Bedrock Geology of the Ace-Fay-Verna-Dubyna Mines Area, Beaverlodge Uranium District

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Abstract

Surface mapping coverage of the Verna-Dubyna mines area was filled in and extended to include the Ace-Fay-Verna mine area during a brief visit to the Beaverlodge uranium district. Recognition of hematite and albitite alteration was hampered in the Ace-Fay-Verna area by poorer bedrock exposure and higher strain, but there are sufficient occurrences to indicate that the alteration extended throughout the area. A new outlier of basal conglomerate indicates that the original extent of the Martin group probably also included the entire Ace-Fay-Verna-Dubyna mine area and beyond. Brief visits to several past-producing mines west of the Black Bay fault show that the mineralization process there was much the same as farther east in the main part of the Beaverlodge uranium district.

Keywords: *Beaverlodge uranium district, vein-type uranium deposit, albitite, Ace-Fay-Verna mine, Dubyna mine, Martin group, geochronology, leucogranite.*

1. Introduction

The vein-type uranium deposits within the Beaverlodge uranium district (Figure 1) of northwestern Saskatchewan were exploited between 1955 and 1982. Previous descriptions of the sixteen past-producing mines and numerous other small pits (*e.g.*, Robinson, 1955; Canadian Institute of Mining and Metallurgy, 1957; Lang *et al.*, 1962, Beck, 1969; Evoy, 1986) are largely outdated, prompting the present ongoing project aimed at updating knowledge of the Beaverlodge deposits (Tracey *et al.*, 2009; Ashton, 2010, 2011). A brief reconnaissance of the Verna-Dubyna mines area in 2011 revealed a network of intense alteration (previously termed episyenite, but renamed albitite in this study) spatially associated with the uranium mineralization (Ashton, 2011). That work was facilitated by excellent bedrock exposure resulting from a 2008 forest fire. This paper documents the results of about a week of field work in 2012 that was intended to fill in and extend the reconnaissance Verna-Dubyna mapping to include the largest past-producing mine in the Beaverlodge uranium district (Ace-Fay-Verna mine; Figure 1). This western extension of the Verna-Dubyna mapping also contains the eastern edge of a structural basin containing the Martin group, a conglomerate-arkose-basalt redbed succession believed by some (*e.g.*, Smith, 1986) to play a genetic role in uranium deposition. Mapping was also designed to determine whether the albitite alteration extended to this more productive western area. A short reconnaissance of three past-producing mines (Cayzor, Rix-Leonard, and Cinch Lake) west of the Black Bay fault (Figure 1) also facilitated a comparison of mineralizing style with that in the eastern part of the uranium district.

A brief summary of previous mapping in the region has been provided elsewhere (Ashton, 2011). The uranium deposits and occurrences in the Ace-Fay-Verna-Dubyna mines area are mainly hosted by highly strained leucogranites of inferred 1.93 Ga age (Hartlaub *et al.*, 2005) and less commonly by Murmac Bay group amphibolites proximal to large bodies of the intrusive leucogranite (Figure 1). The high degree of localized brittle-ductile strain in this area has led to previous misinterpretation of both host-rock types as having sedimentary protoliths (*e.g.*, Beck, 1969; Tremblay, 1972).

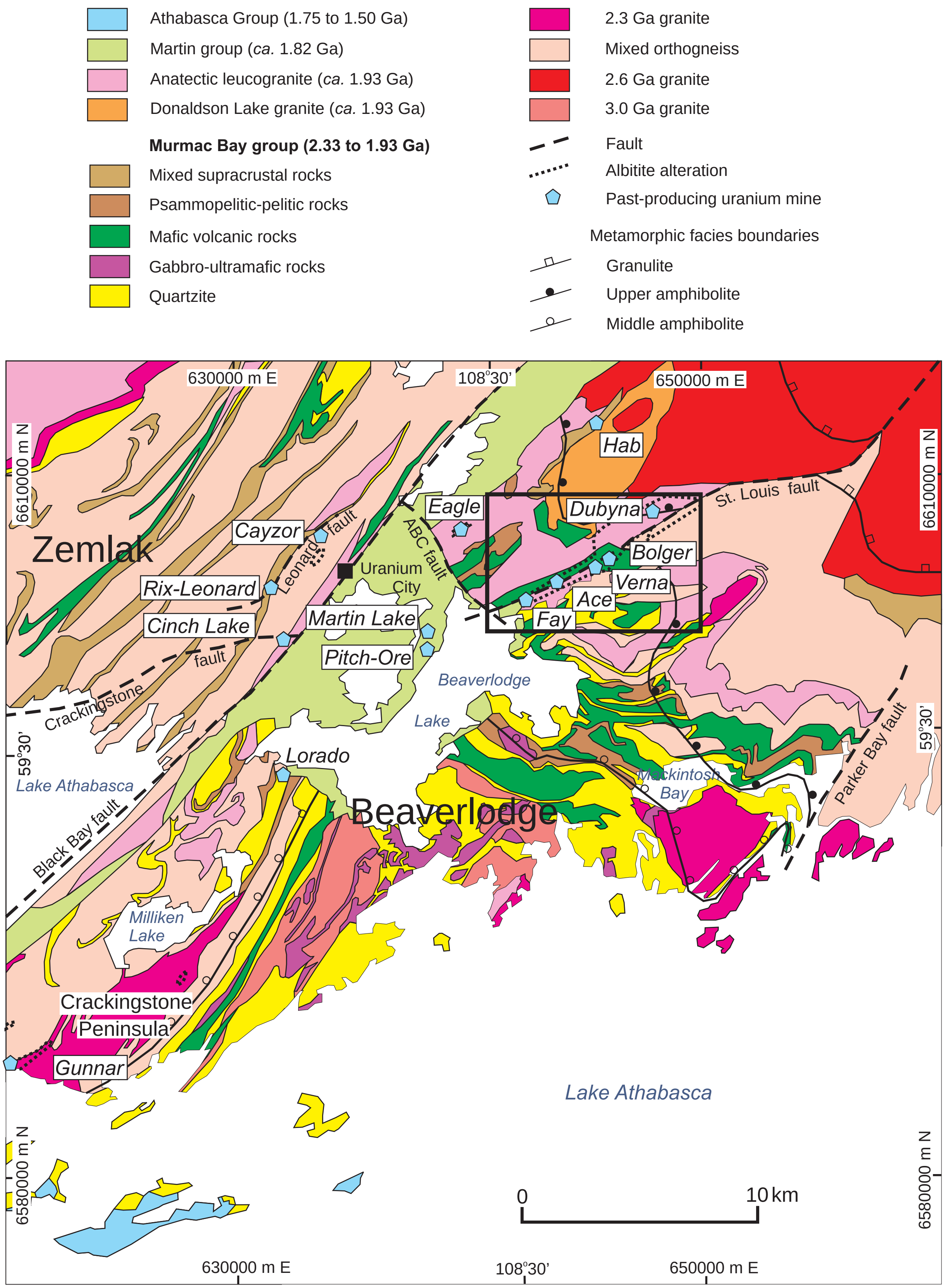


Figure 1 – Location of Ace-Fay-Verna-Dubyna mines area shown in Figure 2 (outlined by solid black line) and other select mines within the regional geological framework of the Beaverlodge uranium district.

A hand-held, high-sensitivity, gamma and neutron radiation spectrometer (Radiation Solutions GR-135) was used to establish average concentrations of eU[1], eTh, and K for the major rock types (Table 1) and to study their variability in altered and mineralized rocks. Due to the short field season, there are insufficient measurements on many rock types to be statistically meaningful and none of the results should be used as substitutes for direct rock assays; nevertheless, they do illustrate some interesting relationships, which are discussed below.

2. Regional Geology

The Beaverlodge uranium district lies within the southwestern Beaverlodge and easternmost Zemlak domains (Figure 1). 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) during the *ca.* 2.5 to 2.35 Ga Arrowsmith orogeny (Berman *et al.*, 2005) and prior to emplacement of 2.33 to 2.29 Ga syn- to post-collisional granites (Hartlaub *et al.*, 2007). Granite emplacement partly overlapped 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. The widespread leucogranite suite that hosts most of the Beaverlodge vein-type uranium deposits was generated during this Taltson orogenic event due to crustal melting. A second amphibolite-facies metamorphic event *ca.* 1.91 to 1.90 Ga associated with a northeast-striking deformational overprint (D3; Ashton *et al.*, 2009b) is apparently tied to tectonic events taking place in the vicinity of the Snowbird

Table 1 – Average and range of spectrometer results from the main rock types in the Ace-Fay-Verna-Dubyna mines area.

Rock Type	Rock Code	n=	eU (ppm)	eTh (ppm)	%K	Total cps
Mineralized veins-average		2	**1872.30**	**190.65**	*	**20000.00**
Mineralized veins-range			1976.3	281.1	*	20000
Albitite alteration-average		16	**100.98**	**22.19**	**2.22**	**1160.31**
Albitite alteration-range			6.4 to 289.3	0 to 80.7	0 to 4.1	220 to 3025
Alaskite		1	**0**	**36.3**	**3.9**	**240**
Martin basalt-average	Rgv	2	**7.40**	**5.40**	**0.10**	**130.00**
Martin basalt-range			5.9 to 8.9	4.2 to 6.6	0 to 0.2	120 to 140
Martin sedimentary rocks-average	Rb	2	**4.55**	**19.50**	**2.20**	**207.50**
Martin sedimentary rocks-range			3.3 to 5.8	9.7 to 29.3	0.1 to 4.3	165 to 250
Cream leucogranite-average	Ald	13	**5.91**	**13.43**	**2.06**	**221.62**
Cream leucogranite-range			2.6 to 16.5	2.2 to 25.6	0.5 to 2.9	130 to 390
Pink leucogranite-average	Alp	10	**8.21**	**16.95**	**1.34**	**229.50**
Pink leucogranite-range			1.8 to 21.5	3.4 to 70.1	0 to 2.5	120 to 350
Sheared leucogranite-average	Alp'	2	**6.35**	**11.00**	**2.15**	**185.00**
Sheared leucogranite-range			3.1 to 9.6	1.6 to 20.4	1.7 to 2.6	120 to 250
Sheared-cataclastic leucogranite-average	Alp-s	3	**15.40**	**16.33**	**0.57**	**393.33**
Sheared-cataclastic leucogranite-range			2.1 to 29.5	5.2 to 36.8	0 to 1.5	160 to 800
Mylonitic leucogranite-average	Alp-m	2	**0.90**	**9.00**	**0.35**	**130.00**
Mylonitic leucogranite-range			0 to 1.8	5.7 to 12.3	0.3 to 0.4	90 to 130
Murmac Bay group amphibolite-average	Ma	2	**9.45**	**2.55**	**0.75**	**41.50**
Murmac Bay group amphibolite-range			3 to 15.9	0.3 to 4.8	0.5 to 1.0	0 to 83
Murmac Bay group quartzite	Mq	1	**43.8**	**7.4**	**1.4**	**1000**
Average upper continental crust			**2.7**			

Alp' refers to pink leucogranite that has undergone late shearing.
* denotes spurious high values of %K due to improper internal spectrometer corrections
for eU concentrations above several hundred ppm.

[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.

tectonic zone, about 200 km to the west. This was followed by deposition of the virtually non-metamorphosed Martin group during D4 at about 1.82 Ga (*ibid.*) and the unmetamorphosed Athabasca Group between about 1.75 Ga (Rainbird *et al.*, 2007) and 1.50 Ga (Creaser and Stasiuk, 2007).

