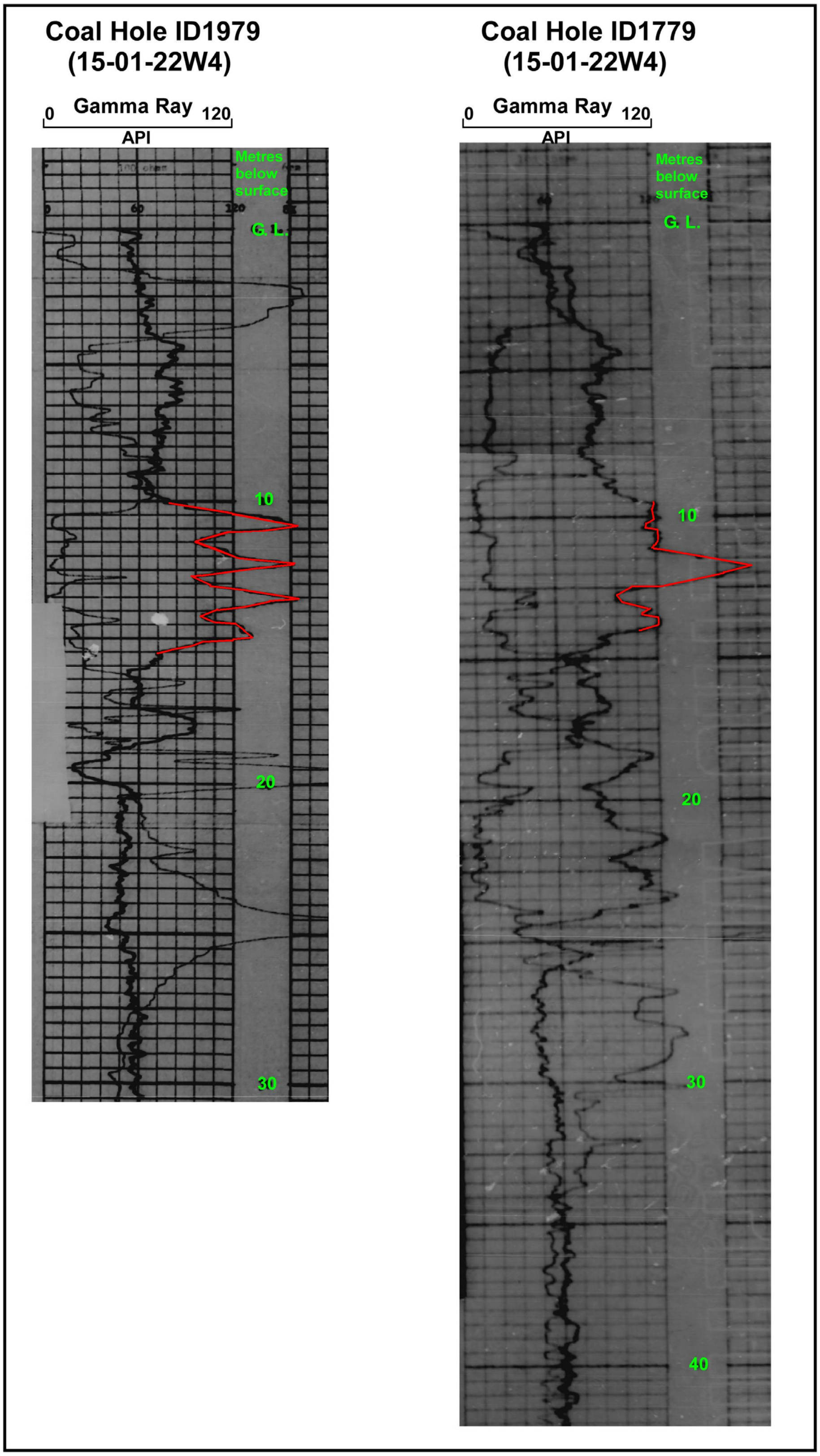


Figure 24. Radioactive intervals on coal-hole logs, with the anomalous interval on the gamma plot highlighted in red. Thin black line is the resistivity plot.

