A New Look at Selected Deposits in the Historic Beaverlodge Uranium District: Variations on the Vein-type Uranium Theme

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__________ (2011): Geology of the Verna-Dubyna mines area (part of NTS 74N/09); 1:5 000-scale prelim. geological map *with* Summary of Investigations 2011, Volume 2, Saskatchewan Geological Survey, Sask. Ministry of Energy and Resources, Misc. Rep. 2011-4.2.

Abstract

The host rocks to a number of vein-type uranium occurrences and deposits immediately northeast of the Ace-Fay-Verna mine and along the northeast-striking St. Louis fault are re-interpreted as variably sheared pink seriate leucogranites that have intruded Murmac Bay group quartzite and amphibolite. Pitchblende mineralization occurs in discrete fault zones, fractures, and veins. The leucogranite contains a kilometre-scale anastomosing network of episyenitic alteration which hosts, or is spatially associated with, most of the mineralization. Minor uranium mineralization is also found in mylonitized equivalents of the leucogranite about 1 km south of the St. Louis fault.

About 3 km to the north, and immediately adjacent to the Martin group unconformity, is a second northeast-trending zone of pink leucogranite-hosted uranium deposits and occurrences. The style of pitchblende mineralization is very similar to that of the first zone, although the alteration differs somewhat. The associated alteration rocks have been hematized, but the majority either lack the de-quartzified character of episyenite, or have been subsequently re-silicified.

The past-producing Lorado mine, which is southwest of Beaverlodge Lake, differs from uranium occurrences in the two northeast-trending zones northeast of Beaverlodge Lake by being hosted by Murmac Bay group graphitic chlorite-sericite-pyrite schists thought to be derived from black shales.

Many questions remain regarding deposit models for the studied Beaverlodge uranium deposits and occurrences, including the source of the uranium, the reduction mechanism, and the role of the Martin group, but they all lack the clay alteration of the unconformity-type Athabasca Basin deposits and are thus considered distinct. The leucogranites are relatively fertile rocks and may have been the source of the uranium, leached from previously sheared to mylonitic equivalents by fluids moving along later brittle structural conduits.

Keywords: *Beaverlodge uranium district, vein-type uranium deposit, episyenite, Ace-Fay-Verna mine, Eagle mine, Dubyna mine, Lorado mine.*

1. Introduction

The vein-type uranium deposits within the past-producing Beaverlodge uranium district (Figure 1) in northwestern Saskatchewan were exploited between 1955 and 1982. Although many of the sixteen past-producing mines and numerous small pits have been previously described (*e.g.*, Robinson, 1955; Canadian Institute of Mining and Metallurgy, 1957; Lang *et al.*, 1962; Beck, 1969; Evoy, 1986), most descriptions predate most modern uranium mineralization models and classifications (*e.g.*, Nash *et al.*, 1981; Ruzicka, 1993; Cuney and Kyser, 2008; International Atomic Energy Agency, 2009). An M.Sc. thesis project, initiated in 2009 by M. Tracey at the University of New Brunswick, was aimed at updating some of these deposit descriptions and studying the genesis of uranium mineralization. Preliminary results based on the 2009 field work focussed on the Hab mine and 46 zone, which are within the Verna-Dubyna locale (Figure 1; Tracey *et al.*, 2009). In the summer of 2010, several more deposits were studied, but the project was unexpectedly discontinued before the report and maps had been prepared.

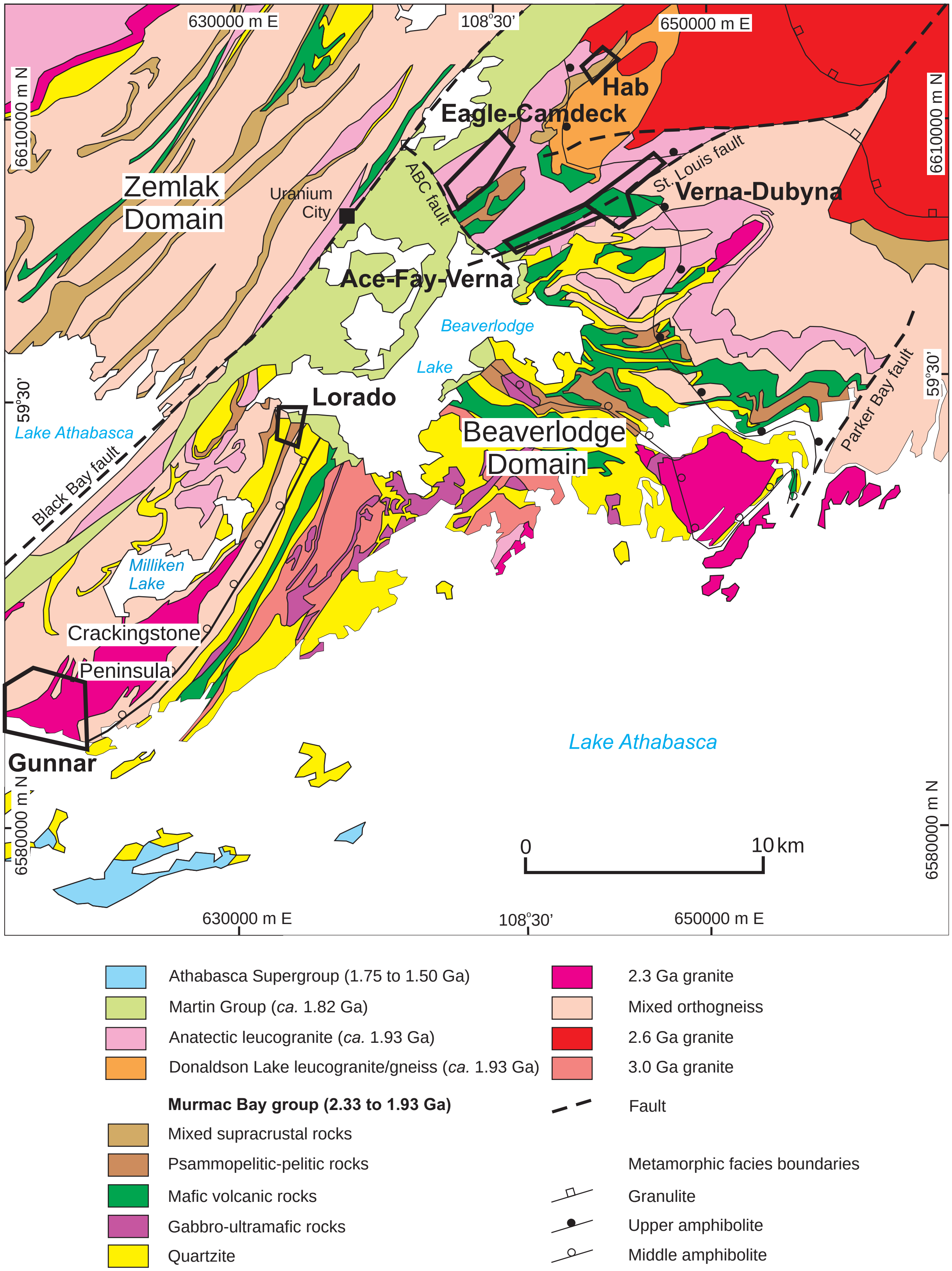

Figure 1 – Location of studied deposits and occurrences in the Beaverlodge uranium district within the regional geological framework. Black boxes outline areas discussed in text and/or on accompanying figures and map separates.

This paper documents the results of three weeks of field work conducted in 2011 by the Saskatchewan Geological Survey that was intended to complete and supplement Tracey's 2010 mapping.

The northeastern Beaverlodge uranium district has been mapped several times (*e.g.*, Christie, 1953; Tremblay, 1972), most recently as part of a 1:20 000-scale regional mapping project (Ashton *et al.*, 2000) that was subsequently compiled at 1:50 000 scale (Ashton and Hartlaub, 2008). Mineralization in the Beaverlodge uranium district was summarized by Beck (1969), who described about 250 of the more than 1,000 pitchblende occurrences, including 16 past-producing mines. Most were considered vein, breccia or disseminated types of mineralization, or some combination thereof, which early geochronological work suggested was emplaced at about 1.78 Ga (Koeppel, 1968).

The deposits/occurrences studied in this report include: 1) the 46, 21, 11, and 83 zones and the Dubyna mine in the Verna-Dubyna mines area along the St. Louis fault; 2) the Eagle shaft, and Intermediate, Gully, and Camdeck zones along a second northeast-striking trend north of Beaverlodge Lake; and 3) the Lorado deposit southwest of Beaverlodge Lake (Figure 1). The deposits/occurrences comprising the first two groups are hosted by highly strained leucogranites of inferred 1.93 Ga age (Hartlaub *et al.*, 2005) and amphibolites proximal to large bodies of leucogranite (Ashton and Hartlaub, 2008). The high degree of brittle-ductile strain led to previous misinterpretation of both rock types as having sedimentary precursors (*e.g.*, Beck, 1969; Tremblay, 1972). Uranium deposits/ occurrences comprising each of these first two groups have much in common and are thus described together. In contrast, the Lorado deposit is hosted by highly strained graphite- and sulphide-bearing mica schists, interpreted here as metamorphosed black shales of the Paleoproterozoic Murmac Bay group, and is thus treated separately.

A hand-held, high-sensitivity, gamma and neutron radiation spectrometer (Radiation Solutions RS-230) was used to establish average concentrations of eU, eTh, and eK[1] for the major rock types (Table 1) and to study their variability in altered and mineralized rocks. Although these spectrometer assays are informative, they should not be used as substitutes for direct rock assays.

2. Regional Geology

The Beaverlodge uranium district lies within the southwestern Beaverlodge and easternmost Zemlak domains. The regional geology has been previously described (Ashton *et al.*, 2000; Ashton and Hartlaub, 2008), and can be briefly summarized as follows. *Circa* 3.0 and 2.6 Ga granitoids were metamorphosed at about 2.37 Ga (Koster and Baadsgaard, 1970; Ashton *et al.*, 2009a), which is attributed to the *ca.* 2.5 to 2.35 Ga Arrowsmith orogeny (Berman *et al.*, 2005), prior to emplacement of 2.33 to 2.29 Ga syn- to post-collisional granites (Hartlaub *et al.*, 2007). Granite emplacement partly overlapped with deposition of the Murmac Bay group, which began at about 2.33 Ga and lasted until at least 2.17 Ga (Ashton *et al.*, 2009a). All of these rocks were then affected by regional deformation attributed to the Taltson orogeny that produced a west-northwest–striking S1-S2 transposition fabric and associated amphibolite facies metamorphism at about 1.94 to 1.92 Ga. A second amphibolite facies metamorphic event *ca.* 1.91 to 1.90 Ga and development of a northeast-striking deformational overprint (D3; Ashton *et al.*, 2009b) are apparently tied to tectonic events taking place in the vicinity of the Snowbird tectonic zone which lies about 200 km to the west. This was followed by deposition of the Martin group during a fourth phase of deformation at about 1.8 Ga (Ashton *et al.*, 2009b) and the unmetamorphosed Athabasca Supergroup between about1.75 (Rainbird *et al.*, 2007) and 1.50 Ga (Creaser and Stasiuk, 2007).

3. Verna-Dubyna Mine Area

The Verna-Dubyna mine area, which includes the 46, 11, and 21 zones, is located directly northeast of the past-producing Ace-Fay-Verna mine and spans the St. Louis fault (Figures 1 and 2). Amphibolite, along with minor quartzite and pelitic gneiss of the Murmac Bay group occur both *in situ* and as xenoliths in widespread leucogranite. Variable strain produces near-massive to mylonitic textures in the leucogranite and locally flattens the xenoliths to produce a gneissic texture. Episyenitic alteration, marked by the removal of quartz and K-feldspar, coupled with the addition of albite and hematite, forms a semi-continuous network within the leucogranite.

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[1] The 'e' is an abbreviation of equivalent inferring that these elements are not measured directly. Also note that K contents are reported as %K and not %K_2O. To convert, multiply %K values by 1.2047.

Table 1 – Magnetic susceptibility and average radiometric measurements from the main rock types.