3. Ace-Fay-Verna-Dubyna Mines Area

The Ace-Fay-Verna-Dubyna mines area, which also includes the '46', '11', '21', and '83' zones (Ashton, 2011), spans the moderately southeast-dipping St. Louis fault northeast of Beaverlodge Lake (Figures 1 and 2). Amphibolite and minor quartzite and pelitic schist of the Murmac Bay group occur both *in situ* and as xenoliths in the widespread leucogranite. The degree of strain is relatively low in the northeastern portion of the area (*i.e.*, the 11 Zone–Dubyna Lake area; Figure 2), where primary grain sizes are preserved in the leucogranite and the metre- to decimetre-scale supracrustal xenoliths are angular and randomly oriented to variably foliated parallel to the regional S1-S2 foliation. In the west (*i.e.*, Fay shaft–11 Zone area; Figure 2), however, the rocks have been variably sheared to mylonitized giving them a well layered appearance due to attenuation of the xenoliths (Ashton, 2011).

Alteration marked by the removal of quartz and, to a lesser extent, K-feldspar, coupled with the addition of albite, hematite, and carbonate, forms a semi-continuous network throughout the northeastern part of the area where the least-deformed rocks and excellent exposure facilitates its recognition within the leucogranite. It is much more difficult to recognize in the west due to the finer grain size resulting from mylonitization, but newly recognized surface occurrences (Figure 2), together with its historical documentation in the Ace-Fay-Verna mine (Dawson, 1956; Morton and Sassano, 1972; Hoeve, 1982) suggests that the network of albitite alteration is continuous throughout the Ace-Fay-Verna-Dubyna mines area.

The Martin group unconformity has also been linked by some (*e.g.*, Smith, 1986) to uranium mineralization due to its close spatial relationship to many of the large deposits. Basal units of the Martin group unconformably overlie mineralized leucogranites and Murmac Bay group amphibolites in the vicinity of the Fay and Ace shafts on surface and are found underground at the Fay and Verna ends of the mine (Morton and Sassano, 1972; Figure 1). A new outlier of basal Martin group conglomerate was recognized this summer over 2.5 km northeast of the Verna mine (Figure 2), suggesting that the redbed succession originally covered the entire map area. Uranium mineralization is also hosted by Martin group mafic volcanic rocks at the Martin Lake and Pitch-Ore mines (Figure 1).

a) Unit Descriptions

Due to the restricted extent of new mapping, the reader is referred to the legend on the accompanying map separate and to Ashton (2011) for detailed descriptions of the rock types. Nevertheless, a few comments are warranted based on new and/or newly processed information.

Murmac Bay Group

The **Murmac Bay group amphibolite (unit Ma)** in the map area differs from that described from elsewhere in the Uranium City area (Hartlaub *et al.*, 2004) in that it is more pervasively sheared and overprinted by cataclastic deformation. Many of the rocks also tend to be more chlorite than amphibole rich, and locally contain hydrothermal carbonate-albite-hematite ± rutile veins, suggesting that they have been affected by alteration. It would require further work to determine whether this alteration resulted from the same fluids responsible for albitization of the leucogranites, but there is no reason to suspect that such widespread post-magmatic metasomatism would not have affected other rocks types in the immediate area. Two spectrometer readings on the amphibolite show low K and eTh values as expected for rocks of this composition, but the eU values are quite variable, probably reflecting localized mineralization (Table 1). A single reading from **Murmac Bay group quartzite (unit Mq)** shows a similarly higher-than-expected concentration of eU.

Syn-tectonic Granitoids

The medium-grained (1 to 5 mm), seriate to equigranular leucogranites that intrude the Murmac Bay group have been subdivided based on colour, presence of abundant xenoliths, and degree of deformation. The most common variety is **pink leucogranite (unit Alp**; Figure 3A in Ashton, 2011), the pink to red colour of which has been shown by various studies (*e.g.*, Dawson, 1956) and petrography to largely result from an abundance of microscopic hematite as inclusions in feldspar, grain coatings, and as veins and fracture linings. Pink leucogranites of similar age and appearance are found throughout the eastern and central Zemlak and western Beaverlodge domains (Ashton, 2009). It is unclear whether the hematitic alteration controlling their colour is deuteric or the result of a subsequent widespread hydrothermal event. The **cream-coloured variety of leucogranite (unit Ald**; Figure 3A) lacks or contains significantly less hematite. Although it is less abundant in the map area than the pink variety, it extends

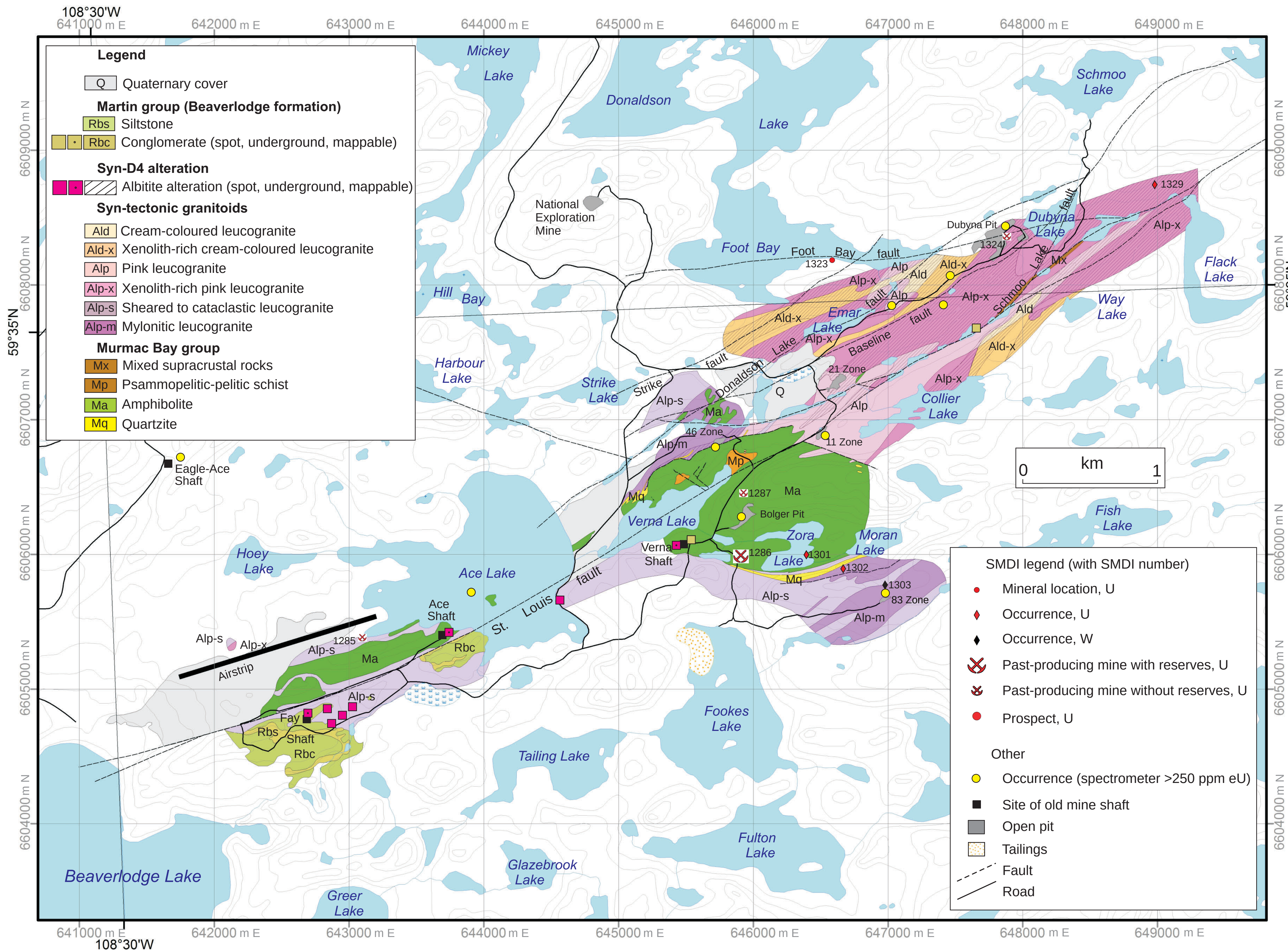


Figure 2 – Simplified geological map of the Ace-Fay-Verna-Dubyna mines area showing locations of past-producing uranium mines, Saskatchewan Mineral Deposits Index (SMDI) sites, and anomalous eU spectrometer occurrences.

