Geochronological Update and Basement Geology Along the Northern Margin of the Athabasca Basin East of Fond-du-Lac (NTS 74O/06 and /07), Southeastern Beaverlodge–Southwestern Tantato Domains, Rae Province

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Ashton, K.E., Knox, B.R., Bethune, K.M., and Rayner, N. (2007): Geochronological update and basement geology along the northern margin of the Athabasca Basin east of Fond-du-Lac (NTS 74O/06 and /07), southeastern Beaverlodge–southwestern Tantato domains, Rae Province; *in* Summary of Investigations 2007, Volume 2, Saskatchewan Geological Survey, Saskatchewan Ministry of Energy and Resources, Misc. Rep. 2007-4.2, CD-ROM, Paper A-9, 22p.

Abstract

New U-Pb age dating from the area mapped in 2006 has shown that a magnetic, multi-phase intrusion of quartz monzonite and gabbro, located about 10 km west of Fond-du-Lac, is 2345 ±11 Ma in age and probably related to the Arrowsmith Orogen. The same study showed that the psammopelitic component of a granulite-facies quartzite-pyribolite-psammopelite succession spanning an area 10 to 35 km west of Fond-du-Lac was deposited between 2030 ±16 and 1910 ±6 Ma, which are similar depositional age constraints to those of both the Waugh Lake Group on the Saskatchewan-Alberta border and supracrustal gneisses in the Snowbird Lake area of the Northwest Territories. Both rocks dated in this study underwent metamorphism at 1909 to 1907 Ma.

New 1:20 000-scale mapping east of Fond-du-Lac has shown that the southeastern Beaverlodge Domain is dominated by structurally intercalated psammopelitic to pelitic gneiss and granitic to tonalitic plutonic rocks and derived orthogneiss of the Eastern Plutonic Complex. Following development of the main regional foliation, the southeastern Beaverlodge Domain underwent close to isoclinal F_2 folding at about 1.91 Ga. This F_2 folding was probably coeval with development of the Oldman-Bulyea Shear Zone and, together with subsequent open to isoclinal F_3 folds best developed adjacent to the shear zone, resulted in a broadly west-northwest–trending regional foliation. D_4 deformation produced open to tight northeast-trending folds throughout the domain, but focused strain within the dextral Grease River Shear Zone in the south. Late lamprophyre dykes and massive to locally sheared muscovite-biotite-garnet granite stocks and dykes postdate this regional deformation.

The southwestern Tantato Domain is dominated by the porphyroclastic, ca. *2.6 Ga Mary Granite. Reconnaissance mapping east of the Mary Granite revealed garnetiferous felsic gneisses, at least some of which appear to be of siliciclastic origin, and intrusive mafic granulites. An early, variably mylonitic, east-striking foliation affecting all three rock types has previously been considered Archean in age; however, the garnetiferous felsic gneiss and intrusive mafic granulite strongly resemble the assemblage of rocks in the southeastern Beaverlodge Domain, suggesting a broad lithological correlation across the Grease River Shear Zone. Thus, although an Archean foliation may have developed in the Tantato Domain, it is probable that the dominant, broadly east-striking, regional foliation is more likely correlative with the* ca. *1.91 Ga D_2 foliation of similar orientation in the Beaverlodge Domain. If this model is correct, then the boundary between the upper and lower decks of the Tantato Domain probably developed as a Paleoproterozoic thrust fault that may represent an eastern extension of the Oldman-Bulyea Shear Zone.*

Keywords: *Beaverlodge Domain, Tantato Domain, Rae Province, Churchill Province, Fond-du-Lac, Fond du Lac, Snowbird Tectonic Zone, granulite facies, metamorphism, lamprophyre, uranium, aeromagnetic map, U-Pb geochronology.*

1. Introduction

The Fond du Lac Project, which was initiated last year (Ashton *et al.*, 2006), is directed towards developing a better understanding of the geological history along the northern margin of the Athabasca Basin. The Fond du Lac region lies within the southeastern Beaverlodge Domain of the Rae Province (Figure 1). Most of the basement to the Athabasca Group to the west was recently mapped as part of the Uranium City Project (Figure 1; Hartlaub and

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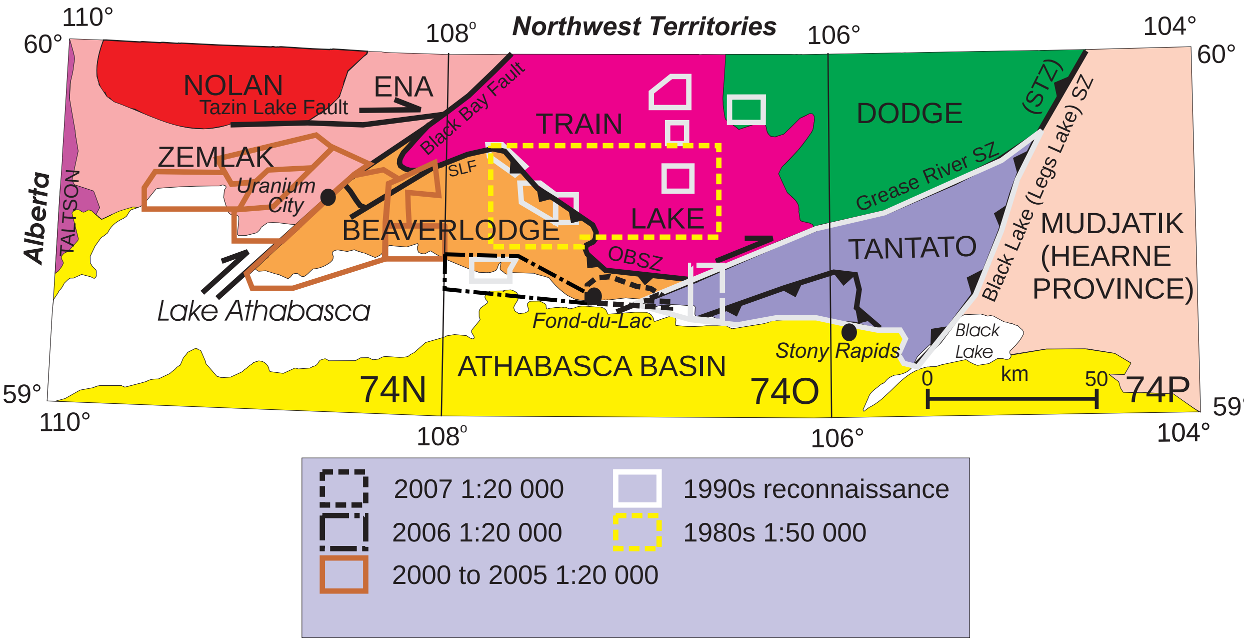