Rock Type*	Rock Code	Average Radiometric Measurements						Magnetic Susceptibility (10^3 SI)			
		n=	eU (ppm)	eTh (ppm)	eTh/eU	%eK	counts per sec	n=	Mag (high)	Mag (low)	Mag (ave)
Martin group (T)	Rb	10	7.9	11.2	1.4	4.0	338.0	4	0.23	0.08	0.13
Martin group (N)	*Rb*	*9*	*6.1*	*11.1*	*1.8*	*4.3*	*258.9*				
Verna-Dubyna Leucogranites											
pink seriate leucogranite (T)	Alp	31	37.9	20.5	0.5	1.9	870.0	25	0.39	0.12	0.21
pink seriate leucogranite (N)	*Alp*	*26*	*9.6*	*20.8*	*2.2*	*1.7*	*525.4*				
pink seriate leucogranite-episyenite altered (T)	Alp-e	11	112.2	23.4	0.2	1.7	1133.6	5	0.34	0.14	0.22
pink seriate leucogranite-episyenite altered (N)	*Alp-e*	*5*	*9.2*	*20.0*	*2.2*	*1.5*	*608.0*				
pink seriate leucogranite-xenolith rich (T&N)	*Alp-x*	*17*	*9.1*	*18.4*	*2.0*	*2.3*	*420.0*	*9*	*0.28*	*0.12*	*0.19*
pink seriate leucogranite-xenolith rich-episyenite altered (T)	Alp-x-e	8	24.2	28.0	1.2	0.9	647.5	3	0.33	0.13	0.30
pink seriate leucogranite-xenolith rich-episyenite altered (N)	*Alp-x-e*	*6*	*10.3*	*35.0*	*3.4*	*1.0*	*496.7*				
gneissic leucogranite (T)	Alp-g	12	22.0	12.4	0.6	1.4	510.0	13	0.62	0.08	0.22
gneissic leucogranite (N)	*Alp-g*	*8*	*3.9*	*12.8*	*3.3*	*1.4*	*198.8*				
gneissic leucogranite-episyenite altered (T)	Alp-g-e	9	29.4	13.4	0.5	2.2	740.0	10	0.29	0.04	0.12
gneissic leucogranite-episyenite altered (N)	*Alp-g-e*	*8*	*9.1*	*10.9*	*1.2*	*0.9*	*382.5*				
sheared leucogranite-83 zone(T&N)	*Alp-s*	*16*	*4.1*	*14.9*	*3.6*	*2.3*	*387.2*	*9*	*0.36*	*0.09*	*0.19*
mylonitic leucogranite-83 zone (T)	Alp-m	24	7.0	19.3	2.8	2.3	521.7	10	0.40	0.08	0.19
mylonitic leucogranite-83 zone(N)	*Alp-m*	*23*	*5.9*	*18.3*	*3.1*	*2.2*	*379.1*				
Eagle-Camdeck Leucogranites											
leucogranite (T)	Alp-n	62	24.9	26.9	1.1	2.4	752.7	25	0.36	0.10	0.16
leucogranite (N)	*Alp-n*	*44*	*7.1*	*21.3*	*3.0*	*2.3*	*420.8*				
schistose leucogranite-Eagle (T)	Alp-sc	18	6.2	17.9	2.9	2.3	389.4	10	0.54	0.15	0.32
schistose leucogranite-Eagle (N)	*Alp-sc*	*17*	*4.5*	*16.9*	*3.8*	*2.4*	*321.2*				
cataclasite (T)	Alp-c	10	5.2	10.9	2.1	1.2	310.5	2	0.55	0.15	0.20
cataclasite (N)	*Alp-c*	*9*	*3.1*	*10.1*	*3.3*	*1.3*	*211.7*				
Murmac Bay Group											
amphibolite (T)	Ma	37	16.7	4.3	0.3	0.9	377.4	34	2.49	0.31	0.81
amphibolite (N)	*Ma*	*32*	*3.2*	*4.0*	*1.3*	*0.9*	*214.5*				
chlorite-sericite schist (siltstone-argillite)-Lorado (T)	Mcs	15	22.8	17.4	0.8	2.6	672.0		n/a	n/a	n/a
chlorite-sericite schist (siltstone-argillite)-Lorado (N)	*Mcs*	*12*	*6.6*	*17.3*	*2.6*	*2.1*	*345.8*				
pelite-46 zone (T&N)	*Mp*	*3*	*4.7*	*10.9*	*2.3*	*1.7*	*233.3*	*3*	*0.33*	*0.10*	*0.20*
quartzite (T)	Mq	13	7.3	6.3	0.9	0.6	293.1	3	1.50	0.03	0.37
quartzite (N)	*Mq*	*12*	*4.2*	*6.0*	*1.4*	*0.6*	*209.2*				
impure quartzite (T)	Mqi	17	11.6	11.3	1.0	1.7	445.3		n/a	n/a	n/a
impure quartzite (N)	*Mqi*	*15*	*5.8*	*11.8*	*2.0*	*1.7*	*328.0*				
Basement											
granite (T)	G30	7	10.3	13.1	1.3	2.5	402.9		n/a	n/a	n/a
granite (N)	*G30*	*5*	*3.3*	*13.0*	*3.9*	*2.9*	*274.0*				

* T, total; and *N*, non-mineralized (arbitrarily defined as having <20 ppm eU) samples only.

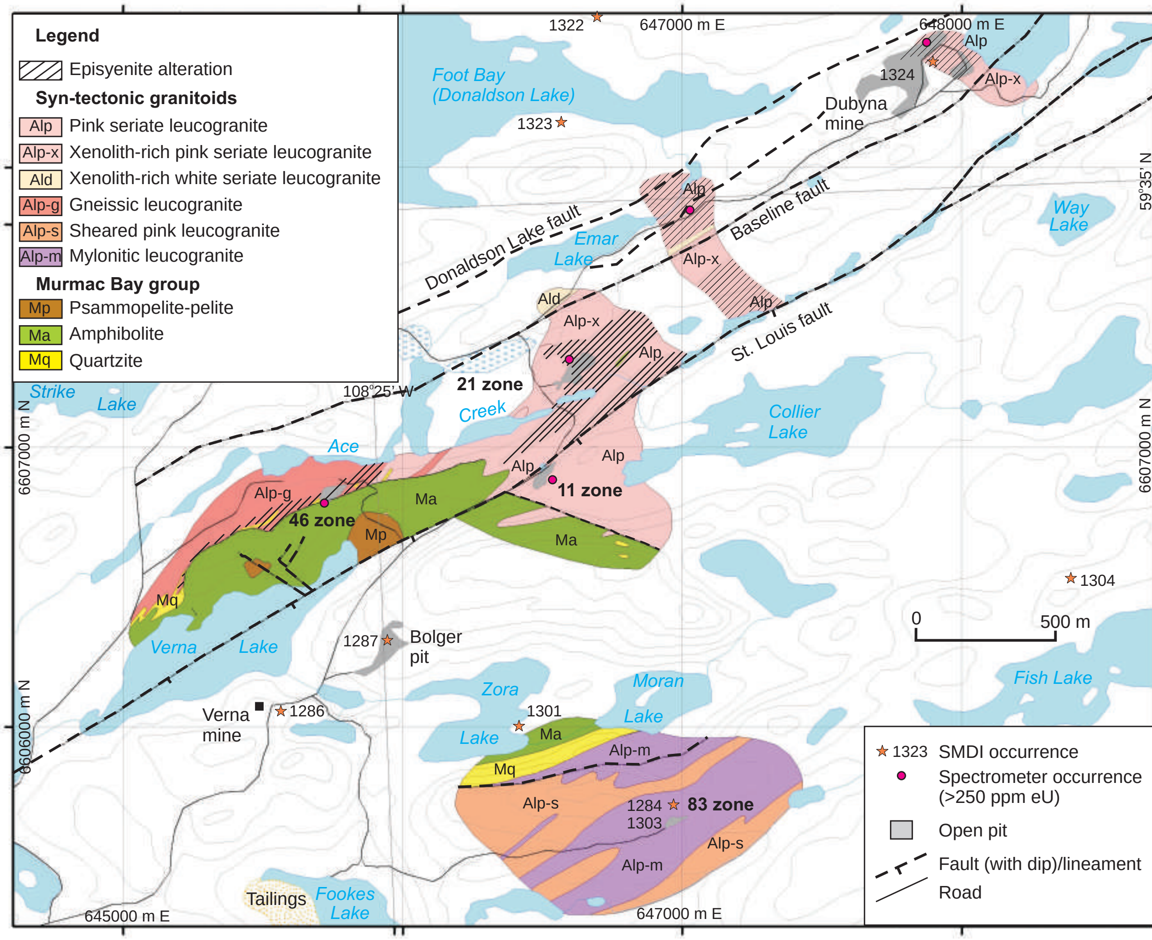


Figure 2 –Simplified geological map of the Verna-Dubyna area.

a) Unit Descriptions

Murmac Bay Group

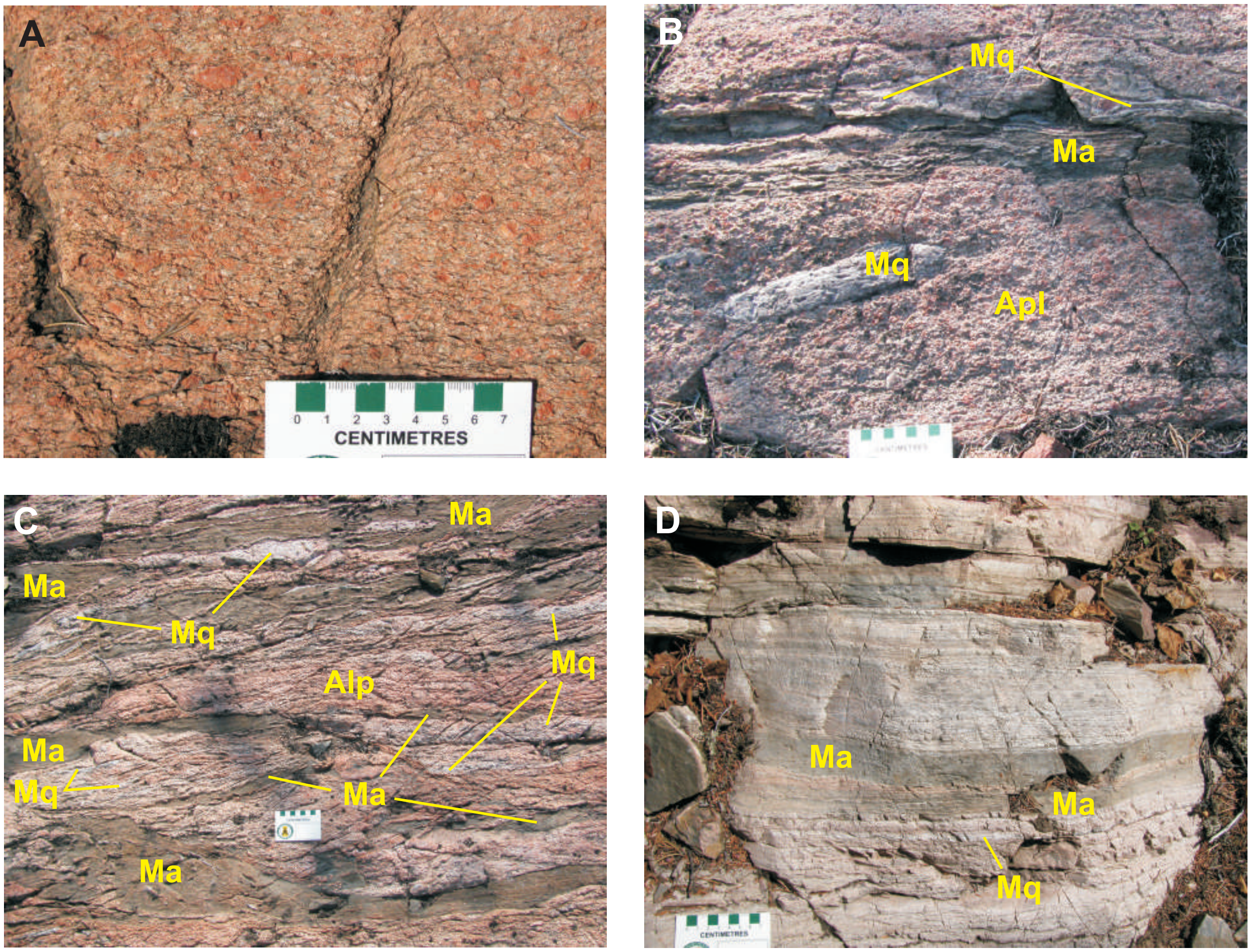
White to pale pink quartzite (Mq) is exposed north of Verna Lake, south of Zora Lake, and as inclusions within the leucogranite (Figure 2). It is weakly layered, commonly displays a strong fracture cleavage, and is variably sheared to mylonitized. Local centimetre-scale chlorite-rich shear zones may have been initiated in mafic dykes. Most rocks are fine grained, recrystallized, and contain in excess of 95% quartz with minor feldspar and/or sericite.

Amphibolite (Ma) is closely associated with the quartzite and is also a common inclusion type in the leucogranite. It weathers grey-green to brown-green and is dark green on fresh surfaces. It is generally fine grained, foliated and variably sheared to mylonitic with a platy foliation, but in local strain lows is near massive and fine to medium grained. A cataclastic overprint, particularly near faults, has resulted in fracturing and quartz, carbonate and epidote veining. The approximately 50% hornblende has been largely replaced by chlorite and minor epidote. Decimetre-scale, pale-pink, medium-grained, granitic dykes, some exhibiting episyenite alteration, intrude the amphibolite at several localities. Due to the general lack of primary features, it is unclear if the amphibolite is derived from Murmac Bay group volcanic rocks or co-genetic gabbro.

Psammopelitic to pelitic chlorite-sericite schist (Mp) is spatially associated with the amphibolite near Verna Lake (Figure 2). It is grey-brown to pale green, fine to medium grained and variably sheared to mylonitic. Late deformation has locally produced crenulations of the schistose foliation. Typical rocks contain 10 to 35% combined muscovite and chlorite, and are interpreted as psammopelitic to pelitic metasedimentary rocks of the Murmac Bay group.