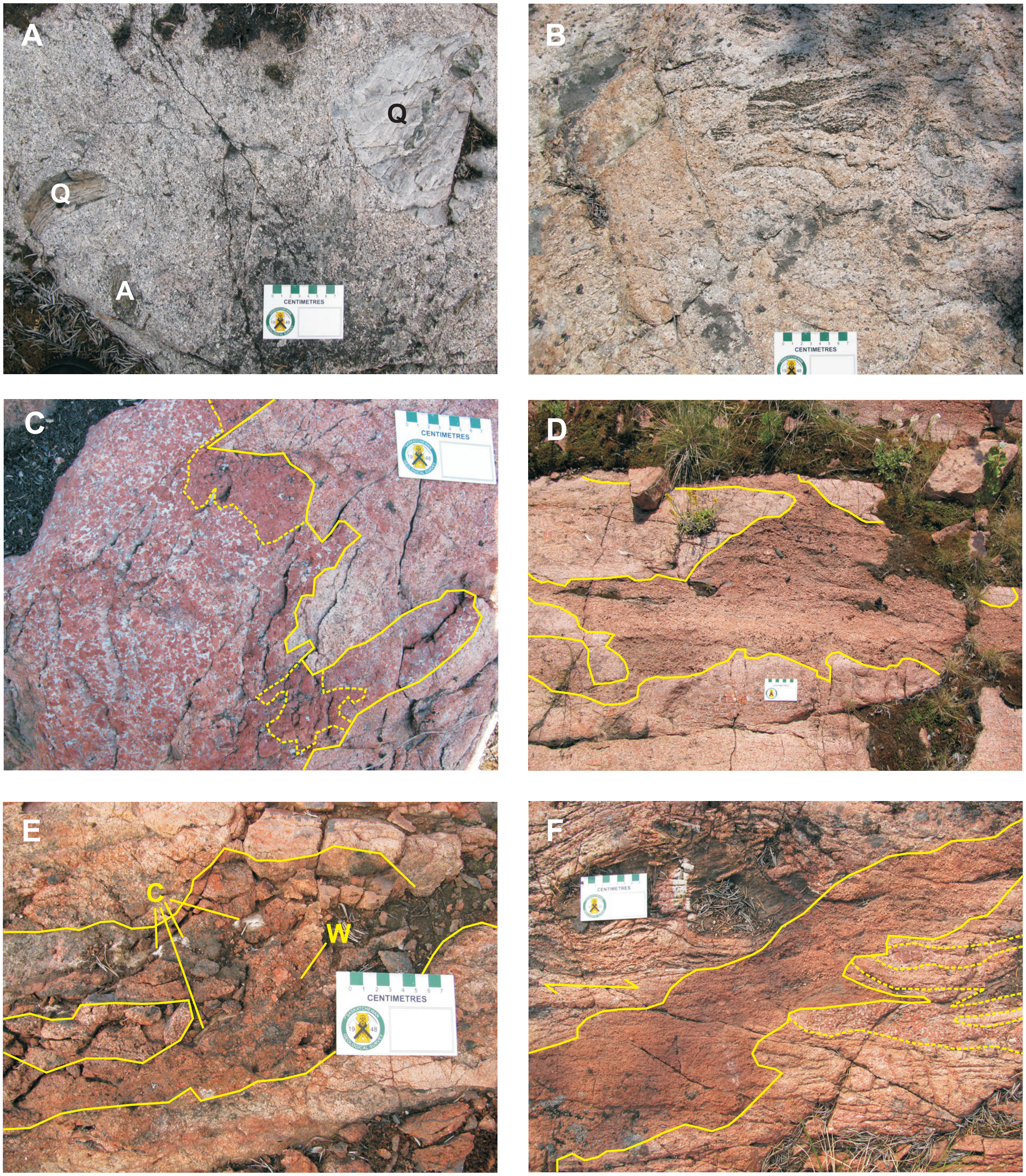


Figure 3 – Outcrop photos showing: A) cream-coloured leucogranite containing randomly oriented xenoliths of Murmac Bay group quartzite (Q) and amphibolite (A) (UTM 648362 m E, 6608309 m N); B) migmatitic appearance to cream-coloured leucogranite containing hornblende as mafic phase due to partial assimilation of amphibolite inclusions (UTM 645848 m E, 6607693 m N); C) pink leucogranite (right side) with large pod of alaskite (left side, delineated by solid yellow line) containing patchy albitization (distinguished by yellow dotted lines) (UTM 645963 m E, 6607612 m N); D) network of discordant albitite alteration in pink leucogranite showing irregular surface weathering due to quartz-carbonate dissolution and new, more resistant albite grains (UTM 647413 m E, 6607853 m N); E) zone of albitite alteration along brittle fault – note white carbonate veinlets (C) within albitite and pitted weathering surface (W) due to quartz/carbonate dissolution (UTM 646843 m E, 6607580 m N); and F) albitite alteration crosscutting main S1-S2 foliation (yellow foliation symbol) and broadly concordant 'alaskite' (outlined by dashed yellow lines) within pink leucogranite (UTM 646652 m E, 6607528 m N). Note: all UTMs in NAD 83, zone 12.

semi-continuously northwestward for 3.5 km across strike where it is termed the Donaldson Lake gneiss or Donaldson Lake granite (Figure 1; Ashton and Hartlaub, 2008). All other characteristics of the two varieties are the same and contacts are gradational, confirming that they have been derived from the same leucogranite protolith. Since the pink variety results from the addition of hematite, the cream-coloured variety is considered the most pristine. Spectrometer values are also similar, averaging 5.91 ppm eU for the cream-coloured variety and 8.21 ppm eU for the pink leucogranite (Table 1). Although most outcrops of both leucogranite varieties contain at least some xenoliths of Murmac Bay group quartzite and amphibolite, some contain up to 40% (Figure 3A; Figure 3B in Ashton 2011). An attempt has been made to distinguish these **xenolith-rich varieties of leucogranite (units Ald-x and Alp-x**) from their more homogeneous equivalents (Figure 2; see accompanying map separate), but contacts are understandably gradational. The pink and cream-coloured leucogranites, including the xenolith-rich varieties, contain chlorite as the main mafic mineral, presumably resulting from the retrogression and/or alteration of biotite. In the area immediately south of western Foot Bay, however, the cream-coloured leucogranite has infiltrated and partially assimilated some amphibolite xenoliths, locally producing gneissic to migmatitic rocks and hornblende as the dominant mafic mineral (Figure 3B). This probably marks both a northward transition from middle to upper amphibolite facies metamorphism in that area (Ashton and Hartlaub, 2008), and better preservation of the prograde metamorphic assemblage.

Another common feature of all these varieties of leucogranite is the presence of centimetre- to decimetre-scale pods and semi-continuous sheets of red, coarse-grained granite, here informally termed ‘alaskite’ (Figure 3C). It contains dark pink to red feldspars of unknown composition, quartz, little to no mafic material, and is generally massive to weakly foliated and concordant to the main regional foliation in the leucogranite. A lone spectrometer reading suggests it has a K-rich granitic composition, is Th rich and devoid of U (Table 1). It is unclear whether the ‘alaskite’ is a late magmatic phase of the leucogranite, a partial melt produced during metamorphism, or results from a subsequent hydrothermal event.

In the eastern part of the area, both colour variations of the leucogranite and the abundance of xenoliths are easily distinguished due the excellent bedrock exposure and generally low intensity of deformation (Figure 3A; Figures 3B and 3C in Ashton, 2011). In the Verna Lake area and westward (Figure 2), however, the rocks are more intensely deformed, significantly changing their appearance. The leucogranites are finer grained, the xenoliths are attenuated and transposed giving the rocks a more layered appearance, and the rocks are generally more intensely fractured (Figures 3D and 3E in Ashton, 2011). The most common variety has been termed **sheared to cataclastic leucogranite (unit Alp-s)**. Most is pink and sugary textured with a variably developed/preserved ductile shear fabric and locally preserved millimetre-scale feldspar porphyroclasts. The cataclastic overprint is characterized by abundant, variably oriented fractures, commonly lined with chlorite and, less commonly, hematite. Where best developed, this late fracturing and cataclasis obscures a variably developed, earlier ductile fabric, giving these rocks a near-massive appearance. Nevertheless, most of the leucogranites in the west were probably subjected to ductile deformation prior to the cataclastic overprint. Where an early mylonitic fabric is well preserved, the rocks have been distinguished as **mylonitic leucogranites (unit Alp-m**; Figure 3E in Ashton, 2011). The best example is north of Verna Lake where the sheared to cataclastic leucogranite is gradational into the mylonitic variety, which is in turn overprinted by cataclasis (Figure 2). The contact between these mylonitic leucogranites and less-deformed pink and cream-coloured varieties northeast of Verna Lake is obscured by Quaternary cover. It may be gradational, but could alternatively be a sharp discontinuity, possibly an extension of the northwest-striking fault juxtaposing pink leucogranite and amphibolite south of the St. Louis fault (Figure 2). Minor local shearing of the leucogranite (two such rocks denoted as Alp' on Table 1) does not appear to significantly affect spectrometer values, but rocks within the extensive sheared to cataclastic leucogranite unit (Alp-s) show a distinct loss of K, near-constant eTh, and an accompanying gain in eU, again suggesting alteration with minor associated concentration of U. The mylonitic leucogranites have experienced losses in eU, eTh, and K (Table 1).

Albitite

The term ‘episyenite’ has been applied to granitic rocks that have been hydrothermally altered so that quartz, and commonly K-feldspar, have been replaced by albite along with hematite (Cathelineau, 1986; Petersson 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 of the Ace-Fay-Verna-Dubyna mines area (Figure 1; Ashton, 2010), where the alteration, marked by hematization and quartz dissolution, was easily recognized in the coarse-grained, homogeneous Gunnar granite, and an accompanying loss of K-feldspar was indicated by spectrometer readings. Usage of the term episyenite was continued during the 2011 mapping in the main Beaverlodge camp (Ashton, 2011) but, given the finer grain size and more heterogeneous leucogranite to leucotonalite compositional range there (*i.e.*, it is not always clear whether K-feldspar was in the protolith), the term ‘**albitite**’ has been adopted. Recognition of albitite was based on documented quartz dissolution and addition of albite and hematite (Figure 4 in Ashton, 2011). Rocks exhibiting a darker red colour due to the addition of hematite, but containing quartz, are far more extensive, suggesting that a much larger area was affected by hydrothermal fluids. These may well have been the same fluids responsible for albitization, but due to differing fluid characteristics, quartz was not leached and albite may not have been precipitated. Spectrometer readings show that the albitite alteration has similar K values to those of the cream-coloured and pink leucogranites, is slightly enriched in eTh, but contains significantly more eU (Table 1), suggesting either that it is a preferred host for U mineralization and/or that the fluid responsible for albitization also precipitated U.

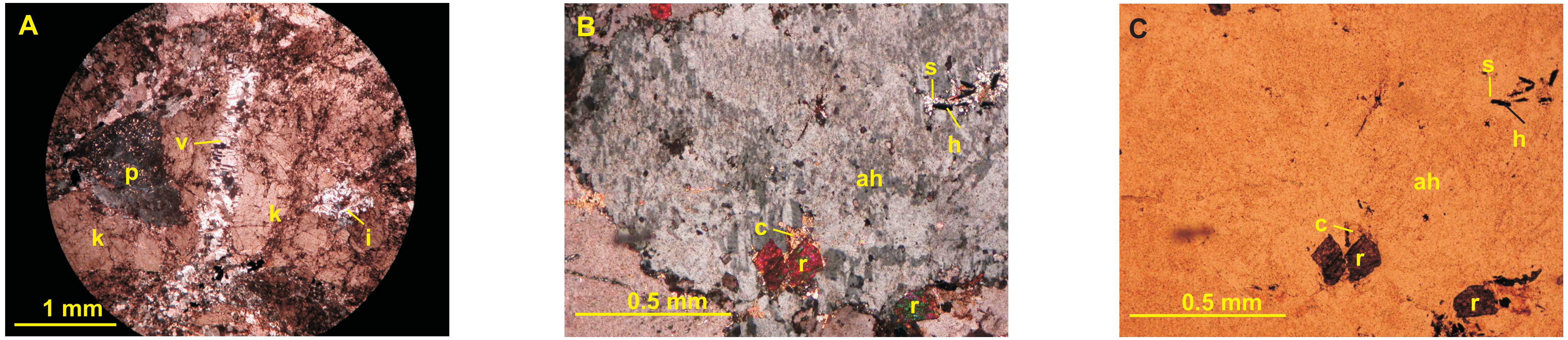
The best exposures of albitite are in the area northeast of Verna Lake where it forms a semi-continuous network (Ashton, 2011) that has now been extended at least to the areas northeast of Dubyna Lake, south of the St. Louis fault, and north to Foot Bay of Donaldson Lake (Figure 2). The poor exposure and fine-grained nature of the highly deformed rocks southeast of Verna Lake make recognition difficult in the Ace-Fay-Verna mine area, but several small occurrences were identified (Figure 2 and accompanying map separate). Rocks described in a similar fashion to the albitites were also described as alteration from underground in the Ace-Fay-Verna mine (Dawson, 1956; Hoeve, 1982), suggesting a genetic link between albitization and uranium mineralization.