Figure 25. Cuttings from well 00/06-19-011-27W4. The sample contained fine-grained sandstone fragments, gypsum flakes, limonite grains and a few coal grains.

Figure 26. Cuttings from well 00/06-19-011-27W4. The sample fine- to medium-grained sandstone, ~1% limonite grains and a few quartz grains.

Figure 27. Cuttings from well 00/12-20-006-26W4. The sample contained medium-grained, greenish sandstone, massive light grey siltstone, and reddish and brown siltstone.

Figure 28. Snail shell in cuttings from well 00/04-12-015-27W4.

Table 6. Description of drill cuttings from selected wells in the Claresholm area.

Well ID	Location		KB Elevation (m)	Maximum Gamma		Cuttings Logged		Description	Scintillometer Reading (cps)[1]
	Longitude	Latitude		Value (API)	Depth (m)	From (m)	To (m)		
00/12-20-006-26W4	-113.476	49.488	1144.6	190	812	805	810	Light grey, fine-grained sandstone, orange-brown siltstone/mudstone (30%); light grey with yellow staining	66
00/12-20-006-26W4						810	815	Light greenish grey, medium-grained sandstone, massive light grey siltstone, reddish brown siltstone, rusty siltstone; angular quartz grains, calcareous	61
00/12-20-006-26W4						815	820	Medium-grained, greenish grey sandstone, dark purple and rusty siltstone; thin calcite film on siltstone	
00/06-19-011-27W4	-113.676	49.921	1010.4	195	620	618	621	Very fine grained sandstone, gypsum flakes, few coal grains; corase-grained sandstone (<1%), very weakly calcareous, light brown with some grey, very small chips are light brown	56
00/06-19-011-27W4						621	624	Fine- to medium-grained sadnstone, very rare rusty grains, small quartz grains (2-4%), few coal pieces, not calcareous, light-brown with some grey	60
00/06-19-011-27W4						624	627	White sandstone and dark grey shaly siltstone, no rust, very weakly calcareous, grey to greenish grey	64
00/06-19-011-27W4	-113.676	49.921	1010.4	180	470	460	463	Fine-grained sandstone, calcareous, no rusty grains, 1% quartz grains, chips of brown sandstone are bigger than grey sandstone, brown sandstone more competent than grey	62
00/06-19-011-27W4						463	466	Sandstone with rusty grains (<5%), predominantly brown, few angular quartz grains, calcareous	60
00/06-19-011-27W4						466	469	Fine- to medium-grained sandstone, ~1% rusty grains, few quartz grains, calcareous, oxidized	66
00/06-19-011-27W4						469	472	Fine- to medium-grained sandstone, angular quartz grains, no rusty grains, calcareous, possibly with carbonate grains, oxidized	63
00/06-16-012-27W4	-113.635	49.996	1012.6	190	329	320	325	Fine-grained light-grey sandstone, >5% rusty fragments, calcareous	61
00/06-16-012-27W4						325	330	Fine-grained light-grey sandstone, abundant rusty fragments, calcareous; possibly organics and pyrite, angular quartz grains, coal fragments	62
00/06-16-012-27W4						330	335	Fine-grained sandstone, ~5% gypsum flakes, ~5% rusty fragments, calcareous, dominantly grey greenish with some brown	64
00/06-16-012-27W4						335	340	Fine-grained sandstone, chert pieces, 3–5% rusty fragments, gypsum flakes, calcareous, greenish grey	62
00/06-16-012-27W4						340	345	Fine-grained sandstone, chert pieces, <1% rusty fragments, few gypsum flakes, angular quartz fragments, noncalcareous, dark grey, greenish grey	65
00/06-16-012-27W4						345	350	Fine-grained sandstone, noncalcareous, light grey	60
00/04-12-015-27W4	-113.595	50.239	1008.6		359	353	356	Medium-grained sandstone, light grey and greenish, fine-grained massive brown sandstone, well-rounded quartz grains, fossil snails (photo), coal fragments, calcareous	66
00/04-12-015-27W4						356	359	Light grey to greenish grey, fine-grained sandstone, white medium-grained sandstone, black flaky shale, angular quartz fragments, well-rounded fine-grained sandstone, noncalcareous	63
00/04-12-015-27W4						359	362	Predominantly grey-green and brown grains of fine-grained (mainly) sandstone, light grey medium-grained sandstone, chert pieces, gypsum flakes, brown shale flakes, weakly calcareous	61