Figure 1 - Location map showing lithotectonic domains in the Rae Province of northwestern Saskatchewan and the boundaries of previous mapping; area mapped in 2007 outlined by heavy dashed line. OBSZ, Oldman-Bulyea Shear Zone; SLF, St. Louis Fault; STZ, Snowbird Tectonic Zone; and SZ, shear zone.

Ashton, 1998; Hartlaub, 1999, Ashton *et al.*, 2000, 2001; Ashton and Hunter, 2003, 2004). The Tantato Domain to the east was mapped in the 1990s by the Geological Survey of Canada (GSC) (Hanmer, 1994, 1997) and continues to be the focus of university-based studies (*e.g.*, Baldwin *et al.*, 2003; Mahan *et al.*, 2003). The Grease River Shear Zone, which separates the eastern Beaverlodge and western Tantato domains, has also been recently studied (Slimmon and Macdonald, 1987; Lafrance and Sibbald, 1997). The southeastern Beaverlodge Domain, however, has received little attention since the 1950s and 1960s, when the GSC completed 1:63,360-scale mapping spanning the NTS 74O-74N boundary in the west (Blake, 1955) and 1:250 000-scale mapping of 74O in the east (Baer, 1969). In the area immediately north of that covered by the Fond du Lac Project, an east-west transect was undertaken by Saskatchewan Energy and Mines in the mid-1980s (Scott, 1983; Thomas, 1985; Harper, 1986), and some detailed mapping was completed in the Adair Bay area west of Fond-du-Lac and along the Oldman-Bulyea Shear Zone (Ashton and Card, 1998; Card and Bethune, 1999; Card, 2001).

A hand-held, high-sensitivity, gamma and neutron radiation spectrometer (Exploranium GR-135 Plus) was used in the field for the first time this summer. Analyses were obtained from almost half of the outcrops visited and used to establish high, low, and average concentrations of K, U, and Th for most of the major rock types (Table 1). Results for felsite and lamprophyre dykes, some of which host uranium showings mapped last summer (*e.g.*, Saskatchewan Mineral Deposit Index #1565) are included for reference.

Access and Exposure

The area summarized in this report is accessible by float plane from Stony Rapids or can be reached by boat from either Stony Rapids or Fond-du-Lac. Elevation ranges from about 210 m at Lake Athabasca to 365 m on northern hilltops. The topography is generally lower in the west, where glacio-fluvial deposits are most common and have been used to develop both the town of Fond-du-Lac and a road connecting it to Mackenzie Lake. Otherwise, the bedrock exposure is generally good, although an interconnected series of deep bogs located about 1 km inland from the shore of Lake Athabasca is a major impediment to access.

2. Geochronological Update of 2006 Mapping

Geological work completed prior to last year's initiation of the Fond du Lac Project is summarized by Ashton *et al.* (2006). The area mapped in 2006 extended for about 45 km along the northern shore of Lake Athabasca west of Fond du Lac (Figure 1). The rocks had all undergone granulite-facies metamorphism and included: 1) granitic rocks and garnetiferous diatexites in the west, collectively termed the 'West-Central Plutonic Rocks'; 2) predominantly

Table 1 - Radiometric characteristics of major rock types.

Rock Type	n =		Total	K (%)	U (ppm)	Th (ppm)
Late muscovite leucogranite (Unit Lg)	3	high	26.8	5.0	9.7	39.7
		low	15.3	3.6	0.8	12.0
		average	**20.1**	**4.1**	**3.8**	**22.2**
Biotite granite-tonalite (Unit Etb)	10	high	23.2	5.4	3.2	31.6
		low	10.2	2.1	0.0	0.0
		average	**15.1**	**3.9**	**1.8**	**11.6**
Garnet-biotite granite (Unit Egb)	8	high	16.2	3.7	4.0	32.2
		low	9.0	1.6	0.0	1.4
		average	**12.3**	**2.8**	**1.2**	**15.5**
Garnetiferous granite-tonalite (Unit Egt)	75	high	21.9	6.0	6.2	41.6
		low	6.0	1.5	0.0	0.0
		average	**11.5**	**3.0**	**1.5**	**8.8**
Granite-tonalite (Unit Et)	26	high	20.9	4.4	4.7	42.9
		low	8.7	1.8	0.0	0.0
		average	**11.3**	**3.2**	**1.6**	**8.3**
Pyroxene granite-tonalite (Unit Eto)	8	high	13.9	5.3	2.9	14.9
		low	3.5	1.2	0.0	0.0
		average	**8.6**	**2.7**	**1.1**	**3.8**
Psammopelitic to pelitic gneiss	97	high	32.9	7.9	12.4	51.3
(Unit Pm)		low	4.0	0.8	0.0	0.0
		average	**14.5**	**3.1**	**2.0**	**17.6**
Mary Granite (Unit Tgm)	7	high	20.2	4.5	7.5	25.8
		low	9.4	2.9	0.0	10.0
		average	**16.3**	**3.6**	**3.4**	**19.6**
Tantato paragneiss	14	high	14.2	3.1	4.3	18.3
		low	3.1	0.8	0.0	0.0
		average	**7.9**	**1.9**	**1.2**	**6.2**
Tantato norite	3	high	2.3	0.5	0.5	1.8
		low	1.9	0.0	0.0	0.1
		average	**2.1**	**0.3**	**0.2**	**0.7**
Uranium showing 1: felsite	6	high	53.1	7.8	28.7	65.3
		low	29.6	3.2	16.8	26.6
		average	**44.1**	**6.0**	**22.6**	**51.4**
Uranium showing 1: Lamprophyre	3	high	64.3	7.0	35.4	88.5
		low	51.6	6.6	21.5	53.1
		average	**56.5**	**6.8**	**29.9**	**75.4**
Uranium showing 2: felsite	2	high	47.2	6.5	18.7	71.7
		low	47.0	5.8	15.3	60.9
		average	**47.1**	**6.1**	**17.0**	**66.3**
Uranium showing 2: Lamprophyre	1		**30.6**	**4.6**	**15.5**	**34.0**
Other Lamprophyre	3	high	45.0	7.7	14.7	68.4
		low	29.7	5.2	2.3	28.9
		average	**34.9**	**6.3**	**8.6**	**44.3**