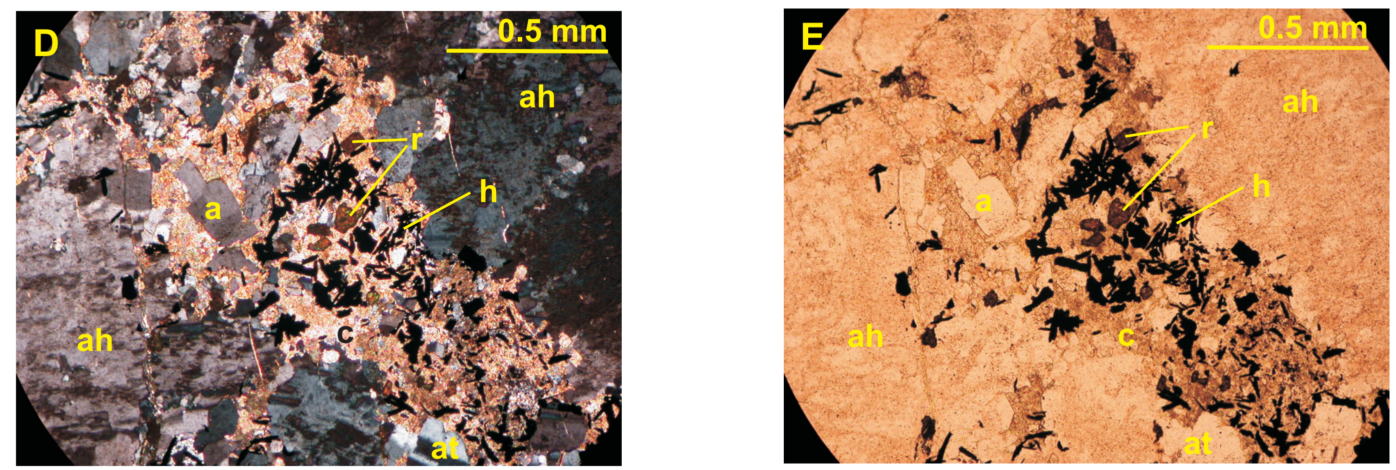
Albitite alteration occurs in an anastomosing network of layer-parallel and crosscutting veins (Figure 3D). Some of these veins follow faults and fractures (Figure 3E), which are clearly providing fluid conduits, but many extend a significant distance from structural discontinuities into the wall rocks (Figures 3D and 3F). Individual branches range from millimetre-scale linings of fractures up to several metres in thickness. The albitite is recognizable in outcrop by increased reddening due to the addition of microscopic hematite and by an accompanying reduction in the amount of visible quartz in the host leucogranite (Figures 3D, 3E, and 3F). The colour ranges from pale pink through orange pink and pink red to red brown with increasing hematite content. Weathered surfaces are typically irregular due to the dissolution of quartz, or more commonly, secondary carbonate, leaving a surface defined by millimetre-scale albite grains (Figures 3D, 3E, and 3F). Albite occurs ubiquitously in the matrix and as crosscutting veins. The intensity of alteration varies, but where near complete, the albitite contains 3 to 15% carbonate (rarely up to 35% where heavily veined) both in the matrix and as crosscutting veins (Figure 5D in Ashton, 2011), along with up to 5% chlorite and 2% specular hematite.

Thin sections show that the alteration ranges from pervasive, where the primary igneous mineralogy of the leucogranite has been completely replaced, to partial, where albitite occurs as rims on primary feldspar grains, crosscutting veinlets, and/or interstitial pods (Figure 4A). Hydrothermal albite can be distinguished from primary igneous plagioclase based on grain shape, alteration, and twinning. Primary plagioclase tends to be anhedral and polysynthetically twinned, but has been intensely sericitized, making the twinning difficult to discern. By contrast, hydrothermal albite ranges from anhedral to subhedral and generally contains abundant microscopic hematite inclusions. Polysynthetic twinning is much easier to recognize in the albite, but has been modified by subsequent deformational bending, breaking, and polygonization, which produces a mottled appearance in crossed polarized light (Figures 4B, 4D, and 4F). Pods of alteration occupying interstices amongst the medium-grained albite matrix contain finer-grained albite that appears to be a mix of broken-up fragments of medium-grained albite from the walls of the interstices and new albite growth, which takes the form of well-twinned, subhedral grains containing few, if any, inclusions (Figures 4D and 4E). These interstitial pods also tend to contain: platy(?) opaque grains interpreted as specular hematite; a yellow-brown (in plane transmitted light), high-relief, accessory-type mineral thought to be rutile; an unknown, speckled (in crossed polarized light), clay-type mineral; and carbonate (Figures 4B to 4G). These small interstitial pods of alteration may be filling the voids left behind by quartz dissolution, although the common presence of Fe-bearing hematite and Ti-bearing rutile suggests an input from primary biotite. The subhedral nature of the albite and rutile in these interstitial pods suggests that they grew from a fluid phase. Carbonate tends to at least partly enclose the minerals within the alteration pods (Figures 4B to 4F). It also occurs within the albitite matrix, where it locally extends into medium-grained albite grains, and as veinlets, some of which crosscut albitite veinlets, together suggesting that the carbonate either precipitated late or during multiple cycles. Based on these observations, a preliminary paragenetic sequence can be put forward: 1) leaching of quartz and replacement of primary feldspars by medium-grained albite during hematite precipitation (microscopic inclusions); 2) filling of interstitial voids left by leached quartz ± biotite by fine-grained albite, rutile(?), and specular hematite(?) (precipitation of microscopic hematite inclusions in albite cease during this stage); and 3) precipitation of carbonate. The precipitation of carbonate may overlap that of albite, thus explaining its presence in some albite veinlets. Most of the high-grade uranium mineralization observed in pit walls is in late carbonate veins and rare quartz veins that crosscut albitite and may represent this last phase of carbonate precipitation in the paragenetic sequence. This alteration did not postdate all of the deformation as indicated by the variably polygonized nature of the hydrothermal albite, and breakup of hydrothermal rutile in high-strain zones (Figures 4F and 4G).

Martin Group

The basal Beaverlodge formation of the Martin group is exposed at both the Fay and Ace shafts, where it rests unconformably on sheared to cataclastic leucogranite (Alp-s) and comprises polymictic conglomerate and minor siltstone. The Martin group occurrence at the Fay shaft represents the eastern extent of the remnant structural basin centred on Martin Lake, whereas the occurrence at the Ace shaft is an outlier. Both are situated in the hanging wall of the moderately southeast-dipping St. Louis fault (Figures 1 and 2). Mine cross sections show that the Martin group was also encountered at depths of more than 1000 m in the footwall of the St. Louis fault near the Fay shaft,





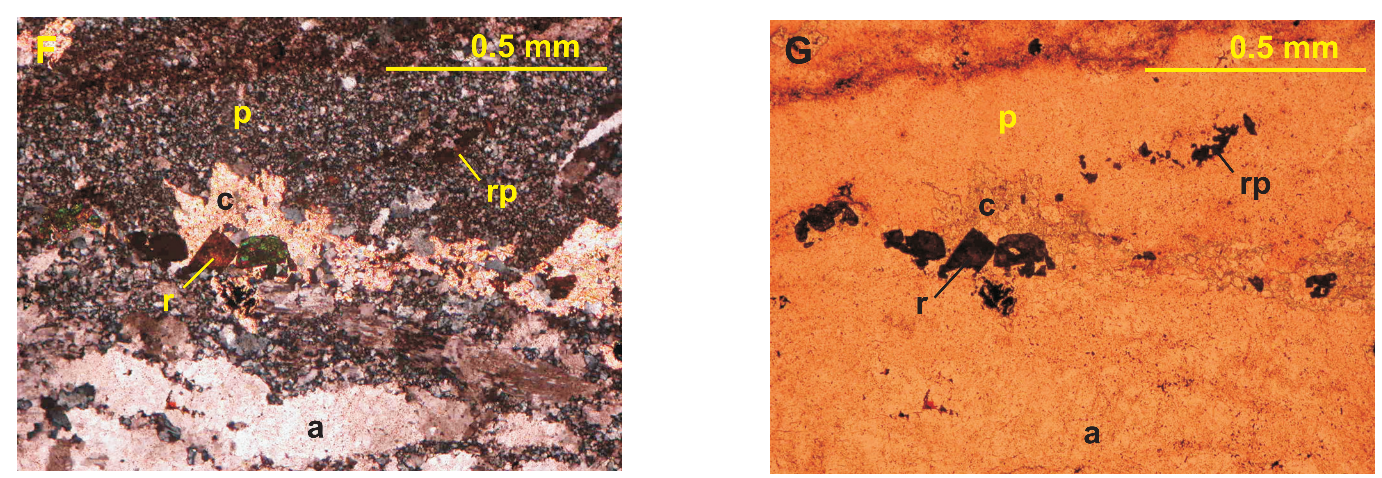


Figure 4 – Photomicrographs of albitite alteration showing: A) an albitite vein (v) crosscutting relict igneous K-feldspar (k) and an interstitial albitite pod (i) possibly filling void left by leached quartz, section also contains relict igneous plagioclase (p); crossed polarized light; B) rutile(?) (r) partially enclosed by carbonate (c), and platy specular hematite (h) partially enclosed by an unidentified, speckled, clay mineral (s) within medium-grained, hydrothermal albite (ah) displaying mottled polysynthetic twinning and containing abundant microscopic hematite inclusions, crossed polarized light; C) plane polarized light view of B); D) interstitial pod of alteration in albitite containing subhedral hydrothermal albite (a) displaying far fewer microscopic hematite inclusions and better developed twinning (at) than medium-grained hydrothermal albite (ah) bordering pod, along with subhedral rutile(?) (r) and platy specular hematite (h) within carbonate matrix (c), crossed polarized light; E) plane polarized light view of D); F) coarse, subhedral rutile (r), largely enclosed by carbonate (c) within variably deformed albitite (a); note that in high-strain zones (rp) marked by polygonization (p) of albitite, rutile has been broken up ; and G) plane polarized light view of F).

perhaps indicating a component of reverse displacement (Morton and Sassano, 1972). It has also been reported from both the footwall and hanging wall, the latter at depths of more than 750 m, in the vicinity of the Verna shaft (*ibid.*). These outliers and faulted occurrences suggest that the Martin group was at one time more extensive than at present and covered the entire Ace-Fay-Verna area. This interpretation is supported by the discovery of another decimetre-scale outlier of Martin group conglomerate (Figure 5A) more than 2.5 km northeast of the Verna mine along the St. Louis fault, expanding the original extent of the Martin group to at least the Dubyna mine area (Figure 2).

Clast types show that the Martin group basal conglomerate was locally derived (*e.g.*, Ashton, 2011). In the Ace-Fay-Verna-Dubyna area, they are dominated by granitoids, vein quartz and minor Murmac Bay group rocks, but also include coarse-grained alaskite of the kind that occurs as discontinuous dykes, sheets, and pods within the various varieties of leucogranite (Figure 5B). Red-brown clasts resembling albitite alteration were also noted in the Martin group conglomerate in the vicinity of the Fay shaft (Figure 5C), although more work needs to be done to confirm this relationship, as it would indicate that albitite alteration predated Martin group deposition. The best age estimate for Martin group deposition comes from a mafic dyke located about 20 km west-southwest of Uranium City along the northern shore of Lake Athabasca. The dyke is part of a suite that has very similar lithological, geochemical, and metamorphic characteristics to those of the Martin mafic volcanic rocks of the Gillies Channel formation (Ashton and Hartlaub, 2008; Morelli *et al.*, 2009). It yielded an 1818 ±4 Ma U-Pb baddeleyite age, suggesting that Martin group deposition was underway by that time.

b) Structure

The regional structural history has been previously summarized (Ashton *et al.*, 2009b; Ashton, 2010), as have structural observations collected last summer in the Verna-Dubyna mine area (Ashton, 2011). Structural data collected in 2012 are generally consistent with those previous observations. The sheared to mylonitic leucogranites (units Alp-s and Alp-m) and Murmac Bay supracrustal rocks (Mq, Ma, and Mp) north of Verna Lake (Figure 2) are moderately southeast dipping and contain gently southwest-plunging stretching lineations. Kinematic indicators were not recognized, however, so the displacement may have been either oblique sinistral-reverse or dextral-normal in its present configuration. Since the stretching lineations are broadly collinear with lineations farther south in the Beaverlodge Lake–Mackintosh Bay area, where the regional S1-S2 fabric is oriented broadly east-west (Ashton and Hartlaub, 2008), this phase of mylonitization is thought to be of D2 age.