Well ID	Location		KB Elevation (m)	Maximum Gamma		Cuttings Logged		Description	Scintillometer Reading (cps)[1]
	Longitude	Latitude		Value (API)	Depth (m)	From (m)	To (m)		
00/16-31-015-27W4	-113.696	50.307	1021.8	190	292	285	290	Light grey fine-grained sandstone (very small chips), 10% massive light grey siltstone, noncalcareous	64
00/16-31-015-27W4						290	295	Pure sand and bits of sandstone; grey, poorly rounded; same rock type as above but disintegrated	61
00/16-31-015-27W4						295	300	90% siltstone, light grey massive, <10% light grey sandstone, weakly calcareous	65
02/12-03-015-24W4	-113.228	50.230	973.4	225	302	295	300	Dark grey massive shale, siltstone	
02/12-03-015-24W4						300	305	Very fine grained, light grey massive shale (80%), light grey siltstone, a bit fizzy with 10% HCl (10%), dark grey massive shale (5%), coal fragments and calcite films (<1%)	
02/12-03-015-24W4						305	310	Very fine grained, light grey massive shale (80%), light grey siltstone, a bit fizzy with 10% HCl (10%), dark grey massive shale (5%), coal fragments and calcite films (<1%)	
00/08-16-015-24W4	-113.238	50.256	971.0	205	705	700	705	Light grey siltstone (30%), light brown siltstone (30%), very light grey sandstone, even white (10%), dark grey shale (10%), coal (<1%), almost no reaction with HCl	
00/08-16-015-24W4						705	710	Light grey greensih siltstone (30%), dark grey brownish shale? (20%), brown-yellow siltstone (<10%), light grey fine-grained sandstone (<10%), coal fragments (<1%)	
00/08-16-015-24W4						710	715	Light grey greenish siltstone (30%), dark grey brownish shale? (20%), brown yellow siltstone (<10%), light grey fine-grained sandstone (<10%), coal fragments (<1%)	
00/11-21-015-24W4	-113.249	50.274	973.0	185	375	370	375	Grey-brown siltstone (30%), light grey fine-grained sandstone (40%), light grey siltstone (10%), coal fragments (<1%)	
00/11-21-015-24W4						375	380	Grey-brown siltstone (30%), light grey fine-grained sandstone (40%), light grey siltstone (10%), coal fragments (<1%)	
00/11-21-015-24W4						380	385	Grey-brown siltstone/shale (80%), light grey to white sandstone (20%), coal fragments (<1%)	

[1] Scintillometer readings were collected using GR-135

77 wells have anomalous gamma values within sandstone. In most cases, the wells with high radioactive intervals in sandstone are spatially isolated. Clusters of wells with high gamma readings in sandstone occur in NTS map areas 82O, 83G, 83O and 84D.

Uncased coal logs studied during this project proved useful for identification of shallow radioactive intervals, but their usefulness is limited by the relatively small numbers of coal holes in the area of interest and the difficulty in accessing the data from microfiche.

Testing drill cuttings from oil and gas wells that cover radioactive intervals was unable to confirm the source rocks for the radioactive anomalies but provided insight into the rock types of these intervals.

Most importantly, an examination of the gamma logs in the Claresholm area of southern Alberta revealed radioactive sandstone within a cluster of wells in the area defined by Townships 10 to 15 and Ranges 27W4 to 28W4. High gamma values occur within a rock package with generally low background gamma values (<90 API). The interpretations outline an area for future detailed evaluation of sandstone-hosted uranium potential in southern Alberta.