supracrustal gneisses in the centre; and 3) a granitic to gabbroic suite in the east termed the 'Eastern Plutonic Complex' (Figure 2). The West-Central Plutonic Rocks and central supracrustal gneisses extend at least 5 km west of the 2006 map to the Dead Man Channel area (Macdonald and Slimmon, 1985; Slimmon, 1989), where psammopelitic gneiss was intruded by the *ca*. 2.62 Ga 'Dead Man Granite' (Hartlaub and Ashton, 1998; Hartlaub *et al.*, 2004; Bethune, 2006), and yielded chemical monazite ages indicative of *ca.* 2.3 Ga and 1.9 Ga metamorphic events (Hartlaub, 2004).

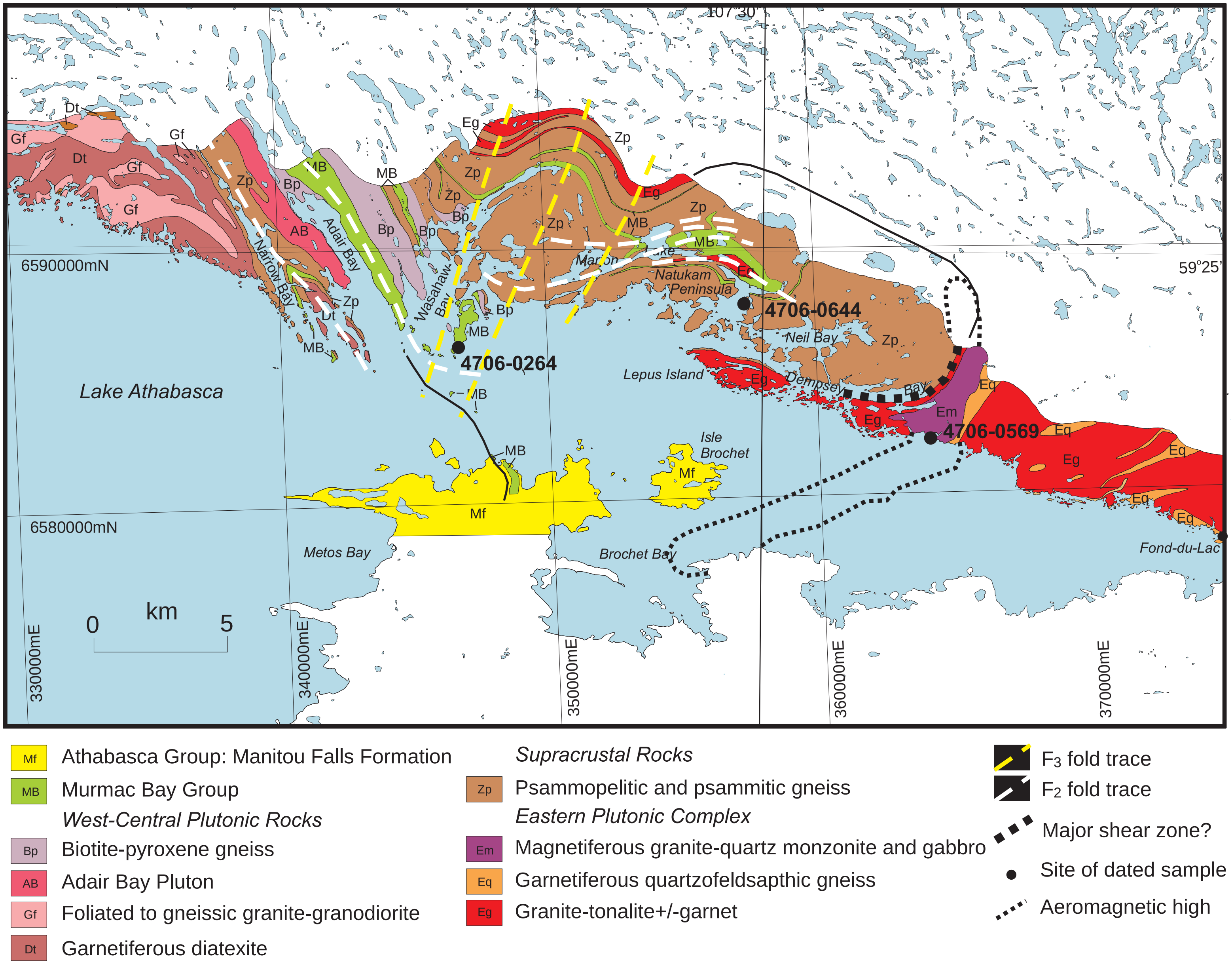


Figure 2 - Simplified geological map of the area covered in 2006 showing locations of dated samples.