Leucogranite

Leucogranite is the most common rock type in the Verna to Dubyna area, but occurs in many forms, thereby causing some confusion in recognition and classification. In its least-deformed variety, in the vicinity of the 21 zone, the leucogranite (Alp) is pale to salmon pink with a seriate grain size ranging from 1 to 5 mm. It is homogeneous and massive to weakly foliated (Figure 3A) in that area, but elsewhere is variably sheared. The leucogranite contains up to 10% chlorite (generally 3 to 5%) after biotite, along with local sericite±specular



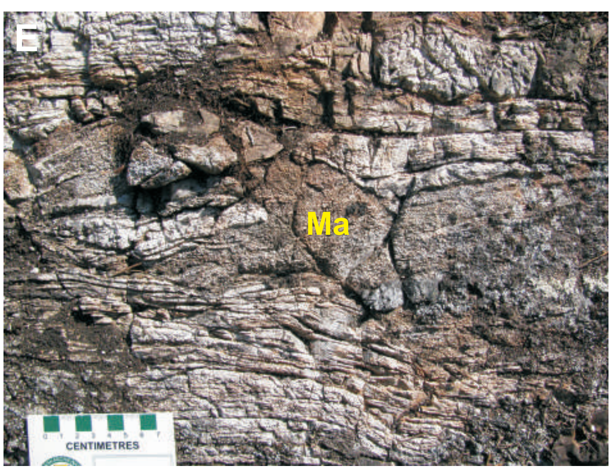


***Figure 3** – Outcrop photos showing variations in appearance of leucogranite: A) pink seriate leucogranite illustrating seriate texture and weakly foliated character; from 21 zone (UTM 646838 m E, 6607269 m N); note apparent sinistral shear running from top to bottom of photo; B) xenolith-rich pink seriate leucogranite containing tabular xenoliths of Murmac Bay group quartzite and amphibolite; from 21 zone (UTM 646594 m E, 6607367 m N); C) xenolith-rich pink seriate leucogranite illustrating fine scale of leucogranite infiltration and gneissic texture developed by flattening of abundant Murmac Bay group quartzite and amphibolite xenoliths; from 21 zone (UTM 646631 m E, 6607452 m N); D) gneissic granite containing quartz-rich and mafic layers derived from Murmac Bay group quartzite and amphibolite, respectively; from 46 zone (UTM 645144 m E, 6606477 m N); and E) mylonitic leucogranite illustrating platy foliation; from 83 zone (UTM 647332 m E, 6605827 m N); note absence of platy foliation in amphibolite inclusion. Abbreviations: leucogranite (Apl), quartzite (Mq), and amphibolite (Ma). Note: All UTM coordinates are in NAD 83, zone 12, unless otherwise specified.*

hematite. Inclusions of Murmac Bay group quartzite and amphibolite are common and locally comprise up to 60% of exposures where they form the xenolith-rich pink seriate leucogranite (Alp-x). The metre-scale xenoliths range from angular to rounded although most are lenticular, having been flattened during deformation (Figure 3B). The xenoliths can be very intimately mixed with the leucogranite due to the fine scale of its infiltration which, with increasing strain, results in a gneissic texture (Figure 3C). Variably dismembered, decimetre-scale, salmon-pink, coarse-grained granite dykes within the leucogranite may be co-genetic. At the north end of the 21 zone and in a small area east of Emar Lake (Figure 2), the colour of the leucogranite matrix is different creating a subunit of xenolith-rich white seriate leucogranite. This variety is virtually identical to a much more extensive unit of 'inclusion-rich to migmatitic leucocratic granite to tonalite' that includes the former 'Donaldson Lake Gneiss' (Ashton and Hartlaub, 2008) exposed about 1 km to the northwest (Figure 1). The gradational relationship between pink and white colour variants, and between varieties containing abundant xenoliths and those containing few or none, supports the idea that all of these are co-genetic forms of the same intrusive leucogranite unit.

With further increasing deformation, quartzite and amphibolite xenoliths within the leucogranite in the '46 zone' (Figure 2) become even more layer like, forming a gneissic leucogranite (Alp-g). The resulting quartz-rich and mafic layers are up to several centimetres thick and most rocks are sheared to mylonitic (Figure 3D) with a variable cataclastic overprint. The leucogranite forming the matrix to the flattened xenoliths is cream, pink, or grey, fine to very fine grained, and contains up to 10% (generally 3 to 5%) chlorite after biotite, along with minor sericite. Decimetre-scale pods of salmon-pink, coarse-grained granite are interpreted as dismembered varieties of the dykes noted in the less-deformed leucogranite.

South of the St. Louis fault, in the '83 zone' area (Figure 2), intense deformation has produced a sheared pink leucogranite (Alp-s). It varies from pink to pink-red and is fine grained with local feldspar porphyroclasts up to 1 mm in size. Quartz displays 5:1 aspect ratios (locally up to 10:1) although the strong foliation is commonly masked by a strong cataclastic overprint. Murmac Bay group xenoliths are rare. Still higher intensities of deformation in the '83 zone' produce mylonitic leucogranite (Alp-m; Figure 3E), which is cream, pink, or grey and fine to very fine grained with pink leucogranite remnants up to centimetre scale visible on fresh surfaces. It is characterized by platy weathering and ≥10:1 quartz aspect ratios. A variably strong cataclastic overprint has resulted in abundant chlorite-lined fractures. Typical rocks contain up to 10% (generally 3 to 5%) chlorite after biotite, along with minor sericite and pyrite. Rare quartz and mafic-rich layers are interpreted as attenuated Murmac Bay group xenoliths.

Late Dykes

Pale pink, medium-grained granitic dykes, which are generally 30 to 40 cm thick and broadly concordant, were noted intruding the quartzite and amphibolite. They are near massive, but locally boudinaged and contain about 5% chlorite. Salmon-pink, coarse-grained leucogranite dykes are common in the leucogranite units. Most are concordant, but crosscutting relationships were observed in quartzite inclusions. The leucogranite dykes are up to about 30 cm in thickness and near massive, but variably dismembered in highly deformed host rocks.

Episyenite Alteration

The term 'episyenite' has been applied to rocks that have been hydrothermally altered so that quartz, and commonly K-feldspar, have been removed from the system and replaced by albite along with hematite (Cathelineau, 1986; Peterson and Eliasson, 1997; International Atomic Energy Agency, 2009). Episyenite alteration was described in a recent study of the past-producing Gunnar uranium mine 32 km to the southwest (Figure 1; Ashton, 2010) and the reader is referred to that work for a more detailed description. In the Verna-Dubyna mines area, episyenitic alteration occurs in a semi-conformable, anastomosing network with individual branches up to tens of metres wide and extending over a strike length of at least 3.5 km. It is recognizable by a reduction in the amount of visible quartz in the host leucogranite and by its reddening due to the addition of microscopic hematite (Figure 4). The colour ranges from pale pink to orange-pink to pink-red to red-brown with increasing hematite content. Weathering surfaces are locally pitted due to the dissolution of quartz, or more likely, carbonate, which

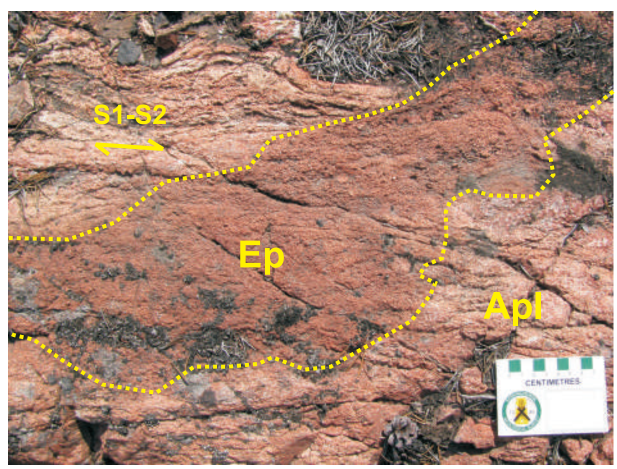


Figure 4 – Red episyenite (Ep) alteration (within yellow dotted lines) cutting across S1-S2 foliation in pink seriate leucogranite (Apl); from 21 zone (UTM 646633 m E, 6607515 m N).

commonly occurs in the matrix of episyenite and as veins comprising up to 30% of some exposures. Typical rocks also contain 2 to 5% chlorite and 1 to 2% specular hematite, with the remainder inferred to be mostly albite. Episyenite alteration affected the pink seriate leucogranite, both varieties of xenolith-rich leucogranite, and the gneissic leucogranite. It may have also affected the sheared pink and mylonitic leucogranites of the 83 zone and the supracrustal rocks, but would be more difficult to identify in those units.

Table 1 illustrates changes in the concentrations of eU, eTh and eK due to deformation and episyenitic alteration based on spectrometer measurements. The average eK contents of the best-preserved and least-altered, pink seriate and xenolith-rich pink seriate leucogranites are 1.9 and 2.3% eK, respectively, consistent with more granodioritic to tonalitic compositions (Le Maitre, 1976). Episyenitic alteration of these two rock types results in a loss of eK to 1.7 and 0.9%, respectively. Average eTh concentrations of 20.5 and 18.4 for the pink seriate and xenolith-rich pink seriate leucogranites, respectively, are consistent with values for granitoid rocks (Cuney and Kyser, 2008). Increases in average eTh for the altered equivalents of both rock types (23.4 and 28.0, respectively) suggest that Th is added during alteration, perhaps in the form of hydrothermal monazite. The more deformed varieties of the leucogranites all have reduced eTh values indicating a net loss during deformation; eU values are highly variable in the leucogranite suite since the samples are located in close proximity to uranium mineralization. Nevertheless, altered varieties consistently contain higher concentrations of eU than their unaltered counterparts, whereas the most deformed varieties have experienced a loss of eU.

b) Structure of the Verna-Dubyna Mines Area

The regional geology has been summarized elsewhere (Ashton *et al.*, 2009b; Ashton, 2010). Within the Verna-Dubyna mine area, the main regional S1/S2 transposition foliation is defined by mineral alignment and xenolith flattening, and varies in intensity from near massive to mylonitic. Rare isoclinal F2 folds are refolded by more common, open to tight, F3 folds with northeast-striking, moderately to steeply dipping axial planes and gently south-southwest–plunging fold axes. Rare quartz rodding is approximately co-linear with the F2 and F3 fold axes and is likely coeval with the latter. Stretching lineations noted in mylonitic gneissic granite also plunge gently to moderately to the south-southwest, but are probably related to mylonitization. The age of this early ductile shearing is unclear since early D2 discontinuities could have been rotated into the dominant northeast-striking D3 orientation. Since the rare F2 isoclinal folds deform the mylonitic fabric, shearing is thought to have developed during D2 time. Late northeast- and northwest-striking crenulation cleavages affect schistose mylonitic rocks. The northwest-striking cleavages have been classified as D4, whereas the former may include both late-D3 and D4 structures.

The ductile mylonites are mainly found in the 46 zone (gneissic leucogranite and Murmac Bay group), 83 zone (sheared and mylonitic leucogranites), and western 11 zone (amphibolite) and extend over a wide area to the west and northwest (Figure 2). Thus, the early ductile D2(?) event appears to predate development of the St. Louis fault, which is a brittle to brittle-ductile structure that consistently dips 50° to 55° to the southeast and is marked by silicification, hematization and, east of Verna Lake, by carbonatization, (Tremblay, 1972). The sense and magnitude of the main displacement along the St. Louis fault has been long debated. Christie (1953), for example, suggested about 335 m of dextral displacement, whereas Smith (1952) thought the sense was sinistral; Tremblay (1972) agreed and calculated a 365 m sinistral offset. However, all of these inferred displacement models were based on the offset of single marker units, which is considered tenuous. Ashton *et al.* (2009b) suggested that the St. Louis fault was genetically linked to the Black Bay fault system and inferred a dextral sense for the main period of displacement on both faults. Subsequent to the early dextral fault development, a normal re-activation of the fault is indicated by the downdropping of Martin group rocks on the southern block (Tremblay, 1972). The current study showed that the shearing, brecciation, and intense fracturing that mark the St. Louis fault are mostly restricted to within tens of metres of the fault lineament. The leucogranite in this zone is recrystallized to a much finer grain size, whereas the amphibolite takes on a platy foliation. Quartz veining spatially related to the fault includes a dominant steep west-northwest–striking set, which, if recording the extension direction, would infer a dextral sense of displacement. In the 11 zone, where carbonate veining was noted, the northeast-striking vertical pit wall exhibits abundant dip-slip slickensides, consistent with the idea of a late normal re-activation. Given that the main rock types on both sides of the fault appear to be the same, and that there is little apparent offset, the magnitude of displacement is probably no more than tens to hundreds of metres. Warping of the amphibolite-leucogranite contact on the northern block of the St. Louis fault (*i.e.*, footwall), assuming this is due to faulting and not regional folding, is consistent with a component of dextral displacement, although the lack of exposure and complications arising from an unrelated northwest-striking fault on the southern block (hanging wall) precludes confirmation of that model.

c) Economic Geology of the Verna-Dubyna Mines Area

The Verna-Dubyna mines area is immediately adjacent to the composite Ace-Fay-Verna mine (Figures 1 and 2), which was by far the biggest past-producer in the Beaverlodge uranium district, producing 22 269 t U_3O_8 at an average grade of 0.24% (Ward, 1982) from sporadic zones of mineralization in both the hanging wall and footwall over a 5 km distance along the St. Louis fault. The host rocks were previously mapped as variably granitized: 1) argillites and hornblende schists, 2) quartz-chlorite schists and Donaldson Lake gneiss, and 3) metasomatic granites (Tremblay, 1972). However, based on a reconnaissance of exposures in the Ace-Fay-Verna area and the current study, these rocks are now re-interpreted as variably deformed: 1) amphibolite, 2) gneissic leucogranite, and 3) pink leucogranite, respectively. Wall-rock alteration, consisting of near-monomineralic plagioclase with hematite dusting, was previously referred to as oligoclasite (Dawson, 1956), feldspar rock (by local miners as reported by Tremblay, 1972), or feldspathic quartzite (Tremblay, 1972), but is here considered correlative with episyenite. The Bolger pit is a surface expression of the mineralized zones at the Verna mine (Figure 2), and is likewise hosted by altered hanging-wall amphibolite.