The St. Louis fault (Figure 2) is one of a set of northeast-striking discontinuities marked by topographic lows, fault scarps, and high uranium concentrations. They are thought to represent brittle-ductile faults, but their displacement history, particularly that of the St. Louis fault, has long been debated (see Ashton, 2011 for summary). Southeast of Dubyna Lake, the St. Louis fault appears to split into two parallel discontinuities (Figure 2). The southern splay is exposed as a steeply southeast-dipping shear zone (Figure 5D) developed within more cataclastically deformed pink leucogranite (Figure 5E). The shear zone contains rare south-southwest–plunging stretching lineations, although the sense of displacement is unclear. Another of these northeast-striking shear zones, previously termed the Donaldson Lake fault, extends through the eastern end of Foot Bay on Donaldson Lake (Figure 2). It is moderately southeast dipping, and although no stretching lineations were recognized, shear bands suggest a dextral component of displacement (Figure 5F). This is consistent with a broadly east-west–shortening regime as suggested for D4 time at *ca.* 1.8 Ga (Ashton *et al.*, 2009b).

Two-dimensional Regional Analysis of D4 Fractures and Veins

The relatively steep nature of most mineralized and non-mineralized fractures and carbonate, quartz and albitite veins in the Ace-Fay-Verna-Dubyna mines area facilitates their presentation on rose diagrams (Figure 6) and allows a two-dimensional interpretation. Most of the fractures and veins measured during this study are oriented east-northeast to east-southeast (Figure 6A), similar to the findings of Tremblay (1972), although the foliation-parallel northeast-striking orientations appear under-represented in that study, whereas the cross-cutting southeast-striking orientations appear over-represented. Nine fractures and veins measured at the Pitch-Ore uranium deposit (Figure 6B), which is hosted by Martin group mafic volcanic rocks (Figure 1), demonstrates that these dominant east-northeast–striking to east-southeast orientations are post-Martin group and, therefore, of D4 age. These post-Martin fracture orientations are similar to those recorded by Tremblay (1972) who showed that the southeast-striking orientations belong to a set of extensional faults that developed in the hinge zone of the F4 Martin Lake syncline. A more detailed fracture and vein study was completed at the Bolger pit, where 26 non-mineralized fractures and veins have developed in two main directions: east-northeast and north-northwest striking (Figure 6C). Fifteen mineralized fractures and veins at the Bolger pit are mainly oriented in the east-northeast to east orientation (Figure 6D). Although fewer fractures and veins at the Dubyna pit were measured, both non-mineralized and mineralized varieties have similar orientations to those at the Bolger pit (Figures 6E and 6F, respectively).

The dominant east-northeast to east-southeast orientation of both non-mineralized and mineralized fractures and veins is interpreted as including both dextral and extensional fault planes, respectively, and is broadly consistent

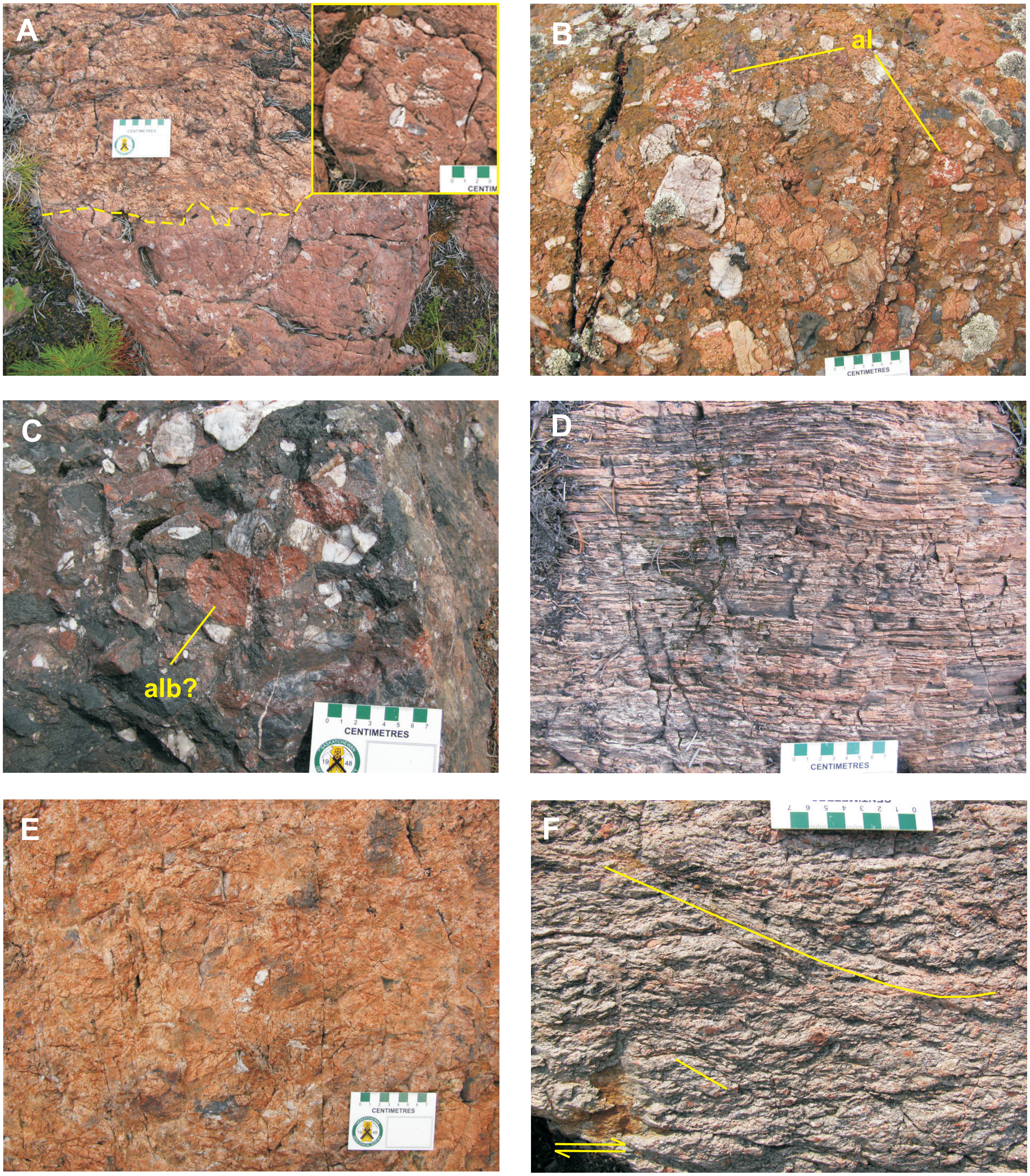


Figure 5 – A) Newly discovered Martin group unconformity with basal conglomerate (below dashed yellow line) containing rounded clasts of granite and vein quartz (inset) resting unconformably on intensely fractured pink leucogranite (UTM 647656 m E, 6607677 m N). B) Martin basal conglomerate at Fay mine site containing clasts of red coarse-grained alaskite (al) (UTM 642376 m E, 6604575 m N). C) Martin basal conglomerate at Fay mine site containing clast of possible albitite (alb?) (UTM 642574 m E, 6604578 m N). D) Platy mylonitic fabric developed in amphibolite containing abundant millimetre- to centimetre-scale layers of injected leucogranite, southern splay of St. Louis fault south of Dubyna Lake (UTM 648946 m E, 6608948 m N). E) Cataclastic pink leucogranite (UTM 648759 m E, 6608172 m N). F) Sheared cream-coloured leucogranite along the Donaldson Lake fault displaying dextral shear bands (solid yellow lines) (UTM 647237 m E, 6608134 m N).

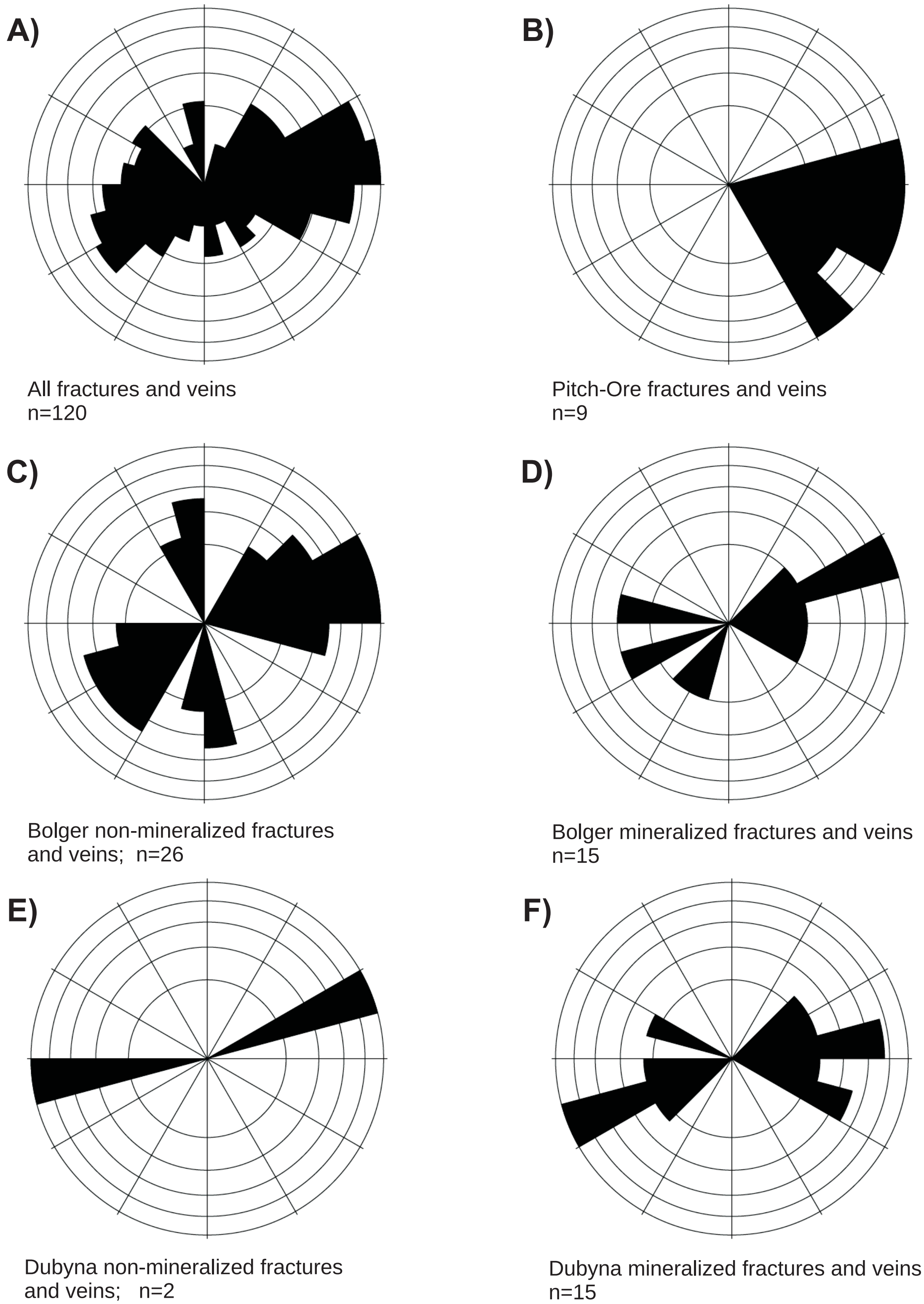


Figure 6 – Rose diagrams showing orientations of fractures and veins. Regional fractures and veins (A); fractures and veins at the Pitch-Ore deposit hosted by Martin group mafic volcanic rocks (B); non-mineralized (C) and mineralized (D) fractures and veins at the Bolger pit, and non-mineralized (E) and mineralized (F) fractures and veins at the Dubyna pit.