5 References

Davis, J.F. (1969): Uranium deposits of the Powder River basin; Contributions to Geology, v. 8, no. 2, pt. 1, p. 131–141.

Denson, N.M. (1959): Uranium in coal in the western United States, 1959; United States Geological Survey, 315 p.

Dufresne, M.B., Eccles, D.R. and Leckie, D.A. (2001): The geological and geochemical setting of the mid-Cretaceous Shaftesbury Formation and other Colorado Group sedimentary units in northern Alberta; Alberta Energy and Utilities Board, EUB/AGS Special Report 009, 654 p., <http://www.ags.gov.ab.ca/publications/abstracts/SPE_009.html>, [July 2009].

Grushevoi, G. and Pechenkin, I. (2003): Metallogeny of uranium bearing sedimentary basins of central Asia; All-Russian Geological Research Institute, Moscow, p. 10–97.

Hage, C.O. (1968): Report on exploration, Quartz mineral exploration permits numbers 32 and 33, Cypress Hills area, Alberta; Alberta Research Council, Alberta Geological Survey, Mineral Assessment Report MIN 19680008, 28 p, URL <http://www.ags.gov.ab.ca/publications/abstracts/MIN_19680008.html> [October 2009].

Kochenov, A.V., Kruglova, V.G., Haldey, A.E. and Halezov, A.B. (1995): Factors determining concentration and composition of microelements in ores of infiltration-type uranium deposits in paleovalleys and intermontane basins; *in* Genesis of rare metal and uranium ores in sedimentary rocks, Nauka, Moscow, 1995.

Lebel, D. and Williams, E.P. (1994): Geology, Cardston, Alberta; Geological Survey of Canada, Open File 2854, 1 map, scale 1:50 000.

Mack, G.H. and Jerzykiewicz, T. (1989): Provenance of post-Wapiabi sandstones and its implications for Campanian to Paleocene tectonic history of the southern Canadian Cordillera; Canadian Journal of Earth Sciences, v. 26, p. 665–676.

Matveeva, T. and Anderson, S.D.A. (2007): Sandstone–hosted uranium potential of southern Alberta—preliminary assessment; Alberta Energy and Utilities Board, EUB/AGS Earth Sciences Report 2007-10, 97 p., URL <http://www.ags.gov.ab.ca/publications/abstracts/ESR_2007_10.html> [July 2009].

Matveeva, T. and Kafle, B. (2009a): Sandstone-hosted uranium potential of Alberta: study of oil and gas well logs; Energy Resources Conservation Board, ERCB/AGS Digital Data DIG 2009-0016.

Matveeva, T. and Kafle, B. (2009b): Uranium potential of southern Alberta: 2006–2008 fieldwork results; Energy Resources Conservation Board, ERCB/AGS Digital Data DIG 2009-0017.

Olson, R.A. and Anderson S. (2007): Preliminary water well sampling to assess the uranium potential in the Whiskey Gap area of southern Alberta (NTS 82H/2, 3); Alberta Energy and Utilities Board, EUB/AGS Earth Sciences Report 2007-08, 41 p., URL <http://www.ags.gov.ab.ca/publications/abstracts/ESR_2007_08.html> [July 2009].

Rider, M. (2002): The geological interpretation of well logs; Rider-French Consulting Ltd, Scotland, 280 p.

Sanford, R.F. (1985): Origin of sandstone-hosted uranium deposits, Frome Embayment, South Australia; International Atomic Energy Agency, IAEA-Tecdoc-328, p. 297–313.

Saskatchewan Research Council (2009): Geoanalytical laboratories, 2009 fee schedule; Saskatchewan Research Council, URL <http://www.src.sk.ca/html/labs_facilities/geo_labs/uranium/index.cfm>, [July 2009].

Stepic J. and Matveeva, T. (2010): Sandstone-hosted uranium in southern Alberta: petrographic descriptions of exposed Upper Cretaceous and Tertiary rock formations; Energy Resources Conservation Board, ERCB/AGS Open File Report 2009-13.