The 46 zone is located about 250 m into the sheared to mylonitic footwall of the St. Louis fault (Figure 2). It is situated in amphibolite intruded by leucogranite sheets within a few metres of a 10 m thick unit of quartzite, which is in turn structurally underlain by at least 50 m of episyenite-altered gneissic leucogranite (Figure 5A). The episyenite is broken up by chlorite-rich shear zones, which may have developed in amphibolitic inclusions within the original leucogranite (Figure 5B). An exposed wall at the eastern end of the pit exposes a breccia comprising episyenite clasts in a chlorite-rich matrix (Figure 5C) that also contains carbonate veins. The highest spectrometer reading (257 ppm eU) came from mineralized fractures in the amphibolite.

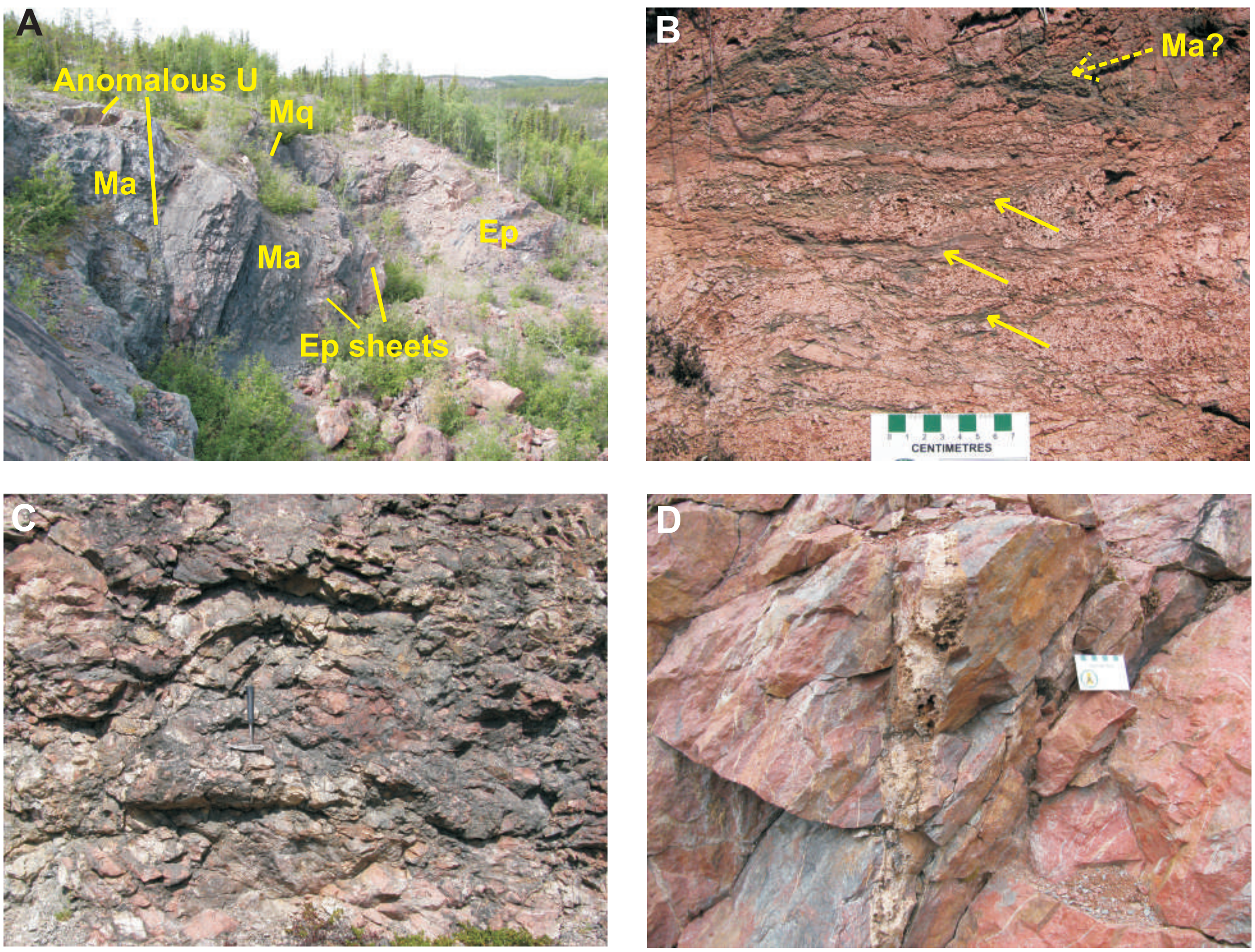


Figure 5 – A) Southwestern pit wall of the 46 zone (UTM 645799 m E, 6606839 m N) viewed to the west. Uranium (U) is concentrated in brittle-ductile fault zones within amphibolite (Ma), which is structurally underlain by 10 m of quartzite (Mq) that is exposed above pit, and extensive gneissic leucogranite that has been altered to episyenite (Ep). Episyenite also occurs as boudinaged dykes and sheets within amphibolite. B) Episyenite alteration viewed on the horizontal top of the northeastern pit wall of the 46 zone (UTM 645824 m E, 6606866 m N) displaying vuggy texture and chloritic shears (solid arrows) that may have developed in amphibolitic inclusions (Ma; dashed arrow) in the gneissic leucogranite precursor. C) Breccia on northeastern vertical face of the 46 zone pit (UTM 645824 m E, 6606866 m N). Breccia comprises episyenite clasts in chloritic matrix (rock hammer for scale). D) Subvertical mineralized carbonate vein crosscutting episyenite forming the northwestern wall of the Dubyna pit (UTM 647882 m E, 6608445 m N). Note numerous thin carbonate veins and chlorite-lined fractures (lower left).

Anomalous uranium radioactivity, including one occurrence[2] based on spectrometer assays, was found in the 21 zone, which is hosted by massive to weakly foliated, episyenite-altered, pink seriate leucogranite about 200 m into the footwall of the St. Louis fault (Figure 2). Typical outcrops in this area contain a mix of pink seriate leucogranite, many containing abundant xenoliths of Murmac Bay group quartzite and amphibolite, and episyenite-altered equivalents characterized by a darker red colour due to more intense hematite dusting of feldspars, little to no quartz, and local carbonate veining. The episyenite is found in concordant layers up to several meters thick, but can also be seen crosscutting the main S1-S2 foliation as veins and along fractures (as seen in Figure 4). The unaltered leucogranite typically contains about 5% chlorite±sericite, whereas these minerals have been variably replaced by about 2% specular hematite in the episyenite alteration. The episyenite also has lower eK concentrations, suggesting replacement of K-feldspar by Na-rich plagioclase, and similar or higher eU values than the pink seriate leucogranite in the same outcrop (Table 1).

Weakly to moderately deformed pink seriate leucogranite with local Murmac Bay group inclusions and episyenite alteration persist to the area east of Emar Lake (Figure 2), where trace disseminated pyrite was also noted in both the unaltered rocks and the episyenite. As noted in the 21 zone, chlorite in the episyenite has been largely replaced by specular hematite, and calcite is a common constituent. Concentrations of up to 260 ppm eU were measured in episyenite at a locality about 450 m northwest of the St. Louis fault, representing a 20-fold increase over unmineralized episyenite of the area (Table 1). Several other faults that are parallel to the St. Louis fault, including one passing through the area of the Emar Lake occurrence may have provided fluid conduits (Figure 2). As well, an east-southeast–trending topographic depression through the southwestern end of Foot Bay in Donaldson Lake may represent an intersecting fault (Figure 2). Crosscutting episyenite alteration was noted along fractures striking at 095° and dipping 80° to the south.

Another kilometre farther northeast is the former Dubyna mine (Saskatchewan Mineral Deposit Index (SMDI) #1324), which is located along the northeastern extension of an unnamed fault and just over 400 m northwest of the St. Louis fault (Figure 2). The Dubyna mine produced 317.4 t U_3O_8 (Ward, 1982) from massive episyenite that has replaced weakly deformed to gneissic pink seriate leucogranite that locally contains abundant xenoliths of quartzite and amphibolite. The episyenite ranges from layer parallel to crosscutting and again displays replacement of about 5% chlorite in the leucogranite with about 2% hematite and minor calcite. Up to 2% pyrite is locally present in the leucogranite and occurs in trace amounts in the episyenite. Steep mineralized fractures and carbonate veins in the main pit wall (Figure 5D) vary from 080° to 105° strike and are broadly parallel to another topographic depression through Foot Bay in Donaldson Lake (Figure 2).

Two other mineralized zones were studied south of the St. Louis fault, in hanging-wall rocks that are generally more intensely deformed. The 11 zone is located within a few metres of the St. Louis fault (Figure 2) and is hosted by pink seriate leucogranite that appears devoid of inclusions. The leucogranite is hematized and contains abundant quartz, although much of the latter may be due to the effects of silicification (Figure 6A). It is unclear if this alteration is distinct from episyenitization or whether early de-quartzification has been overprinted by late

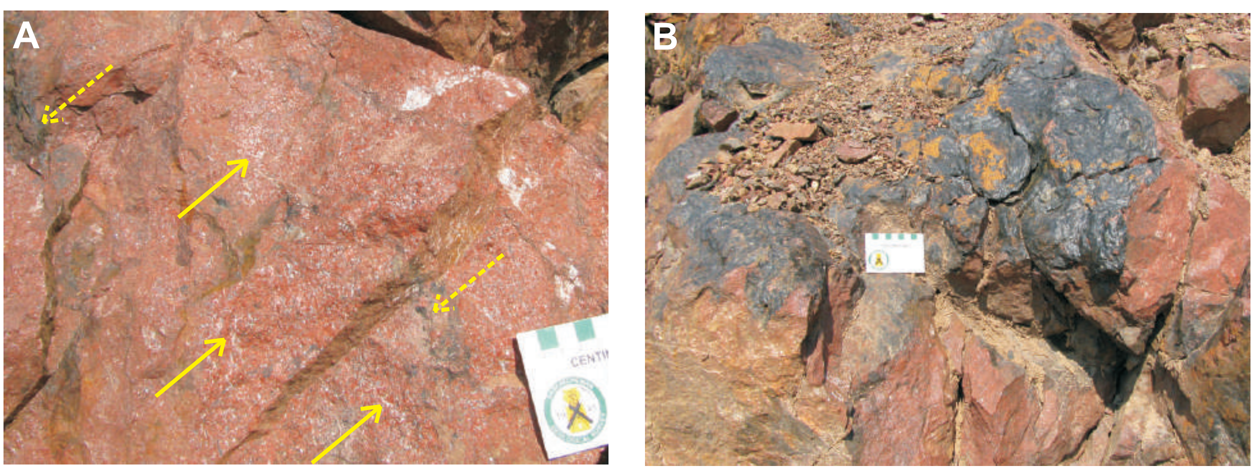


Figure 6 – A) Pink seriate leucogranite in the southeastern wall of the 11 zone (UTM 646514 m E, 6606888 m N). Note vein-like nature of quartz (arrow) as opposed to primary igneous texture; also note chlorite-lined fractures (dashed arrow); and B) thick sheet of monomineralic chlorite several centimetres thick in altered pink seriate leucogranite in the southeastern wall of the 11 zone (UTM 646514 m E, 6606888 m N).

[2] A U occurrence in this paper is defined as having a concentration of 300 ppm U_3O_8 or 250 ppm eU.

silicification. The rocks have been affected by relatively intense brittle-ductile shearing that has produced an anastomosing network of northeast-striking chlorite schist up to decimetres thick (Figure 6B). Down-dip slickensides on these sheared chlorite-rich surfaces probably record late normal displacement. Carbonate veins are also present. A steep southeast-striking fault, which marks the contact between the pink seriate leucogranite and amphibolite, may have helped to supply the fluids responsible for mineralization (Figure 2).