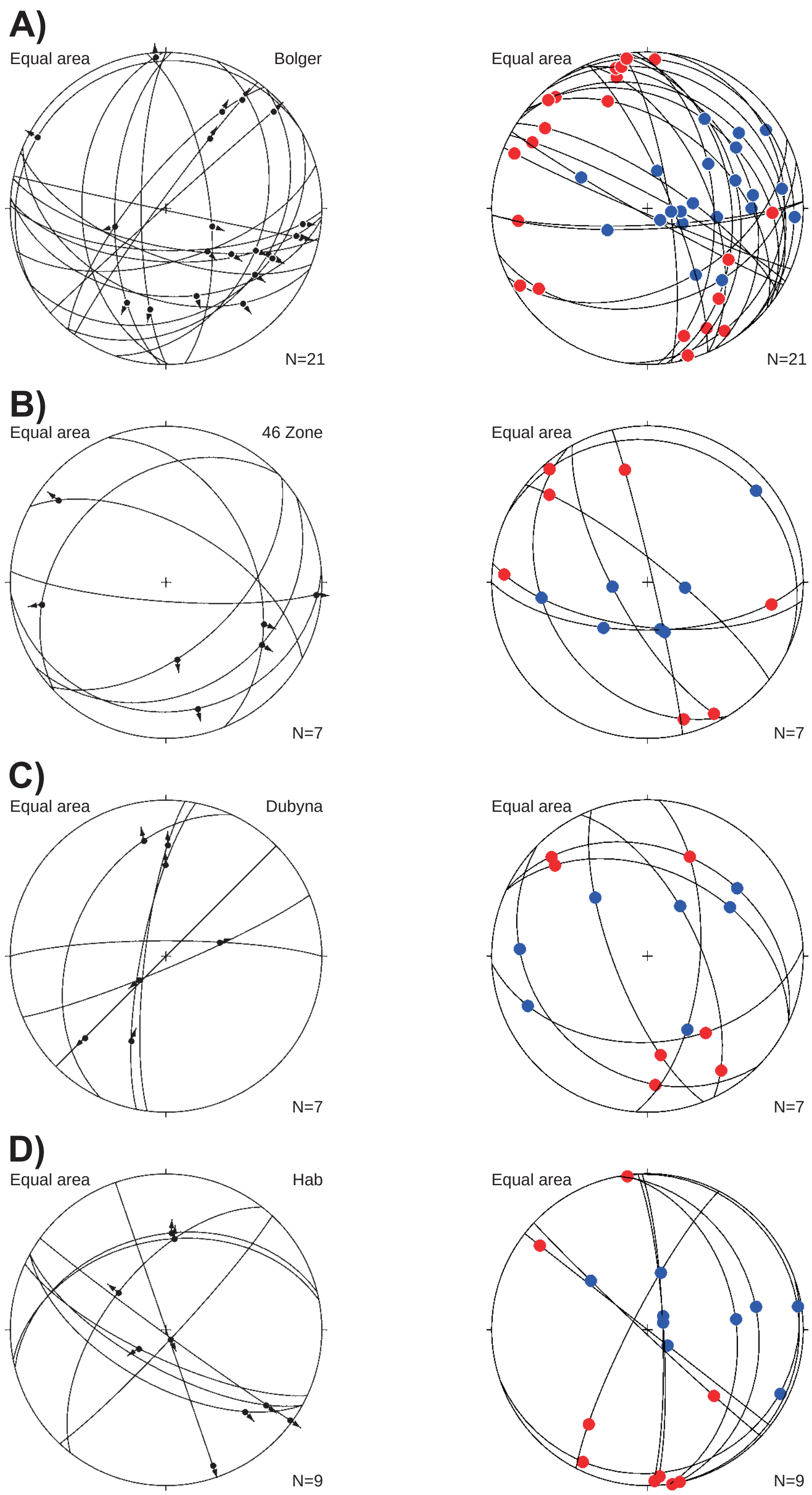


Figure 7 – Lower hemisphere, equal area stereograms on the left side of the figure display plotted trends and plunges of slickenlines (black dots) measured on faults (black great circles), with determined senses of hanging-wall displacement relative to the footwall along the slickenlines (small black arrows). Stereograms on right side of figure show calculated σ_1 (P - blue dots) and σ_3 (T - red dots) axes and movement planes containing both P and T axes for each fault (black great circles). Data from: A) the Bolger open pit, B) 46 Zone, C) Dubyna open pit area, and D) Hab open pit. Note the east-northeast–west-southwest scatter of P axes and north-northwest–south-southeast concentration of T axes. See text for discussion.

with development in the inferred D4 east-west regional shortening regime (Ashton *et al.*, 2009b). In that interpretation, northeast-striking dextral faults (*e.g.*, Black Bay, St. Louis) and southeast-striking sinistral faults (*e.g.*, ABC fault) were thought to form a conjugate set, whereas the main east-west orientation of the Uranium City dykes was interpreted as representing the extension plane. More variation in fracture and vein orientation is to be expected due to the diachronous nature of D4, which included a late period of relaxation as indicated by late normal displacements along the Black Bay and ABC faults (Tremblay, 1972; Ashton *et al.*, 2001).

Three-dimensional Analysis of D4 Fractures and Veins

The stress regime controlling the orientation of fractures and quartz and carbonate veins in the Ace-Fay-Verna-Dubyna mines area can also be investigated in three dimensions using fault-slip data. The following analysis utilizes the orientations of brittle faults and slickenlines, and the senses of fault displacement as determined from minor offsets and slickenline analysis (Petit, 1987). While determining the sense of fault displacement, care was taken to distinguish slickenlines generated by the frictional movement of blocks on either side of the fault from those generated by mineral precipitation during displacement. Data were collected from outcrop-scale faults at the Bolger pit, 46 Zone, and Dubyna mine along the St. Louis fault, and from the Hab mine to the northwest (Figure 1) and were analyzed using FaultKin version 5.2 software, according to the technique outlined by Marrett and Allmendinger (1990) and Allmendinger *et al.* (2011).

Figure 7 shows the orientation of faults, their corresponding slickenlines, and senses of displacement, along with the calculated P (maximum principal stress or σ_1) and T (least compressive stress or σ_3) axes. At the Bolger open pit (Figure 7A), almost all P axes calculated from fault-slip data plot in the northeastern quadrant of the stereonet, and associated movement planes strike north to northwest and dip gently to steeply. The large scatter of movement planes may result from the progression from, or oscillation between, predominantly normal slip to predominantly strike slip through permutation of the σ_1 and σ_2 principal stress vectors (low deviatoric stress). Such a process is not uncommon in extensional regimes (see Hu and Angelier, 2004), and can be due to fluctuations in fluid pressure at relatively shallow levels in the crust. The large scattering of P axes is probably better explained by stress accommodation through slip along pre-existing fractures, where normal and strike-slip, fault-associated P vectors may overlap, rather than by the rotation of fault blocks. T axes calculated from fault-slip data collected in the Bolger pit suggest predominant north-south to northwest-southeast extension (*i.e.*, creating east-west to east-northeast–west-southwest extension planes). Fault-slip data collected at the 46 Zone (Figure 7B), Dubyna mine (Figure 7C), and Hab mine (Figure 7D) show generally similar P-T axes distributions.

Fault-slip data for the above locations are consistent with a predominantly extensional regime of brittle deformation with permutable σ_1- σ_2 stress vectors in an east-northeast direction (Figure 8A) and north-northwest–south-southeast σ_3 extension direction (Figure 8B). Mineralized veins probably formed as a result of this stress regime. Late, sub-horizontal veins (mostly quartz breccias) are not mineralized and may have formed through a compressional event not recognized in the above analysis.

The few fault-slip data collected from the Pitch-Ore and Rix-Leonard mines suggest vein formation in a strike-slip regime, markedly different in orientation from the locations discussed above (Figure 9); however, the mineralized veins appear to have formed in an extensional stress regime, consistent with east-west shortening.

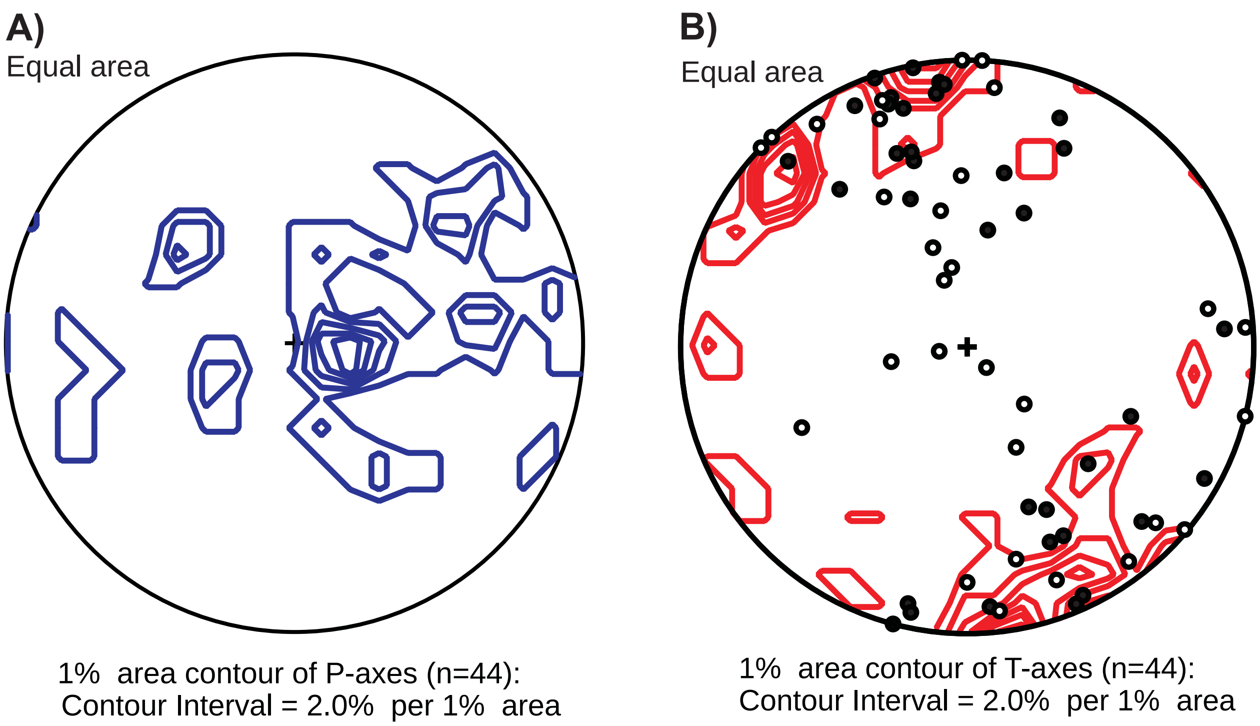


***Figure 8** – Lower hemisphere, equal-area stereograms showing 1% area contours of: (A) P axes and (B) T axes calculated from fault-slip data collected from the Bolger open pit, 46 Zone, Dubyna open pit, and Hab open pit. Poles of radioactive (black circles) and non-mineralized (white circles) veins are shown superimposed in B. The data suggests that mineralized veins formed under a generally extensional stress regime. Non-mineralized, subhorizontal, white, quartz-dominant veins appear to be associated with an unrecognized thrust event.*