The central supracrustal belt of the 2006 map area comprises psammopelitic gneisses (Figure 3) with minor quartzite, psammitic gneiss, and pyribolite. Preliminary SHRIMP results from a sample of the psammopelitic gneiss (sample 4706-0644) collected from the Neil Bay area (UTM 357346 m E, 6587241 m N [3]) included 51 analyses carried out on 38 separate detrital zircons. The majority of the zircons (24 of 38) gave $^{207}Pb/^{206}Pb$ dates between 2125 and 1975 Ma. Within this group, the dominant mode is centred on 2.03 Ga with a subordinate mode at 2.1 Ga. The remaining 14 detrital zircons give a wide range of $^{207}Pb/^{206}Pb$ dates between 2950 and 2150 Ma. There is no dominant age population in this range, only a sporadic distribution of dates. The youngest detrital zircon gives a weighted mean $^{207}Pb/^{206}Pb$ age of 2030 ±16 Ma. Metamorphic zircon growth, which included rims around detrital grains as well as discrete zircon crystals, yielded a weighted mean $^{207}Pb/^{206}Pb$ age of 1907 ±5 Ma. This sample provides clear evidence of Paleoproterozoic supracrustal rocks in the region that are distinct from the Archean psammopelitic gneisses intruded by the *ca*. 2.62 Ga Dead Man Granite to the west. In addition, the new detrital data are similar to controversial results obtained from paragneisses in the Selwyn Lake area, situated 250 km to the northeast (Martel *et al.*, in press). Both contain detrital zircons in the 2.5 to 2.1 Ga range; however, the dominant 2.03 Ga population was not observed in the Selwyn Lake sample, which yielded a youngest reproducible detrital age of 2072 ±20 Ma and underwent metamorphism at 1910 ±7 Ma.

The Eastern Plutonic Complex is dominated by granitic to tonalitic rocks, derived orthogneisses, and minor enclaves of garnetiferous quartzofeldspathic gneiss that have been subsequently interpreted as pelitic paragneisses. A distinctive magnetic unit comprising quartz monzonitic and gabbroic phases can be traced aeromagnetically from the exposed Shield southwestwards to the southern shore of Lake Athabasca (Geological Survey of Canada, 1987; Figure 2). Based on extrapolation of the main regional foliation along the northern shore, the magnetic unit appears to be discordant. The quartz monzonitic phase (sample 4706-0569) of the unit (Figure 4) has yielded a preliminary SHRIMP crystallization age of 2345 ±11 Ma together with a 1909 ±16 Ma metamorphic overprint recorded by both overgrowths on igneous grains and new grains (sample from UTM 364179 m E, 6581905 m N). This result suggests that the magnetic unit is related to a suite of 2.33 to 2.29 Ga compositionally diverse granitoid rocks spanning the area between Uranium City and the Alberta border (Hartlaub *et al.*, 2007; Ashton *et al.*, this volume), and from a more regional perspective, to rocks of the 2.5 to 2.3 Ga Arrowsmith Orogen (Berman *et al.*, 2005).

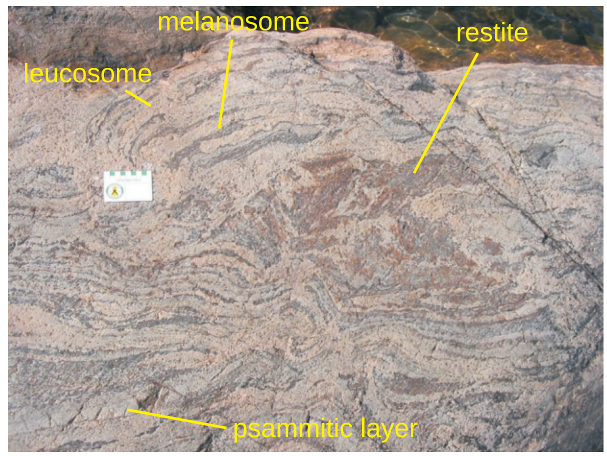


Figure 3 - Psammopelitic gneiss similar to the dated sample; from station 4707-2001 located about 15 km west of Fond-du-Lac (UTM 360219 m E, 6585467 m N). Mafic zones are garnet-sillimanite-biotite melanosome and restite; light-coloured areas are a mix of psammitic layers and melt leucosome. Scale card is in centimetres.

Granulite-facies metamorphic conditions were in place during all three major phases of regional deformation. Following development of the regional S_1 gneissosity, the second phase of deformation produced widespread, tight, west-northwest–oriented F_2 folding. The resultant S_1-S_2 composite foliation was later overprinted by open, northeast-trending F_3 folds (Ashton and Card, 1998) resulting in a northeast-trending regional foliation. An orthopyroxene-bearing granitic sheet (sample 4706-0264; UTM 346517 m E, 6585978 m N), inferred to have been emplaced during D_2 deformation (Figure 16, Ashton *et al.*, 2006; Figure 5), has yielded a 1910 ±6 Ma crystallization age.

Figure 4 - Well-foliated, originally coarse-grained, quartz monzonite of the magnetic unit spanning Lake Athabasca; from station 4706-0569 located 2 km southeast of Dempsey Bay, Lake Athabasca (UTM 364179 m E, 6581905 m N).

3. New Bedrock Mapping East of Fond-du-Lac

The part of the southeastern Beaverlodge Domain mapped this summer (Figure 6) is dominated by the same Eastern Plutonic Complex that formed the eastern

[3] All UTM coordinates are in NAD 83, Zone 13.

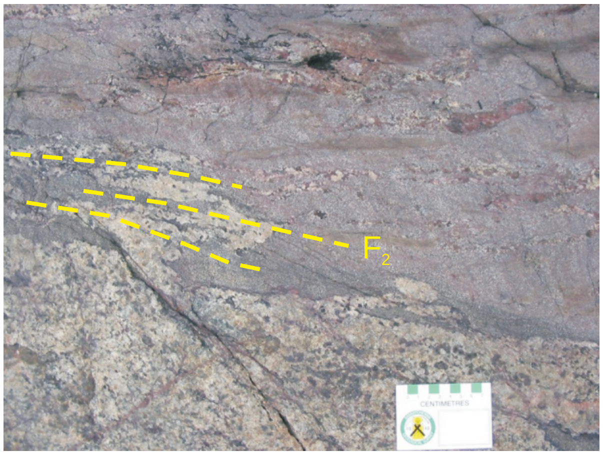


Figure 5 - Orthopyroxene-bearing granitic sheet intruded into pyribolite; from station 4706-0264) located on island in mouth of Wasahaw Bay, Lake Athabasca (UTM 346517 m E, 6585978 m N). Note that apophyses coming off main granite sheet have been folded by F_2.