The 83 zone (SMDI #1284 and #1303) is located 1.3 km southeast of the 11 zone and the St. Louis fault in mylonitic equivalents of the pink seriate leucogranite containing minor amphibolitic inclusions (Figure 2). These rocks are completely recrystallized, exhibiting only minor pink remnants of the leucogranite precursor on fresh surfaces, and are intensely fractured, locally brecciated, and chloritized. Episyenite was not recognized; quartz is generally present, although the fine-grained recrystallized nature of these rocks makes its recognition difficult. There are red hematized alteration zones and carbonate veins striking both northeasterly, parallel to the main regional fabric, and east-southeasterly. The uranium mineralization, which occurs as pitchblende with galena, scheelite, pyrite, and pyrrhotite, coats steep fractures striking 045° and 085° (Beck, 1969).

4. Eagle-Camdeck Area

The Eagle-Camdeck area is situated northeast of the ABC fault and south of the main Martin group unconformity in a region dominated by intensely deformed leucogranite (Figure 1). It is also directly along strike from the previously studied Hab mine (Tracey *et al.*, 2009), about 5 km to the northeast, with which it shares all main rock types and a high degree of strain. In addition to the variably deformed leucogranite, the area includes both *in situ* and abundant inclusions of Murmac Bay group quartzite and amphibolite. The Martin group unconformity is exposed in the northernmost part and outliers of Beaverlodge formation are common in both of the mapped segments. In addition to the Eagle shaft and adjacent pits, the mapped area incorporates the Intermediate and Gulley pits as well as the Camdeck occurrences (Figure 7).

a) Unit Descriptions of the Eagle-Camdeck Area

The quartzite (Mq) and amphibolite (Ma) units of the Murmac Bay group are broadly similar to those described in the Verna-Dubyna mines area, except that the quartzite locally contains diopside. Both the quartzite and the amphibolite are exposed *in situ* at the western end of Eagle Lake, and as decimetre-scale inclusions in the pink leucogranite, particularly in the Camdeck area (Figure 7).

The pink leucogranite (Alp) is generally pale pink to pink with zones of red hematitic alteration and is fine to medium grained. The leucogranite is best preserved immediately northwest of the Intermediate pit (Figure 7) where it contains medium-grained colourless quartz and pink feldspar in a grey-green, fine-grained, recrystallized matrix (Figure 8A). The rock is generally homogeneous, and weakly foliated to sheared or mylonitic with local quartz rodding. It commonly has a variable cataclastic overprint characterized by abundant fracturing, hematite staining, and irregular quartz veins and pods. Typical pink leucogranites contain 20 to 25% quartz, although in many places much of this quartz appears late (Figure 8B). Episyenite is rare in the Eagle-Camdeck area, although red hematite-rich alteration rocks are common and originally de-quartzified rocks may have been subsequently re-silicified. The pink leucogranite also contains 0 to 3% chlorite, 0 to 1% hematite, mostly lining fractures, and rare pyrite. Murmac Bay group quartzite and amphibolite inclusions up to several tens of metres in thickness and length are particularly common in the Camdeck area. Their presence locally results in complex outcrops due to their close interaction with the leucogranite and subsequent folding (Figure 8C). The spectrometer results for the Eagle-Camdeck area yielded eU, eTh, and eK values typical of granitoid rocks (Table 1). It is unclear if the pink leucogranite in the Eagle-Camdeck area is correlative *sensu stricto* with the pink seriate leucogranite in the Verna-Dubyna mine area, but both clearly postdate the Murmac Bay group and have been affected by the same phases of deformation, so they are broadly coeval.

Southeast of the Intermediate pit, mylonitic pink leucogranite (Alp-sc) weathers cream to pale pink-grey and is grey-green on fresh surfaces. The rocks are fine grained and variably layered to laminated, with a well-developed mylonitic, platy foliation resulting from extreme quartz and feldspar flattening (Figure 8D). They contain up to 20% (generally <5%) chlorite after biotite, 5% sericite±trace pyrite. Minor garnet and rare sillimanite(?) were noted in local concentrations of chlorite and sericite. Given their micaceous character and location adjacent to the basal Murmac Bay group, it is tempting to interpret these rocks as metamorphosed saprolites derived from basement granitoids. However, they locally contain centimetre- to rare metre-scale inclusions of Murmac Bay group quartzite and amphibolite, the latter including a centimetre-scale layer of oxide-facies iron formation at one locality (UTM 6404889 m E, 6607069 m N). Together with rarely observed strain gradients, this confirms that they are another variety of highly strained leucogranite (Figure 8E). The mylonitic pink leucogranite is further complicated by a variable late cataclastic overprint. Spectrometer values show significant depletions of eU and eTh relative to the pink leucogranite precursor, although eK remains essentially unchanged (Table 1).

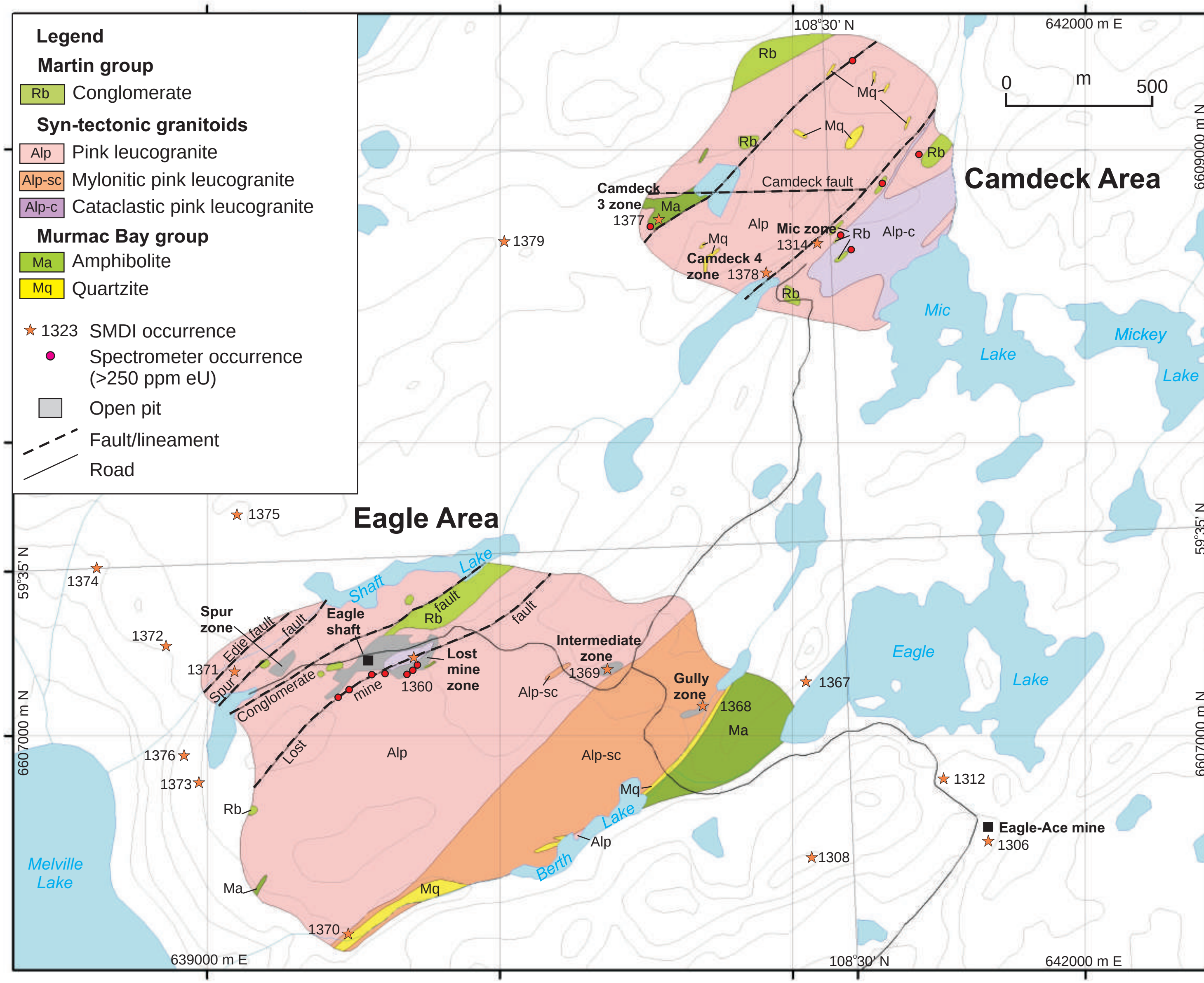


Figure 7 – Simplified geological map of the Eagle-Camdeck area.

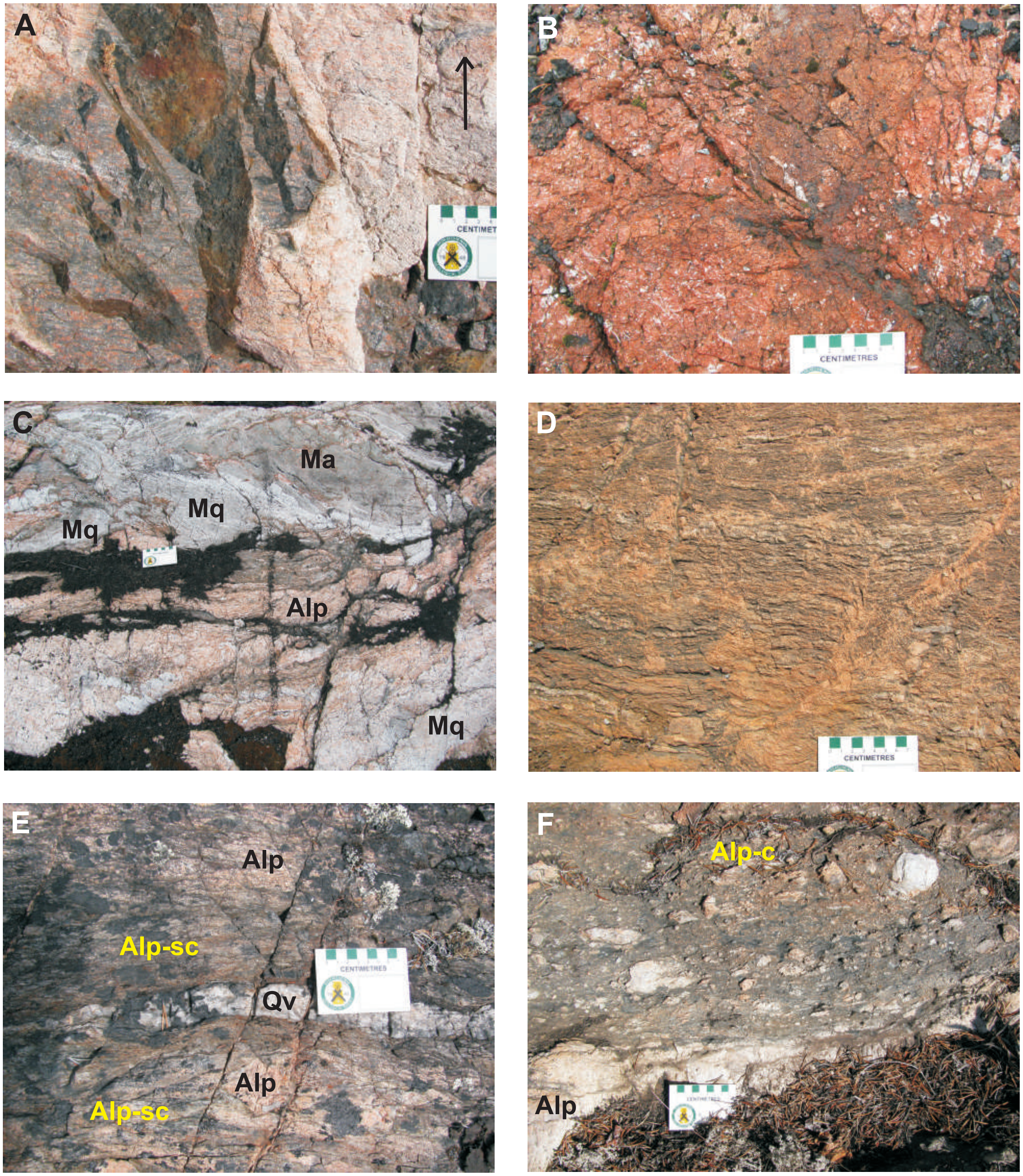


Figure 8 – A) Granitic texture of the medium-grained pink leucogranite hosting uranium mineralization at the Intermediate pit; from the top of the northeastern pit wall (UTM 640408 m E, 6607257 m N). Note pink medium-grained feldspar grains in dark grey-green, fine-grained recrystallized matrix on fresh surface on left side of photo and smoky quartz vein at upper right (arrow). B) Altered pink leucogranite displaying secondary quartz pods, hematization, and zone of intense fracturing; from the northwest wall of the Spur pit (UTM 639229 m E, 6607236 m N). C) Complex outcrop resulting from intrusion of Murmac Bay group quartzite (Mq) and amphibolite (Ma) by pink leucogranite (Alp), followed by metamorphism and ductile deformation; from 350 m north-northeast of SMDI #1314 in the Camdeck area (641213 m E, 6609040 m N). D) Mylonitic pink leucogranite from the southeast end of the Intermediate pit (UTM 640435 m E, 6607224 m N). E) Strain gradient showing transition from pink leucogranite (Alp) to grey-brown mylonitic equivalent (Alp-sc); central white layer is a quartz vein (Qv); from 200 m northwest of Berth Lake in the Eagle area (UTM 639973 m E, 6606726 m N). F) Dismemberment of pink leucogranite (Alp) to form cataclastic leucogranite (Alp-c); from 100 m northeast of SMDI #1314 (UTM 641183 m E, 6608752 m N).