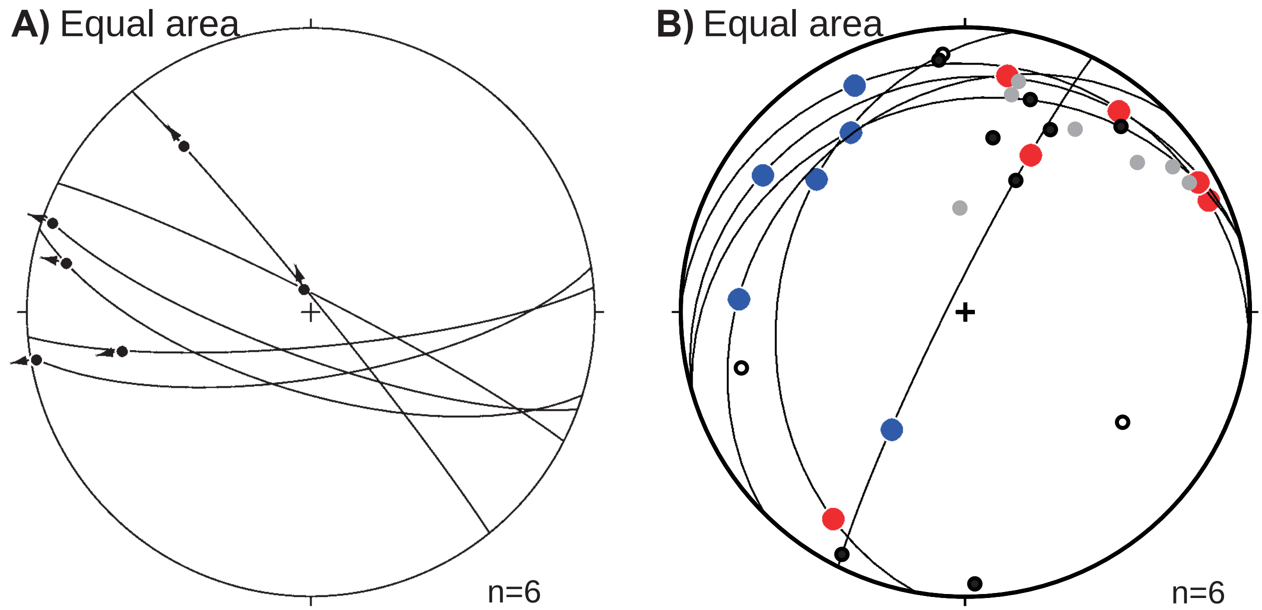


Figure 9 – Lower hemisphere, equal area stereograms showing: A) slickenlined faults and B) associated P axes (blue dots), T axes (red dots), and movement planes for fault-slip data collected at the Pitch-Ore and Rix-Leonard mines. Black dots on faults in (A) represent the trend and plunge of slickenlines on the faults; arrows indicate the sense of movement of the hanging wall relative to the footwall along the slickenline. Note the northwest-southeast concentration of P axes and northeast-southwest extension consistent with vein poles (non-mineralized - white dots; uncertain relationship to mineralization - grey dots; mineralized veins and fractures - black dots). See text for discussion.

c) Economic Geology of the Verna-Dubyna Mines Area

A brief overview of the mines and occurrences in the Ace-Fay-Verna-Dubyna mines area was presented last year (Ashton, 2011). The composite **Ace-Fay-Verna mine** (Saskatchewan Mineral Deposits Index (SMDI) #1285, 1286; Figure 2) was by far the biggest past-producer in the Beaverlodge uranium district, and together with small surface deposits in the immediate area, yielded about 19 700 t U from ore with an average grade of 0.24% (Ward, 1982). Ore was mined from sporadic zones 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) argillite and hornblende schist, 2) quartz-chlorite schist and Donaldson Lake gneiss, and 3) metasomatic granite (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) Murmac Bay group amphibolite, 2) gneissic leucogranite (although this unit may include minor Murmac Bay group psammopelitic rocks in the footwall of the St. Louis fault), 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 (*ibid.*), but is here considered equivalent to the albitite seen at surface.

According to Beck (1969) and Tremblay (1972), ore in the footwall deposits of the St. Louis fault occurs in the amphibolite (Ace ore bodies) as: 1) breccia zones within 20 m of the fault containing pitchblende, galena, quartz, calcite, chlorite and pyrite in the matrix to fragments of amphibolite and quartz; and 2) fault-parallel pitchblende veins and stringers with calcite, quartz, chlorite, pyrite, and minor nolanite and clausthanite. In the hanging wall (Fay ore bodies), ore occurs: 1) at the unconformity between the basement sheared to cataclastic leucogranite and the overlying Martin group, and 2) in breccia and shear zones within the leucogranite. At the Verna mine, pitchblende, accompanied by pink calcite, pyrite, and quartz, occurs within brecciated amphibolite (*ibid.*).

The **Bolger pit** (SMDI #1287; Figure 2), which produced about 290 t U (Ward, 1982), is effectively a surface expression of the mineralized zones at the Verna mine (Figure 2), and is likewise hosted by altered hanging-wall amphibolite. Stringers, blebs, and disseminated pitchblende occur with pink carbonate veins and chlorite in several fractures running sub-parallel to the St. Louis fault (Christie, 1953; Beck, 1969).

Another 3 km farther northeast is the former **Dubyna mine** (SMDI #1324; Figure 2), which is located between the northeast-striking Donaldson Lake and Baseline faults, where they are intersected by the east-trending Foot Bay fault (about 400 m northwest of the St. Louis fault; Figure 2). The Dubyna deposit produced about 285 t U (Ward, 1982). Based on our study, the deposit is hosted by massive albitite that has replaced weakly deformed to gneissic, pink, seriate leucogranite that locally contains abundant xenoliths of quartzite and amphibolite. The albitite ranges from layer parallel to crosscutting and contains about 2% hematite replacing about 5% chlorite in the leucogranite, along with minor calcite. Up to 2% pyrite is locally present in the leucogranite and occurs in trace amounts in the albitite. Steep mineralized fractures and carbonate veins in the main pit wall (Figure 5D in Ashton, 2011) vary from 080° to 105° strike and are broadly parallel to the Foot Bay fault (Figure 2).

4. Other Mine Visits

Ongoing reclamation of past-producing mine sites provided brief access to three previously unvisited locations west of the Black Bay fault. The **Cayzor mine** (UTM 633264 m E, 6607014 m N; Figure 1) is situated at the intersection of the northeast-striking Leonard fault and an east-striking zone of faults and fractures about 1.5 km northwest of Uranium City. The mine produced about 187 t U (Saskatchewan Geological Survey, 2003) from 'quartz-feldspar-chlorite schist and gneiss with minor meta-argillite and quartzite', which was collectively underlain by 'granitized amphibolite' and overlain by 'metasomatic granite'(Beck, 1969). Pitchblende and thucholite occur as veinlets and cement around brecciated fragments of wall rock associated with the later northeast-striking Leonard and intersecting east-striking fault zones, which are characterized by chlorite, kaolinite, and gouge. Pitchblende also occurs within carbonate veinlets. Minor galena permeates the wall rock, which has been strongly hematized (*ibid.*).

Subsequent regional mapping showed that the area was dominated by retrogressed upper amphibolite facies granitic orthogneiss with minor zones of Murmac Bay group supracrustal rocks up to hundreds of metres wide (Ashton and Hartlaub, 2008). The latter supracrustal rocks are equivalent to Beck's (1969) amphibolite and quartzite but, based on the few outcrops visited during this study, his 'quartz-feldspar-chlorite schist, gneiss, and meta-argillite', and 'metasomatic granite' are better re-interpreted as variably deformed granitic orthogneiss and pink leucogranite, respectively. The latter of these is similar to the pink leucogranite of the Ace-Fay-Verna-Dubyna mines area and is considered part of the same suite. The variably mylonitized granitic orthogneiss is exposed at the southern end of the mine workings and displays sharp strain gradients along with several independent kinematic indicators inferring a dextral component of displacement (Figure 10A). This early ductile strain is characteristic of a *ca.* 1 km wide shear zone that predates, but is co-planar with, the Black Bay fault, which is located about 1.5 km to the southeast (Figure 1).

Reconnaissance work about 1 km south-southwest of the Cayzor mine revealed a similar mix of black, fine-grained Murmac Bay group amphibolite and intrusive pale pink, medium-grained leucogranite. The latter is weakly foliated to sheared and contains coarse-grained patches similar to the 'alaskite' described form the Ace-Fay-Verna-Dubyna mines area. The leucogranite also locally includes minor zones of albitite alteration with local anomalous radioactivity, and has been intruded by Uranium City mafic dykes.

The **Rix-Leonard mine** (UTM 631384 m E, 6604626 m N; Figure 1), which produced 77 t U (Saskatchewan Geological Survey, 2003) from ore grading about 0.20%, is located about 2 km south-southwest of the Cayzor mine and 3 km southwest of Uranium City. Beck (1969) reported that that the mine was developed in subvertical northeast-striking, upper amphibolite facies rocks situated near the intersection of the northeast-striking Leonard fault and an east-striking unnamed fault. Pitchblende occurred as high-grade veins and coatings on wall-rock fragments within the veins, and was accompanied by galena, chalcopyrite, hematite, and pyrite (*ibid.*).

During our brief visit, the old mine adit was located in a steep cliff face (Figure 10B), the lower 30 m of which comprises black, medium-grained Murmac Bay group amphibolite containing clinopyroxene-bearing 'sweats'. The amphibolite is both foliated and lineated, and has been intruded by pale pink, medium-grained granite, which also forms the upper part of the cliff face. Minor thin sheets of red coarse-grained 'alaskite', resembling that from the Ace-Fay-Verna-Dubyna mine area, also intrude the amphibolite (Figure 10C). Uranium mineralization occurs within a roughly east-striking curvilinear set of fractures and tension veins (Figure 10D). Most of the veins are composed of carbonate that has taken on a pink colour due to the presence of hematite, which also lines the fractures; rare quartz veins were also observed.

The **Cinch Lake mine** (UTM 631847 m E, 6602837 m N; Figure 1), located about 4 km southwest of Uranium City where the Crackingstone River empties into Cinch Lake, produced about 285 t U (Saskatchewan Geological Survey, 2003). The deposit is situated roughly at the intersection of the east-striking Crackingstone fault with the northeast-striking Black Bay fault (Figure 1), and was previously described as being hosted by mylonitized and brecciated quartz-rich gneiss with minor granite, amphibolite and hornblende gneiss and schist (Beck, 1969; Tremblay, 1972). The pitchblende ore was disseminated throughout a highly chloritized and hematized red mylonite zone termed the Main Ore fault, which runs parallel to, but west of, the Black Bay fault. Pyrite, chalcopyrite, hematite, rutile, graphite, and titanite are also present in minor abundances. Ore also occurs with carbonate and hematite in fracture and breccia zones and veins marking northwest-striking tension faults (*ibid.*).