third of the 2006 map area (Figure 2; Ashton *et al.*, 2006). About half the area mapped is underlain by granulite-facies granitoids or gneissic equivalents; however, there are variations in appearance and mineralogy. This appears to have been brought about by primary compositional variation and/or differences in the degree of metamorphism and subsequent retrogression. The widespread retrogression results not only from re-equilibration during uplift, but also from metasomatic overprinting associated with younger deformation within the Oldman-Bulyea (Harper, 1986) and Grease River (Lafrance and Sibbald, 1997) shear zones (Figure 1, Figure 6). As a result, the plutonic complex has been classified as last year (Ashton *et al.*, 2006) based firstly on the presence or absence of garnet, and secondly, on the degree to which peak metamorphic mineral assemblages have been preserved.

The other major component in the southeastern Beaverlodge Domain is psammopelitic to pelitic paragneiss and derived anatectic granitoid rocks. These are distinguished with difficulty from the orthogneisses based on the presence of rusty weathering, garnet-rich layers interpreted as transposed pelitic beds, as well as local graphite and/or sillimanite. These paragneisses are correlated with part of the 'garnetiferous quartzofeldspathic gneiss' unit (Eq, Figure 2) within last year's Eastern Plutonic Complex (Ashton *et al.*, 2006). They are tentatively thought to predate the <2030 Ma supracrustal gneisses of the central 2006 map area and may be part of the Archean succession that is intruded by the Dead Man Granite to the west (Hartlaub and Ashton, 1998; Hartlaub *et al.*, 2004).

The first two deformational events produced a transposed, broadly west-northwest–striking regional foliation defined by granulite-facies mineral assemblages. This early regional fabric is best illustrated on the 1:250 000-scale Fond-du-Lac NTS 74O map (Slimmon, 1989). The northwest-striking Oldman-Bulyea Shear Zone, which marks the northeastern boundary of the Beaverlodge Domain, is likely a thrust fault (Figure 1; Harper, 1986; Ashton and Card, 1998; Card, 2001) that formed during D_2. Based on the dated granitic sheet from the 2006 map area, it probably developed at about 1.91 Ga. In the north, this early S_1-S_2 fabric was overprinted by a phase of northwest-striking, open to tight folds (F_3) that was not recognized during the 2006 mapping to the west. It deforms the mylonitic fabric within the Oldman-Bulyea Shear Zone (Harper, 1986; Card, 2001) and accentuates the northwesterly regional overprint in that area. Superimposed open to tight northeast-trending F_4 folds are correlative with F_3 structures in last year's map area (Ashton *et al.*, 2006). The dextral Grease River Shear Zone (Slimmon and Macdonald, 1987; Lafrance and Sibbald, 1997) developed during D_4 time and produced a several-kilometre–wide, northeast-striking straight belt characterized by tightened F_4 folds.

A suite of late, massive muscovite-garnet-biotite leucogranite stocks and dykes in the north and east postdate most regional deformation, but have been affected by late brittle-ductile shearing, which is common in a variety of orientations. The lamprophyre dykes that are so abundant throughout the area west of Fond-du-Lac (Ashton *et al.*, 2006) are less abundant in this southeastern part of the Beaverlodge Domain.

The Tantato Domain (Figure 1, Figure 6) was not systematically mapped during this study, but four days of shoreline reconnaissance provided a first-hand glimpse of this high-temperature, high-pressure mylonitic domain (*e.g.*, Hanmer, 1997; Baldwin *et al.*, 2003, 2007). Variably mylonitized porphyroclastic foliates in the west belong to the *ca.* 2.61 Ga Mary Granite and are part of the 'lower deck' of Hanmer (1997). They were intruded by the *ca.* 1.91 Ga Robillard Bay Granite (Hanmer, 1997), and by biotite aplite-pegmatite dykes. Hanmer's (1997) 'upper deck' is dominated by garnetiferous felsic gneisses and mafic granulite sheets, which have yielded *ca.* 2.63 and 2.6 Ga crystallization(?) ages, respectively (Hanmer, 1997). The mafic granulites were intruded by granitic pegmatite dykes prior to being deformed by northeast-trending folds. At least some of the garnetiferous felsic gneisses are similar to the psammopelitic to pelitic gneiss and derived partial melt granitoids of the southeastern Beaverlodge Domain, whereas the Tantato mafic granulites may also have analogs in the southeastern Beaverlodge Domain in the form of mafic dykes/sheets. Although these potential correlations require further testing, they may indicate that rocks of the two domains are broadly correlative.

As in the area mapped in 2006, the southern shore of Lake Athabasca is underlain by the Raibl Member of the Manitou Falls Formation (Ramaekers *et al.*, 2007). These Athabasca Group rocks were not visited during this study.