The southeastern part of the Camdeck area is characterized by cataclastic leucogranite (Alp-c), which formed by intense shearing and shredding of pink leucogranite to form cataclasite (Figure 8F). It comprises 30 to 90% cream-white to pale pink, rounded to irregular leucogranite clasts up to centimetre scale in a grey-brown to pale green, fine-grained, chlorite-rich matrix. A mylonitic foliation is locally preserved in some clasts, but the matrix is massive to only weakly foliated. Thin sections from very similar cataclasite at the Hab mine show that the granitic clasts are aphanitic due to recrystallization and that only minute amounts of chlorite, epidote, and quartz are recognizable. Spectrometer values show significant depletions of eU, eTh, and eK relative to the pink leucogranite precursor (Table 1).

The southern edge of a large unit of Beaverlodge formation belonging to the Martin group is exposed at the northern end of the Camdeck area and there are abundant outliers of basal polymictic conglomerate in both mapped areas. The unconformity was not directly observed, but in the lowermost 10 to 20 m of the exposed section, the polymictic conglomerate has a dark hematitic matrix and an abnormally high abundance of grey-brown, fine-grained siltstone clasts. Stratigraphically above the lowermost section, the matrix in the conglomerate changes to grey-brown and silty for 10 to 20 m, and then becomes pink and arkosic over the next 10 to 20 m. Clasts in this latter pink conglomerate horizon are generally sub-angular and pebble- to rarely boulder-sized. They tend to be randomly oriented, although tabular clasts lie parallel to the bedding plane or, locally, display imbrication suggesting flow from east to west in their present orientation. The majority of clasts appear to be derived from pink leucogranite with a significant contribution of grey-brown, fine-grained siltstone, along with minor vein quartz, amphibolite, and granitic gneiss, although the mix varies from bed to bed (Figure 9). Most of the conglomerate is clast supported, although matrix-supported horizons are also common, and beds of pink arkose up to 25 cm thick are locally present. Erosional remnants of pink polymictic conglomerate with an arkosic matrix generally exhibit more brittle deformation than the main exposure of Beaverlodge formation to the north. The Martin group rocks have the highest concentrations of eK based on average spectrometer results of the main rock types, but eU and eTh values are among the lowest (Table 1).

A sheared, vertical, northeast-striking mafic dyke has intruded pink leucogranite adjacent to an outlier of Martin group conglomerate in the eastern Camdeck area (see accompanying Eagle-Camdeck map separate). The dyke is considered part of the *ca.* 1.82 Ga Uranium City dykes, which have been broadly correlated with mafic flows of the Gillies Channel Formation of the Martin group (Morelli *et al.*, 2009).

b) Structure of the Eagle-Camdeck Area

Rocks within the Eagle-Camdeck area are part of a northeast-trending belt of variably deformed rocks that includes those hosting the Hab mine (Figure 1) 5 km to the northeast (Tracey *et al.*, 2009). The composite S1-S2 foliation is locally deformed by close to tight, northeast-trending F3 folds that are locally accompanied by a steep axial planar S3 foliation. Due to the northeasterly orientation of the regional foliation, it is difficult to determine whether mylonitization took place during D2 or D3. Gently to moderately northeast- to east-plunging quartz rodding in the Intermediate pit area appears to be openly folded along with the S1-S2 foliation, but could have been formed during either D2 or D3. The matrix of the cataclasite lacks any penetrative northeast-trending foliation, but locally exhibits a weak northwest-striking fabric indicating development during D4. Open north- to northwest-trending kink folds and crenulations in the schistose rocks, along with a number of northeast-striking faults, are also attributed to the D4 event. The main sense of displacement has not been determined for these northeast-striking faults although, like the parallel St. Louis fault, they may be genetically related to the dextral Black Bay fault. The downdropped outlier of Martin group rocks exposed south of Shaft Lake (Figure 7) suggests late normal displacement along some of these structures.

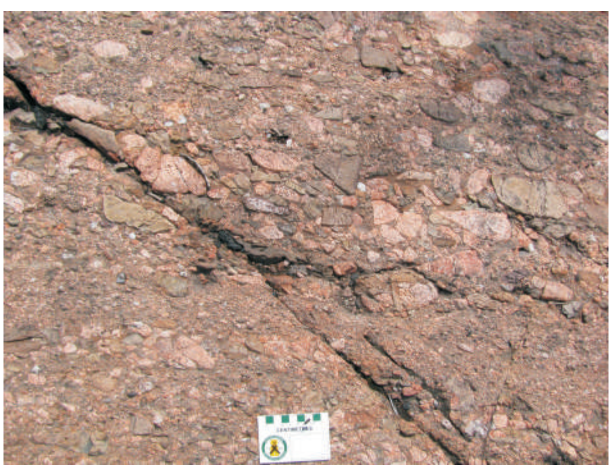


Figure 9 – Bedding in Martin group conglomerate (Rb) from 700 m north-northeast of SMDI #1314 (UTM 640896 m E, 6609323 m N). Note subrounded to subangular nature of pebble- to cobble-sized clasts and preponderance of grey-brown, fine-grained siltstone and pink leucogranite clasts.

c) Economic Geology of the Eagle-Camdeck Area

The uranium deposits and occurrences in the Eagle-Camdeck area have been described by Christie (1953), Robinson (1955), Beck (1969), and Tremblay (1972). The following has been summarized and modified from those publications. The Eagle mine area (SMDI #1360) produced 720.3 t U_3O_8 (Ward, 1982) from variably sheared and cataclastic pink leucogranite, the most deformed varieties of which were originally interpreted as chlorite-epidote rocks, meta-argillite, and quartzite. Copper-stained inclusions of Murmac Bay group amphibolite up to at least metre scale occur in the leucogranite at the southeastern end of the main Eagle pit. Ore was found in four east-northeast–trending fault-related zones (named from east to west: Lost mine, Conglomerate, Spur, and Edie; Figure 7) of concentrated fractures (Figure 10A). Uranium was most concentrated over a *ca.* 600 m by 120 m east-west–oriented area south of Shaft Lake, where it occurred in veins and along fractures striking 085°, 295°, and 065°. Mining operations were concentrated along the major faults, as individual veins and fractures in between were sub-economic. Pitchblende was found in calcite and/or quartz veins as pods, veinlets, and lining fracture walls. High eU values qualifying as occurrences can still be found in the south wall of the main pit along 155°/85°, 103°/76°, and 220°/steep fractures (Figure 10B) with associated red, hematite-rich, episyenite-like (variably de-quartzified and K leached) wall-rock alteration (Figures 10C). Pyrite, chalcopyrite, bornite, and trace galena are spatially associated with the pitchblende, and observed Cu staining was noted along fractures and in a quartz vein within a few metres of uranium-stained fractures. Common gangue minerals include chlorite and hematite, both of which also line fractures (Figure 10B). The uranium mineralization is generally concentrated along fractures in massive leucogranite that is enclosed by sheared and cataclastic equivalents.

The Intermediate zone (SMDI #1369) straddles a 290°/55° shear zone marking the contact between pink leucogranite and mylonitized equivalents to the southeast, the latter of which were previously interpreted as quartzite with argillite and chlorite schist (Beck, 1969). The fault zone is well exposed on the northern wall of the pit (Figure 11A) which includes from top to bottom: 1) 10 m of lineated pink leucogranite (Figure 8A); 2) 1 m of green-brown altered rock containing up to 30% chlorite, 1% graphite, and uranium staining; 3) 1 m red hematized material exhibiting a strong platy cleavage that contains abundant quartz veining; and 4) 2 m pink and grey leucogranite with abundant chloritic shear zones and chlorite-lined fractures. At the northwest corner of the pit, the dark, green-brown, chlorite-rich–altered zone comprises 1 to 2 m of rusty sulphide-rich material lying structurally above chlorite schist. Uranium mineralization is confined to short fractures extending from this shear zone.

The Gully zone (SMDI #1368) is hosted by northeast-striking mylonitic pink leucogranite (Figure 11B) containing abundant metre-scale inclusions of Murmac Bay group amphibolite. The rocks exhibit a strong cataclastic overprint involving the introduction of abundant chlorite (Figure 11C). These rocks were

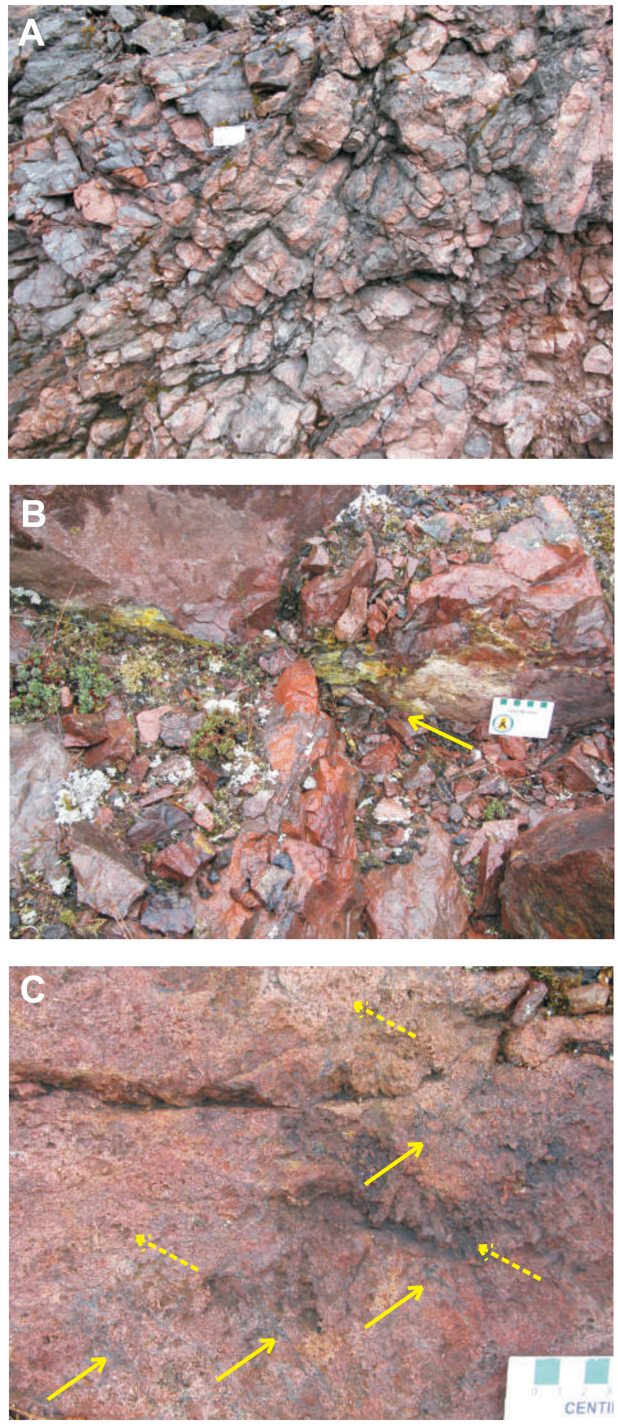


Figure 10 – A) Lost mine fault zone exposed in the southwest wall of the main Eagle pit (UTM 639412 m E, 6607119 m N). Tectonic clasts of pink leucogranite are separated by an anastomosing network of chlorite schist introduced during shearing. Cataclastic overprint has produced abundant fracturing, some of which is lined with specular hematite (blue-grey colour on left side of photo). B) Uranium staining along a subvertical fracture striking at 155° developed in pink leucogranite; from the south wall of the main Eagle pit (UTM 639718 m E, 6607210 m N). Note northeast-trending zone of red hematitic alteration intersecting mineralized fracture. C) Red-brown hematitic, episyenite-like alteration zone within pink leucogranite from the southeast wall of the main Eagle pit (UTM 639487 m E, 6607157 m N). Note specular hematite veinlets (arrows) and pitted weathering due to leaching of quartz or secondary carbonate (dashed arrows).