This summer's reconnaissance of a recently burned area extending for about 0.5 km north and northeast of the mine site revealed a mix of variably sheared granitic orthogneiss (Figure 10E) with a colour index of 10 to 15, abundant metre-scale sheets of pink leucogranite (Figure 10F) containing local coarse-grained 'alaskite' pods, and minor fine-

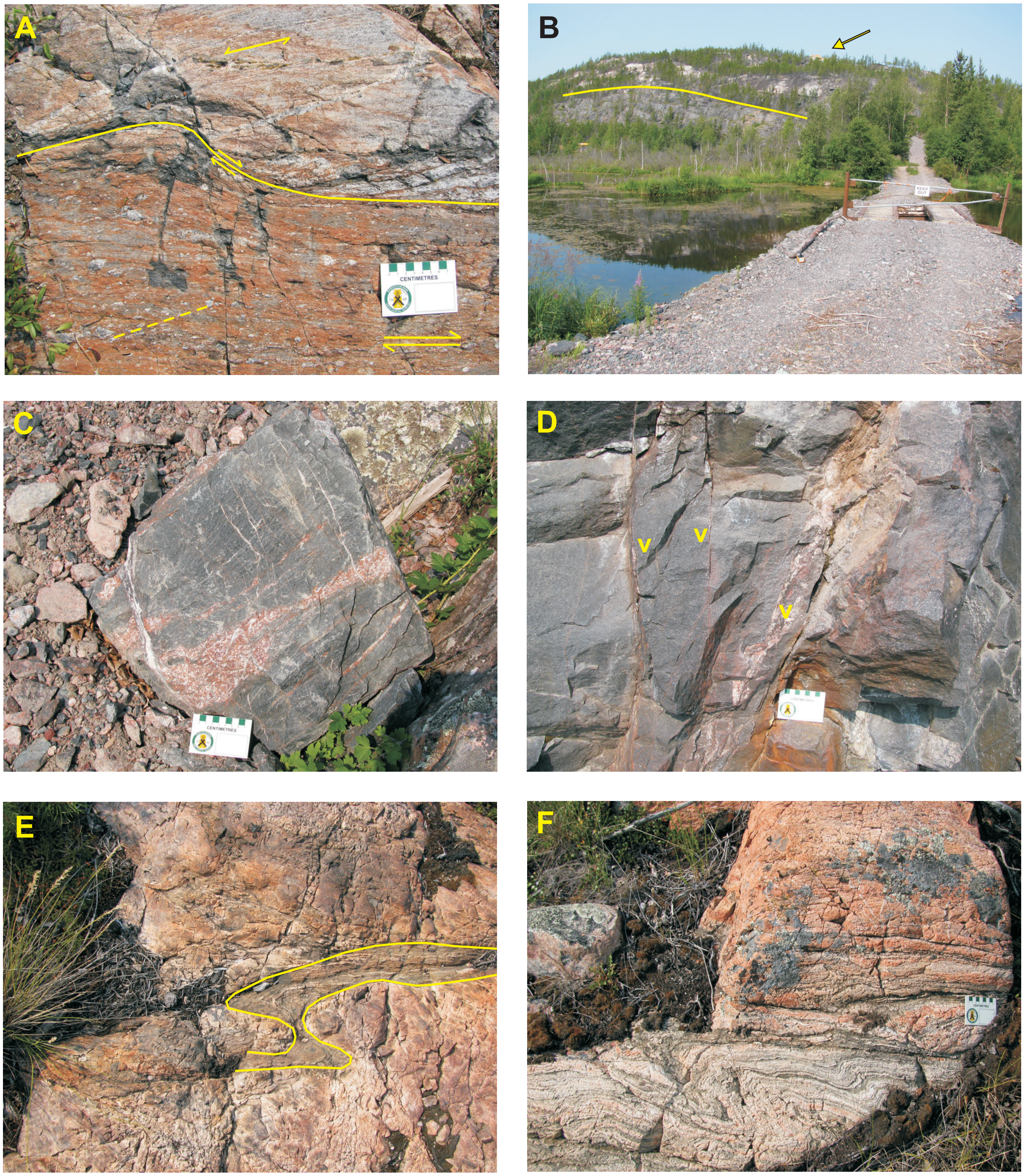


Figure 10 – A) Strain gradient developed in granitic orthogneiss at the southern end of the Cayzor mine workings; upper part of photo shows granitic orthogneiss containing regional foliation (yellow foliation symbol); lower part of photo is derived porphyroclastic mylonite exhibiting 'S' fabric (dashed yellow line); mylonite boundary (solid yellow line) has been displaced along a shear band (small yellow arrows); both kinematic indicators infer dextral component of slip (UTM 633445 m E, 6606745 m N). B) Rix-Leonard mine site showing Murmac Bay group amphibolite in lower cliff face and intrusive granite above (approximate contact denoted by solid yellow line); arrow marks reclamation shed at site of old shaft (UTM 631330 m E, 6604490 m N). C) Dislodged piece of amphibolite intruded by intrusive red coarse-grained granite/alaskite and cut by carbonate veins representing microcosm of age relationships at the Rix-Leonard mine (UTM 631330 m E, 6604490 m N). D) Vertical face near Rix-Leonard adit entrance, showing steep mineralized carbonate-hematite veins (v) cutting amphibolite (UTM 631330 m E, 6604490 m N). E) Folded shear zone (possibly nucleated on amphibolite inclusion) developed in variably sheared and cataclastic pink leucogranite northeast of the Cinch Lake mine (UTM 632046 m E, 6603091 m N). F) Typical rocks north of the Cinch Lake mine showing folded granitic orthogneiss at bottom of photo and pink leucogranite at top (UTM 632046 m E, 6603091 m N).

grained Murmac Bay group amphibolite. These rocks are crosscut by minor coarse-grained granitic and Uranium City mafic dykes, the latter of which locally contain uraniferous quartz veinlets. All of the above rocks are cut by steep, roughly west-northwest–striking sinistral brittle faults, some of which exhibit hematitic alteration, anomalously high radioactivity, and quartz and quartz-carbonate veins.

The Martin group has not been recognized on the immediate west side of the Black Bay fault; however, it is exposed 20 to 25 km to the west in the Camsell Portage area (Ashton and Hunter, 2004) and 20 to 25 km northwest at Tazin Lake (Ashton *et al.*, 2005), suggesting that it may have originally covered the Cinch Lake–Rix-Leonard–Cayzor mines area.

5. Discussion

Several observations can be made based on the deposits visited since initiation of the project in 2009.

1) They are generally hosted by granitoid rocks, most of which are *ca.* 1.93 Ga leucogranites derived by crustal melting, and/or by Murmac Bay group amphibolites, the latter of which may have preferentially provided ferrous iron to reduce oxidized uraniferous fluids. The one known exception to this is the mineralization at the Lorado mine, which is hosted by graphitic chlorite-sericite-sulphide schists (Beck, 1969), although these may have been derived from black shales in which the presence of abundant sulphides would have provided alternative means (*i.e.*, $Fe^{+}2$, H_2S) to reduce oxidizing uraniferous fluids.
2) Most of the deposits are in, or adjacent to, zones of sheared to mylonitic rocks. The mechanical deformation, recrystallization, and potential metasomatism accompanying this early shearing may have helped to de-stabilize or destroy primary uranium-bearing minerals in the granitoid rocks. Uranium liberated in this way can be adsorbed to the minerals that remain/become stable during the shearing event, leaving it much more accessible for dissolution by subsequent circulating fluids (Guthrie and Kleeman, 1986).
3) Late brittle-ductile faults have provided important conduits for fluid transport and extensional zones (*i.e.*, veins) for ore deposition in basement leucogranites that would otherwise not be considered permeable to fluids. The strong spatial association of uranium mineralization with these brittle-ductile discontinuities indicates a genetic link. Presumably the faults were active during D4 time and provided conduits for the fluids responsible for albitization and/or uranium-bearing fluids.
4) All of the ore bodies are situated within widespread hematitic alteration zones and/or have more restricted hematitic alteration associated with individual mineralized veins and fractures, suggesting that a redox reaction involving iron has played some role in ore deposition. One possibility is that this hematitic alteration prepared the host rocks for subsequent mineralization by providing oxidized conduits to facilitate the flow of uraniferous fluids some distance into the basement rocks where a change in fluid character or an encounter with a reducing basement fluid could result in precipitation. The two largest mines (*i.e.*, Ace-Fay-Verna and Gunnar) are situated within extensive networks of albitite. The albitite alteration may have provided channels for higher fluid flow due to the voids left behind following quartz ± K-feldspar ± biotite/chlorite dissolution.
5) The ore generally occurs in narrow brittle to brittle-ductile fault zones, within fractures and breccia zones resulting from cataclasis, and/or within carbonate ± hematite veins following the faults and associated extension zones. The main fault orientations of interest are northeast and east striking. The former are thought to have had mainly dextral displacement (*e.g.*, St. Louis, Black Bay) at the time of mineralization, whereas the latter are thought to have developed in the extension direction within the inferred east-west shortening regime.
6) The Cayzor, Rix-Leonard and Cinch Lake mines differ from the past-producing mines east of the Black Bay fault in that they are contained in upper rather than middle amphibolite facies rocks, some of which may be older than the Murmac Bay group. However, the deposits are similar to those in the east in that they are mainly hosted by Murmac Bay group amphibolite and intrusive leucogranite, and in their spatial relationships to both old, wide, ductile high-strain zones as well as young intersecting networks of brittle-ductile, northeast-, east-, and northwest-striking faults. Although albitite alteration is not widespread west of the Black Bay fault, it is locally present within more extensive zones of hematization. This is similar to the alteration associated with uranium mineralization in the Eagle-Camdeck area (Ashton, 2011). The widespread albitite network at the Gunnar mine (Ashton, 2010) and in the Ace-Fay-Verna-Dubyna mines area also occurs within a more extensive zone of hematization, giving the impression that the replacement of quartz by albite is an end member process resulting from the same fluids responsible for hematization.
7) The role of the Martin group remains unclear, but its proximity to the ore at many deposits indicates a genetic link. It could have supplied uranium from the breakdown of detrital accessory minerals and/or a brine to either transport uranium from the sediments or leach it from the basement rocks (*i.e.*, taken on the inferred role of the Athabasca Group in the unconformity uranium model). Alternatively, subhorizontal bedding in the Martin group could have provided a structural trap, restricting the vertical flow of fluids along steep brittle and brittle-

ductile faults 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.

6. Conclusions

The 2011 mapping in the Verna-Dubyna area was filled in and extended in 2012 both eastward and westward to include the Ace-Fay-Verna mine area. Hematite and albitite alteration was encountered throughout this extended area, although poor exposure and finer grained rocks resulting from ductile deformation in the Ace-Fay-Verna mine area hampered recognition. The uranium ore is generally found within much more restricted brittle-ductile fault zones and accompanying veins within these alteration zones. Recognition of an outlier of basal conglomerate along the St. Louis fault south of the Dubyna mine broadens the known extent of the Martin group, supporting the idea that it has a genetic role in uranium mineralization. Brief visits to three uranium mines west of the Black Bay fault suggest that, in spite of the higher metamorphic grade and more restricted occurrence of albitite, other features of the mineralization appear similar to the past-producing mines east of the Black Bay fault in the main part of the Beaverlodge uranium district.

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