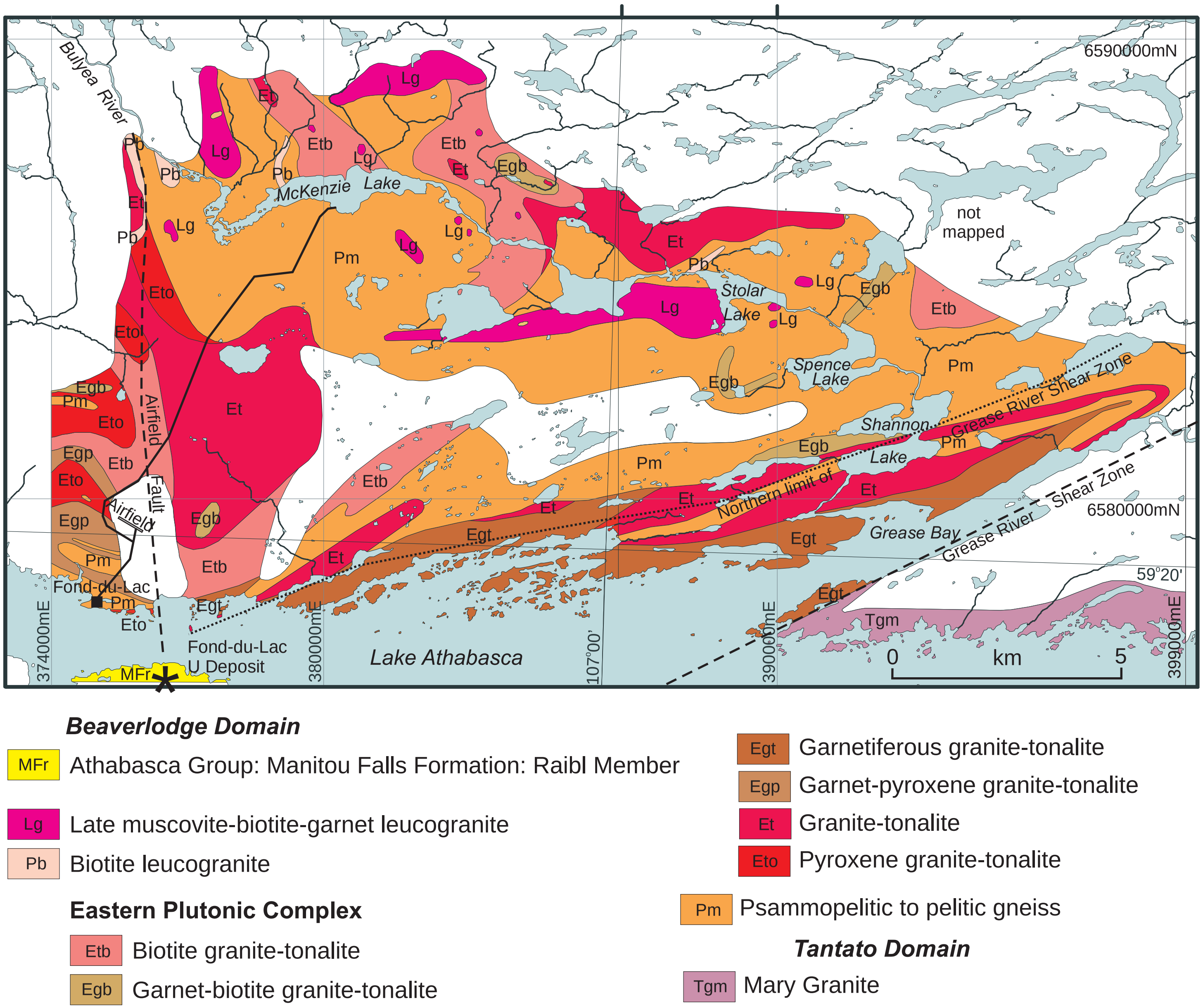


Figure 6 - Simplified geological map of the northern margin of the Athabasca Basin east of Fond-du-Lac.

a) Unit Descriptions

Beaverlodge Domain

Psammopelitic to pelitic gneiss and derived garnetiferous granite-leucogranite (Pm) occurs throughout the area, but is difficult to distinguish either in appearance or radiometrically (Table 1) from the garnetiferous phases of the Eastern Plutonic Complex (*e.g.*, units Egb and Egt). Criteria used to infer a sedimentary origin include rusty weathering, the presence of graphite and/or sillimanite, and layers up to 0.5 m thick containing abundant centimetre-scale garnet porphyroblasts (Figure 7). Typical samples are white-grey and rusty, and fine to medium grained with centimetre-scale garnet porphyroblasts variably pseudomorphed by biotite and/or cordierite. The rocks are generally well layered due both to transposed primary bedding, including the highly garnetiferous layers inferred to be pelitic beds, and development of a centimetre-scale, white, medium-grained, garnetiferous leucosome (Figure 8). Typical exposures contain 10 to 30% combined garnet and biotite. Graphite is common, whereas sillimanite and orthopyroxene are rare. Quartz is blue in some of the least-retrogressed samples.

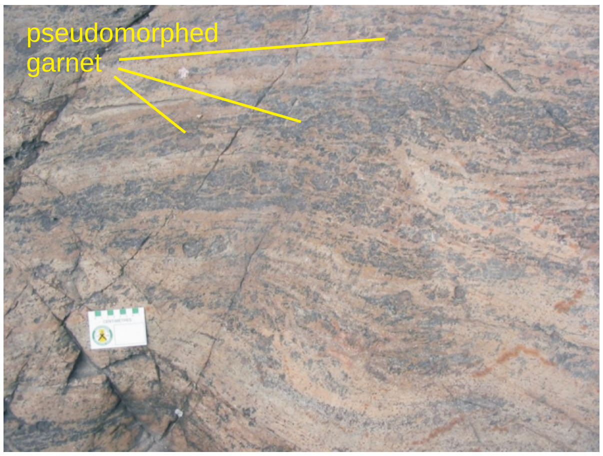


Figure 7 - Pelitic (dark-coloured) layers within psammopelitic to pelitic gneiss distinguished by abundant centimetre-scale garnet porphyroblasts partially pseudomorphed by biotite; from station 4707-0003 located on island about 200 m south of Fond-du-Lac (UTM 373856 m E, 6578052 m N). Leucocratic material adjacent to the pelitic layer is probably injected leucogranite derived by partial melting.

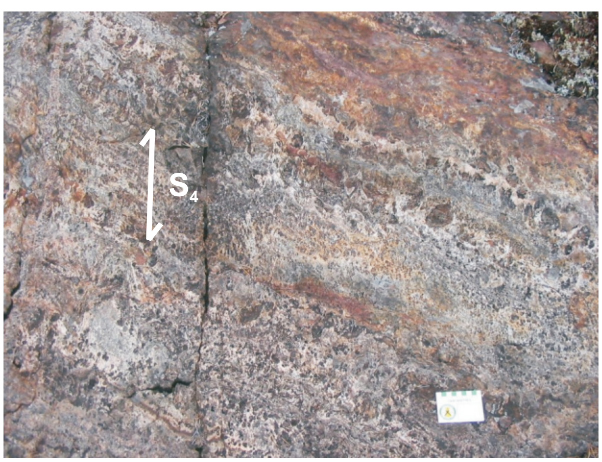


Figure 8 - Well-developed layering in rusty, graphitic, psammopelitic to pelitic gneiss; from station 4707-0133 located 1 km south of Mackenzie Lake (UTM 380500 m E, 6585317 m N). Note layers with abundant coarse garnet and local re-alignment of garnet and its alteration products in S_4 foliation.