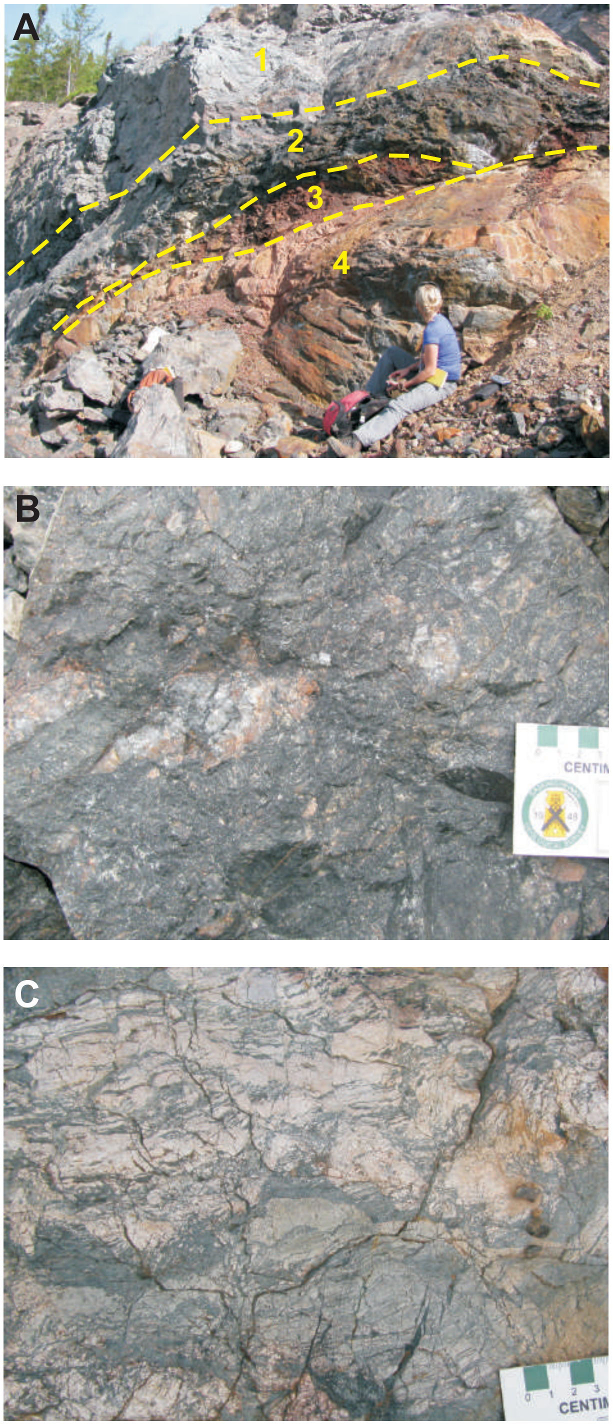


Figure 11 – A) Northern Intermediate pit wall exposing from top to bottom: 1) 10 m of lineated pink leucogranite; 2) 1 m of green-brown chloritic and graphitic altered rock containing uranium staining; 3) 1 m of red hematized and silicified material; and 4) 2 m of sheared and fractured pink and grey leucogranite. B) Fresh surface of mylonitic pink leucogranite (Alp-sc) displaying strong cataclastic overprint with remnants of pink and white leucogranite precursor in grey very fine-grained chloritic matrix; from the northwest Gully pit wall (UTM 640633 m E, 6607064 m N). C) Weathered surface showing the sheared to cataclastic nature of mylonitic pink leucogranite hosting uranium mineralization at the Gully occurrence; from northeast end of pit (UTM 640708 m E, 6607097 m N). Note degree of chloritization.

collectively interpreted in the past as chlorite-epidote rock (Beck, 1969) and pelitic gneiss (Hartlaub, 1999). Pitchblende occurs in short, narrow, quartz-carbonate veinlets with chlorite, hematite, and traces of pyrite, chalcopyrite and galena (Christie, 1953; Beck, 1969).

The Camdeck area lies about 1.7 km northeast of the Eagle mine and includes several uranium occurrences. The Mic showing (SMDI #1314) lies along a northeast-striking fault scarp that appears to be the continuation of the Lost mine–Conglomerate fault system from the Eagle mine area (Figure 7). Mineralization occurs along fractures striking 155° within pink leucogranite and consists of pitchblende with chlorite, quartz, carbonate and hematite. The wall rocks are intensely hematized. About 200 m along strike to the northeast (641427 m E, 6609021 m N), trenches expose radioactive fractures, oriented at 057°/90° and 330°/40°, in variably cataclastic pink leucogranite that is unconformably overlain by Martin conglomerate a few tens of metres to the southeast.

The Camdeck 3 zone (SMDI #1377) is hosted by amphibolite within, and intruded by, pink leucogranite at the approximate intersection of a northeast-striking fault that is broadly along strike of the Spur and Edie faults in the Eagle mine area, and the east-striking Camdeck fault (Figure 7). Pitchblende occurs along a series of near-vertical fractures striking 115° to 140° in amphibolite and to a lesser degree in pink leucogranite, and is generally near the contact between the two. It is commonly accompanied by calcite, pyrite and red hematitic alteration.

The Camdeck 4 zone (Beck, 1969; SMDI #1378) is hosted by pink leucogranite and is not far southwest of the Mic zone (Figure 7). Although the Camdeck 4 zone was not studied, it lies within an area in which the leucogranite contains metre- to decimetre-scale inclusions of Murmac Bay group quartzite. Northeast-trending, decimetre-scale zones of red hematite-altered leucogranite locally cut across unaltered pink leucogranite between the quartzite inclusions. The uranium mineralization occurred in a narrow 130° fracture filled with vuggy quartz, chalcopyrite, umangite and pitchblende.

Decimetre-scale Murmac Bay group quartzite inclusions were also noted proximal to mineralized trenches in pink leucogranite about 900 m northeast of the Camdeck 4 zone (UTM 641198 m E, 6609300 m N). Hematitic alteration and high radioactivity accompanies a main 240°/80° to 256°/steep fracture set, as well as a subordinate 138°/90° set.

5. Lorado Mine Area

The Lorado minesite was chosen for study because it differs from the other areas mapped in that the uranium deposits and occurrences are hosted by Murmac Bay group metasedimentary rocks. The minesite is situated within a northeast-trending syncline, which is flanked on either side by Archean granitoid rocks and unconformably overlain by the Beaverlodge formation of the Martin group (Figure 12). The basement and Murmac Bay group rocks generally exhibit a high degree of strain, complicating the identification of protoliths. Better preserved Murmac Bay group rocks 3 km to the south-southwest at Milliken Lake (Figure 1) suggest that metamorphic conditions attained middle amphibolite facies in the Laredo minesite area.

a) Unit Descriptions of the Lorado Mine Area

White, fine- to medium-grained basement granite (G30) is exposed at the southeastern and northwestern flanks of the mapped area. It varies from homogeneous to gneissic where it exhibits centimetre-scale white leucosome, and grades from near massive to well foliated, locally sheared, and platy. Local brecciation near the contact with the supracrustal rocks may be due to an unconformity or a fault. Typical granites contain 0 to 5% biotite variably altered to chlorite, and 0 to 5% sericite partly derived from the alteration of feldspars. The basement granite is

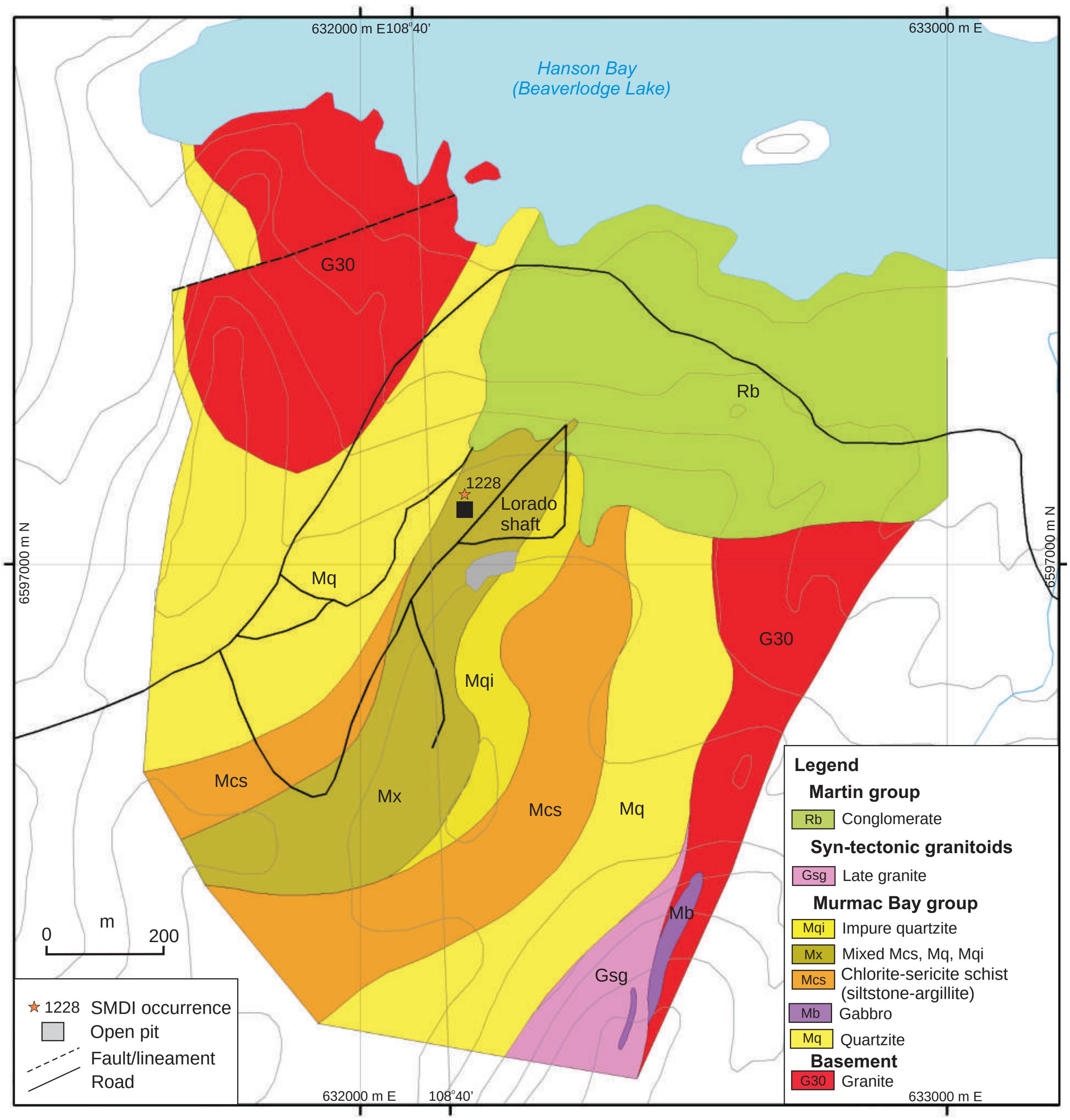


Figure 12 – Simplified geological map of the Lorado area.

commonly intruded by gabbro sheets and pods, which are correlative with Murmac Bay group basalts, and 10 to 30% white, medium-grained leucogranite dykes that have been transposed into the main regional foliation. Spectrometer measurements show that the basement G30 granite has an average eK (2.5) value that is similar to the leucogranites, but that its eU (10.3 ppm) and eTh (13.1 ppm) values are significantly lower (Table 1), possibly due to leaching at the Murmac Bay group unconformity. The basement granite is considered broadly correlative with the *ca.* 3.0 Ga Cornwall Bay and Elliot Bay granites (Hartlaub *et al.*, 2004).

Murmac Bay Group

Murmac Bay group supracrustal rocks are stratigraphically heterogeneous with metre- to decimetre-scale interbedding of distinct rock types (Figure 13A), and are moderately sheared. The basal unit is dominated by white to dark grey, very fine- to fine-grained quartzite (Mq) containing up to 20% centimetre- to metre-scale layers of impure quartzite and chlorite-sericite schist. Typical rocks contain >90% quartz±feldspar±sericite±hematite± graphite and are interpreted as recrystallized quartz arenite. It has been variably sheared and commonly displays a well-developed S1-S2 fracture foliation.

Basement granite in the southeast is intruded by gabbro (Mb), which weathers grey-brown, is dark green on fresh surfaces, and is very fine to fine grained and well foliated. The hornblende-plagioclase metamorphic assemblage has been variably retrogressed to greenschist facies minerals and, like the basement granite, the gabbro is intruded by dykes and small bodies of late granite. Low spectrometer measurements of 1.2% eK, 1.6 ppm eU, and 2.5 ppm eTh are consistent with the basic composition. The gabbro is interpreted as an intrusive equivalent to Murmac Bay group basalt.

The quartzite unit is stratigraphically overlain by chlorite-sericite schist (Mcs) containing minor impure quartzite. The schist is grey to grey-green, and locally red due to hematite staining (Figure 13B). It is fine to very fine grained, locally crenulated, and fractured. Typical rocks contain 5 to 10% chlorite, 5 to 10% sericite, and minor hematite in quartzofeldspathic matrix. Rare fine-grained pits on weathered surfaces probably contained garnet. Spectrometer values for the schist were 2.6% eK, 22.8 ppm eU, and 17.4 ppm eTh (Table 1). The chlorite-sericite schist is thought to be derived from siltstone and argillite.

The chlorite-sericite schist unit appears to pass along strike into a unit of mixed chlorite-sericite schist, quartzite, impure quartzite, amphibolite, and rare graphitic sericite-chlorite±sulphide schist (Mx). Interbedding of rock types is on a scale of tens of centimetres to metres precluding their distinction for mapping purposes at this scale (Figure 13A). The unit is economically important because it includes the graphitic sericite-chlorite±sulphide schist that reportedly hosts the uranium mineralization at the Laredo minesite. Unfortunately, it is a recessive unit and exposures were not found.