Many exposures also include white to rusty, medium-grained, quartzofeldspathic gneiss. The paleosome is homogeneous and foliated but not layered, and contains 5 to 20% combined garnet and biotite. Garnet porphyroblasts may reach more than 1 cm and be variably pseudomorphed by biotite and/or cordierite. These rocks may include both psammitic to psammopelitic compositions of the paragneiss as well as derived various anatectic granitoids. Amongst these are white to rusty, medium-grained, garnetiferous leucogranite sheets tens of centimetres thick containing 3 to 5% combined garnet and biotite along with local graphite. Similar leucogranite sheets are seen in all rock types of the southeastern Beaverlodge Domain and are probably derived by low-percentage, regional partial melting. The presence of garnet and graphite may indicate more local derivation from, or interaction with, the paragneiss.

Eastern Plutonic Complex

The Eastern Plutonic Complex extends from the area west of Fond-du-Lac (Ashton *et al.*, 2006) throughout the southeastern Beaverlodge Domain to the Grease River Shear Zone (Figure 1, Figure 2). It is dominated by medium- to coarse-grained granitic to tonalitic rocks and derived orthogneiss, but some outcrops also include diorite and/or gabbro as transposed layers up to tens of metres thick. Most of the granitic to tonalitic rocks are white to grey and fine to medium grained, although the local preservation of feldspar augen up to 1.5 cm suggests that most of these rocks were originally coarse grained. Exposures vary from homogeneous to gneissic, and mylonitic equivalents are particularly common in the Grease River Shear Zone. The variably retrogressed and deformed nature of these rocks precludes delineation of original igneous phases, so the complex has been subdivided based on mineral assemblages and their preservation. Most contain pyroxene, but about half also have garnet either within the main rock or in the associated leucosome. Pyroxene, garnet, and biotite together comprise 5 to 30% of these rocks, although the pyroxene is variably altered to amphibole and biotite, and garnet is largely replaced by aggregates of biotite up to several centimetres in diameter. Erosion of these biotite pseudomorphs locally results in a pockmarked weathering surface, particularly in the Grease River Shear Zone (Figure 2). Quartz in the least-altered samples is blue.

A brown-weathering, **pyroxene granite-tonalite (unit Eto)** variety of the Eastern Plutonic Complex is the continuation of similar rocks comprising the eastern end of the area mapped in 2006 (Ashton *et al.*, 2006). Rocks of this unit are clearly plutonic in origin and distinguished by brown weathering, which is attributed to the presence of orthopyroxene. Farther east, similar rocks weather white to grey and grade into gneissic equivalents with centimetre-scale leucosome. This **granite-tonalite and derived orthogneiss (unit Et)** lacks recognizable orthopyroxene, but locally exhibits green clinopyroxene and evidence of an originally coarse grain size (Figure 9). It is a widespread unit with a western extent coinciding with the eastern limit of the pyroxene granite-tonalite, suggesting that the two may differ more in the metamorphic conditions they experienced than composition.

Figure 9 - Foliated granite-tonalite (Et) showing its homogeneous nature and relict coarse grain size; from station 4707-0160 located 5.5 km north-northeast of Fond-du-Lac (UTM 377375 m E, 6582612 m N).

Garnetiferous varieties (units Eq and Eg, Figure 2) of the Eastern Plutonic Complex noted last year west of Fond-du-Lac (Ashton *et al.*, 2006) extend eastward. A plutonic origin for the **garnet-pyroxene granite-tonalite and derived orthogneiss (unit Egp)** is implied by its relatively homogeneous nature in which garnet is present both in the paleosome and in a distinct leucosomal phase. In addition to these leucogranite sheets, many outcrops contain metre-scale sheets of white-grey, medium- to coarse-grained granite with 5 to 20% garnet up to 3 cm in size. As elsewhere, garnet is variably retrogressed to biotite. The presence of garnet in these rocks may be due to interaction with nearby paragneiss, but is more likely due to the combination of relatively aluminous compositions and high metamorphic pressures.

Figure 10 - Highly strained gneissic variety of garnetiferous granitite-tonalite gneiss (Egt) from station 4707-5011 located 4.5 km east of Fond-du-Lac (UTM 379329 m E, 6577591 m N). Note coarse pseudomorphed garnet (dashed arrow) defining S_4 foliation (foliation symbol) in leucosome and millimetre- to centimetre-scale high-strain zones (solid arrows) in centre and top of photo.

The **garnetiferous granite-tonalite and derived gneiss (Egt)** is a grey, fine- to medium-grained variety of garnet-pyroxene granite-tonalite in which abundant garnet occurs in injected white, medium-grained granitoid sheets (Figure 10) and pyroxene has been largely retrogressed. Most of this unit lies within the Grease River Shear Zone and is lineated and variably mylonitic (Figure 11). Due to the high strain, these rocks tend to be finer grained and weather darker grey than other Eastern Plutonic Complex rocks. The combined effects of high strain and multiple injections of various granitic melt phases and mafic dykes have locally produced a very heterogeneous appearance (Figure 12). Biotite pseudomorphs of garnet form centimetre-scale clots of medium-grained aggregates that range from equant to flat. The weathering of such clots has locally produced a pockmarked outcrop appearance.