Impure quartzite and minor quartz-sericite schist (Mqi) may stratigraphically overlie or represent part of the chlorite-sericite schist and mixed units (Figure 12). The impure quartzite is white-cream to grey-brown, fine grained, and well foliated to platy due to variable shearing. It contains 5 to 15% sericite, 0 to 5% chlorite, 0 to 5%

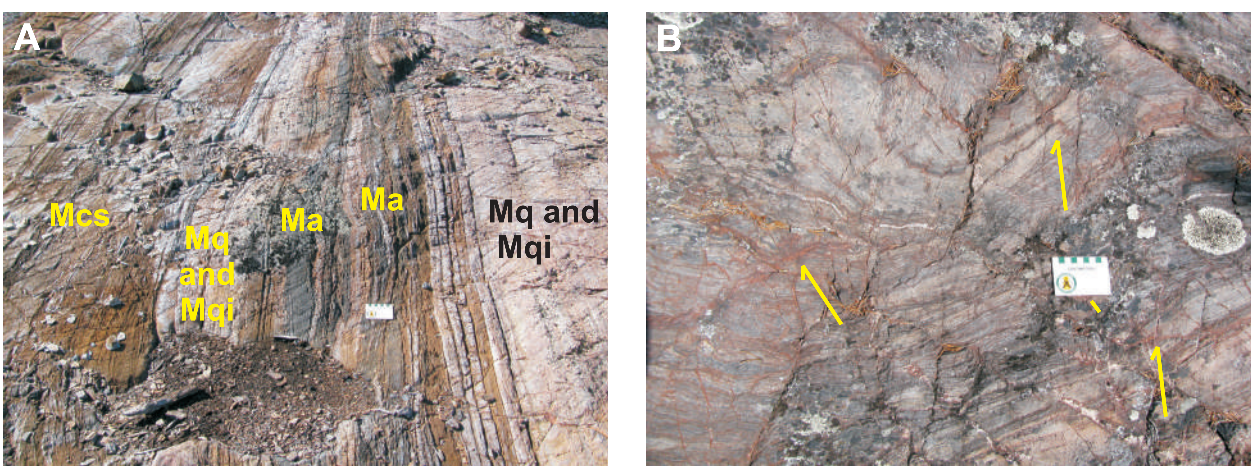


Figure 13 – A) Sheared Murmac Bay group strata characterizing mixed unit (Mx) of thinly intercalated quartzite (Mq), impure quartzite (Mqi), amphibolite (Ma), and chlorite-sericite schist (Mcs); from the Lorado minesite (UTM 632276 m E, 6597187 m N). Uranium mineralization is hosted by graphitic and pyritic varieties of chlorite-sericite schist. B) Chlorite-sericite schist derived from Murmac Bay group siltstone and argillite; from 350 m southeast of Lorado shaft (UTM 632421 m E, 6596874 m N). Note hematite-stained fractures (arrows).

hematite, and rare partially preserved feldspar. Average spectrometer values were 1.7% eK, 11.6 ppm eU, and 11.3 ppm eTh (Table 1). The impure quartzite probably represents a metamorphosed and sheared subfeldsarenite or sublitharenite.

The basement granite, gabbro, and quartzite are intruded by late granite (Gsg) dykes generally ≤30 cm thick and a small pluton in the southeast. Typical rocks of the late granite unit are white to pale pink, fine to medium grained, and homogeneous. They range from massive to weakly foliated, suggesting a lesser degree of deformation than the older rocks, and are variably fractured. They contain 2% sericite and ≤5% chlorite.

The Martin group (Rb) unconformably overlies the basement granite and Murmac Bay group, and is not intruded by the late granite (Gsg). The Martin group rocks were not studied in detail, but the exposures visited comprise pebble to cobble conglomerates of the basal Beaverlodge formation and contain a high proportion of Murmac Bay group quartzite clasts.

b) Structure of the Lorado Mine Area

The Lorado mine area is located within a northeast-trending, pre-Martin group, F3 fold with a moderately to steeply southeast-dipping axial plane that is cored by Murmac Bay group rocks (Figure 12). Tight to open, northeast-trending F3 minor folds are rare and subordinate to poorly defined map-scale and open west-trending kink folds and crenulations that have been assigned to the D4 deformation event. The relatively high strain exhibited in these rocks (Figure 13A) probably developed during D2 or early in D3 as the derived schistose fabrics help to define the F3 and F4 folds. The Martin Group was probably deposited during the D4 event (Ashton *et al.*, 2009b).

c) Economic Geology of the Lorado Mine Area

Uranium mineralized rocks are no longer exposed at the Lorado minesite area; therefore, the following deposit summary has been modified from descriptions by Robinson (1955), Lang *et al.* (1962), Beck (1969), and SMDI #1228. The Lorado mine produced 105 t of U_3O_8 between 1957 and 1960. The mineralization is hosted by moderately southeast-dipping graphitic and chlorite schists that are thought to be derived from Murmac Bay group argillite, and are structurally overlain to the east by quartzite and underlain to the west by sheared pyrite-graphite schists. The main structural control is fracturing along the base and limbs of a gently to moderately northeast-plunging fold, which is defined by the host schists. Pitchblende is spatially associated with disseminated pyrite (which was mined for sulphur for the Lorado leach plant) and chalcopyrite, along with minor bornite, chalcocite, specular hematite and vanadinates (nolanite and tyuyamunite). Pitchblende locally forms the matrix to sulphide minerals, occurs in the gangue as matrix to nolanite, and occurs as thin films along fractures in quartz. In contrast to the uranium deposits and showings north and northeast of Beaverlodge Lake, hematite is conspicuously missing from the wall rocks in the immediate Lorado mine area.

6. Discussion and Conclusions

There are some major differences in the style of uranium mineralization in the three areas studied, but they also have much in common. For example, deposits and occurrences in the footwall of the St. Louis fault are all hosted by, or within decimetres of, the pink seriate leucogranite and are characterized by an anastomosing network of episyenitic alteration involving quartz and probably K-feldspar dissolution, Na metasomatism, and accompanying hematization. Mineralization in the Eagle-Camdeck area and in the hanging wall of the St. Louis fault are also hosted by, or within decimetres of, the pink leucogranite, but its associated alteration, although characterized by hematization, generally does not seem to involve quartz dissolution or does so to a lesser degree. However, many of the rocks in the Eagle-Camdeck area and in the hanging wall of the St. Louis fault in the Verna-Dubyna area appear to have been silicified, suggesting either subtle differences in the physical-chemical conditions of the fluids transporting uranium or that episyenitization was subsequently overprinted by silicification. The recognition of a relationship between Na metasomatism and uranium mineralization is not new in the Beaverlodge uranium district (Hoeve, 1982). However, this study indicates that episyenite, characterized by the replacement of quartz and K-feldspar by albite was more extensive than previously recognized and can be traced at surface for several kilometres along strike as an anastomosing network.

Fluids responsible for uranium mineralization, spatially related to the St. Louis fault, have clearly used that structure as a conduit. Mineralization in the Eagle-Camdeck area and 83 zone is also localized along, or close to, parallel to sub-parallel, major northeast-trending structures. Some of these are D1/D2 ductile mylonite zones that have been re-activated during D3 and/or D4 deformation (*e.g.*, 83 zone), whereas others are brittle D4 faults and/or linked secondary or tertiary structures. Nonetheless, all required brittle faulting to provide fluid conduits. Although the main northeast-striking regional foliation provides the main avenue for brittle faulting and fluid transport, east-southeast– to southeast-striking cross faults and fractures are also important for localizing uranium mineralization. These latter orientations lie in the extension direction to the regional D4 stress field and/or represent the conjugate to the northeast-striking dextral structures (Ashton *et al.*, 2009b). Intersections of these east-southeast– to southeast-striking faults and fractures with northeast-striking faults are thus convenient sites for uranium mineralization, as are bends in the main northeast-striking structures such as the St. Louis fault.

The Martin group unconformably overlies the uranium mineralized rocks of the Ace-Fay-Verna mine in the hanging wall of the St. Louis fault and, prior to erosion, probably extended northeastward to cover at least the hanging-wall occurrences in the Verna-Dubyna area as well (Figures 1 and 2). The Martin group–basement unconformity is also exposed at the main uranium occurrences in the Eagle-Camdeck area and was probably proximal to the others at one time, suggesting a possible genetic link to mineralization. The Martin group could have supplied uranium from the breakdown of detrital accessory minerals and incorporated it into oxidizing fluids (*i.e.*, taken on the inferred role of the Athabasca Group in the unconformity uranium model). Having said this, however, geochemical assays of representative Martin group rocks suggest that they are not particularly uranium rich (73 samples from throughout the Martin group stratigraphy in the Beaverlodge area yielded an average of 3.6 ppm U; D. Quirt, pers. comm., 2010), a finding broadly supported by the spectrometer survey (Table 1). Alternatively, sub-horizontal bedding in the Martin group could have provided a structural trap for fluids, restricting flow to fault conduits in the basement. The enhanced heat flow arising from the added thickness of the Martin group, and/or its mafic volcanism may also have provided the heat for hydrothermal activity.

The abundant highly strained rocks in the basement represent an alternative source for the uranium mobilized into the Beaverlodge uranium deposits. The unaltered and non-mineralized (arbitrarily set at <20 ppm eU) pink seriate leucogranite of the Verna-Dubyna area averages 9.6 ppm eU (n=26; Table 1), whereas the pink leucogranite in the Eagle-Camdeck area averages 7.1 ppm eU (n=44). Even though the latter includes some alteration, these rocks are relatively uranium rich, similar to the 7.0 ppm concentration of eU in the unaltered and non-mineralized Gunnar granite (Ashton, 2010), and easily exceed the 2.7 ppm U average for the upper continental crust (Kyser and Cuney, 2008). The highly reduced concentrations of eU in sheared, mylonitic, and cataclastic varieties of these rocks (Table 1) indicate a significant net loss of uranium. It is not known with certainty where this uranium went or when during the complex faulting history in the Beaverlodge district. However, it is possible that the early, high-temperature, ductile deformation decreased the stability of uraniferous accessory minerals in the leucogranites, making it easier for them to be leached by oxidizing fluids travelling along later, brittle, fault and fracture conduits.

Although the timing has yet to be confirmed, reduction of the oxidizing fluids to precipitate uranium minerals may have been facilitated by accompanying chloritization of biotite in the leucogranite, alteration of hornblende in the amphibolite, and by oxidation of sulphides (Yeo and Potter, 2010). In spite of documented amphibolite-facies metamorphism in this area, biotite has been almost ubiquitously pseudomorphed by chlorite in the granitoid rocks, whereas metamorphic hornblende in the amphibolites has been replaced by mixtures of chlorite, epidote, and tremolite-actinolite. Abundant chlorite has also been added to the system based on its common affinity for lining fractures. Hematite is present as microscopic inclusions throughout the feldspars in the leucogranites, although this is true throughout this widespread rock type and is not directly related to uranium mineralization. However, judging from the generally redder colour, there is a significant increase in the degree of hematite dusting in feldspars within altered rocks associated with uranium zones. Hematite also occurs as specularite replacing chlorite in the episyenite and as a common lining of fractures at some deposits (*e.g.*, Eagle mine; also Figure 10A), probably indicating multiple generations. Alternatively, precipitation of uranium minerals may not have resulted from reduction, but rather from other changes affecting the oxidized uranium transport fluid. Temperature, fluid pressure, pH, and the mobility of other elements can all have significant effects on uranium solubility and would have varied considerably in the inferred depositional environment that included crustal-scale faulting, Martin group volcanism, and widespread fluid incursions during the D4 deformational event.

Mineralization at the Lorado mine differs from that of the other areas north and northeast of Beaverlodge Lake discussed above in that it is hosted by graphitic chlorite-sericite-pyrite schists that were likely derived from pyritiferous black shales of the Murmac Bay group. Based on the hand-held spectrometer results, the chlorite-sericite schists contain significant uranium and could represent the source rock, although potentially fertile pink leucogranites are exposed less than 2 km from the mine site. Transport of uraniferous fluids would have been facilitated by the sheared nature of both the host chlorite-sericite schists and the adjacent mica-rich impure quartzites. The spatial restriction of the Lorado uranium mineralization to pyrite-rich rocks suggests that pyrite was responsible for reduction of uranium from an oxidizing fluid. The Martin group is also exposed at the Lorado mine site with the unconformity only metres away from the main uranium deposit, so it may have also played a role in mineralization in any one of the ways mentioned above.

Although there are no new geochronological results, the studied deposits of the Beaverlodge uranium district are clearly not basement-hosted unconformity deposits originally associated with the Athabasca Basin. Aside from Koeppel's (1968) 1.78 Ma age for epigenetic uranium mineralization in the Beaverlodge district, evidence for this includes the episyenite alteration minerals and estimated fluid temperatures. Alteration related to the Athabasca Basin unconformity uranium deposits is dominated by clay minerals, most commonly the low-K variety illite. Further, ore fluid depositional temperatures in the Athabasca Basin deposits commonly are believed to be in the

180° to 250°C (Pagel *et al.*, 1980; Kyser *et al.*, 2000; Cuney *et al.*, 2003) or 140° to 160°C (Derome *et al.*, 2003) range, whereas alteration associated with the Beaverlodge deposits is characterized by the Na-rich feldspar albite and fluid temperatures estimated to be about 350°C (S. Dieng, pers. comm., 2010).

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