Garnet-biotite granite-tonalite (unit Egb) shares a similar colour, grain size, and texture with other members of the Eastern Plutonic Complex, but generally appears devoid of pyroxene, suggesting a more aluminous composition. Garnet probably made up the majority of the 5 to 25% ferromagnesian mineral content, but has been largely retrogressed to biotite, aggregates of which have been variably eroded to produce a pitted weathering surface. The local presence of graphite, together with its spatial relationship to the psammopelitic to pelitic gneiss (Figure 6), with which it is locally intercalated, may indicate that at least some of this unit was produced by high-percentage partial melting of the paragneiss. This idea is supported by average Th contents that are somewhat higher than those of other Eastern Plutonic Complex units and similar to those of the psammopelitic to pelitic gneiss (Table 1).

Where neither garnet nor pyroxene was recognized, either because they were never present or because they have not survived deformation and metasomatism, biotite was the only ferromagnesian mineral identified. The broadly homogeneous character of most of these **biotite-granite-tonalites and biotite gneisses (unit Etb)** suggests that

Figure 11 - Mylonitic garnetiferous granite-tonalite gneiss (Egt) displaying L4 tectonic stretching lineation (white arrow parallel to lineation) and open F_4 folds; from station 4707-5002 located 10.5 km east of Fond-du-Lac (UTM 385533 m E, 6578703 m N). Note: fine grain size, subtle colour differences resulting from strain gradient, and biotite-garnet leucogranite dyke (black arrow) oriented parallel to axial planes of F_4 folds.

Figure 12 - Locally heterogeneous nature of garnetiferous granite-tonalite gneiss (Egt); from station 4707-5357 located 8.5 km east of Fond-du-Lac (UTM 383399 m E, 6578602 m N). Note: abundant white, medium-grained leucosome, thin mafic layers interpreted as transposed and attenuated dykes (dashed arrows), brittle-ductile shear zone (solid arrows), and late granitic dyke (white arrow).

they are retrogressed granitoid rocks (Figure 6), an idea that is further supported in the north and east where their competent nature produces topographic highs. A north-trending exposure of this unit in the west (Figure 6) may lack pyroxene and/or garnet because they have been destroyed within a nearly kilometre-wide brittle-ductile shear zone locally characterized by phyllonite. It is unclear whether the southern exposure of biotite gneiss is derived from Eastern Plutonic Complex rocks or from the adjacent psammopelitic to pelitic gneiss unit.

Pre- to Syn-Tectonic Dykes and Sheets

Both the psammopelitic to pelitic gneisses (Pm) and the Eastern Plutonic Complex have been injected with abundant centimetre- to metre-scale sheets of white, fine- to coarse-grained leucogranite. In garnetiferous varieties of the Eastern Plutonic Complex, the non-magnetic leucogranite contains ≤5% combined garnet and biotite; otherwise the ferromagnesian minerals are biotite ±pyroxene. In the psammopelitic to pelitic gneiss, it is white to pale pink, generally medium grained, and homogeneous to gneissic where it contains schlieren of psammopelitic gneiss. It contains up to 10% garnet and minor biotite, is non-magnetic, and is thought to be derived by partial melting of the pelitic rocks.

Mafic sheets are a component of many exposures in the Beaverlodge Domain, although most were probably emplaced as dykes and subsequently transposed. They include a set of black, medium-grained, gabbroic dykes containing clino(?)pyroxene and minor garnet. Brown norite(?) sheets rarely exhibit evidence of an originally coarse grain size, but have been recrystallized to a fine to medium-grained ortho(?)pyroxene-plagioclase aggregate. Centimetre-scale, garnetiferous leucotonalite(?) mantles and extends into some of these brown-weathering sheets (Figure 13). It locally grades into metre-scale pods of sulphide-bearing garnetite, almost completely replacing some sheets (Figure 14). The norite(?)sheets bear a strong resemblance to the 'mafic hypersthene gneiss' unit of Slimmon (1989) and the 'Axis two pyroxene ±garnet granulite mafic mylonite' by Hanmer (1994) that makes up much of the south-central Tantato Domain, suggesting a genetic link. Medium-grained, two pyroxene-hornblende mafic sheets bearing a striking resemblance to the pyribolite associated with quartzite in the central supracrustal area of the Fond du Lac west area (Ashton *et al.*, 2006), extend eastwards to within 13 km of the town, but were not recognized within the 2007 map area.

Syn-Tectonic Dykes

Pink to white, medium-grained to pegmatitic **biotite leucogranite (unit Pb)** has been injected into psammopelitic to pelitic gneiss and Eastern Plutonic Complex rocks at several localities in the northwest and locally is spatially associated with major brittle-ductile shear zones (Figure 6). It varies from massive to gneissic and is porcelaneous due to recrystallization where sheared. It contains about 5% biotite ±garnet. **Biotite-garnet leucogranite dykes** crosscut the main S_1-S_2 regional foliation at a small angle. They appear approximately axial planar to F_4 folds (Figure 11), and have apophyses that have been folded by these northeast-trending F_4 structures.

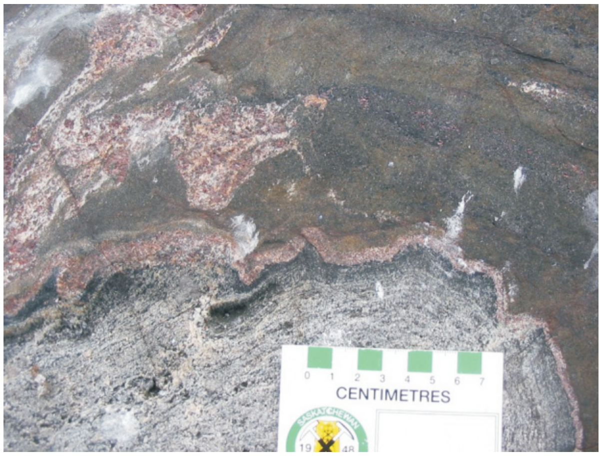


Figure 13 - Garnetiferous leucotonalite developed within norite(?) sheet and as reaction rim along contact with garnetiferous granite-tonalite (Egt); from station 4707-5130 located 7.5 km east of Fond-du-Lac (UTM 382340 m E, 6577853 m N).

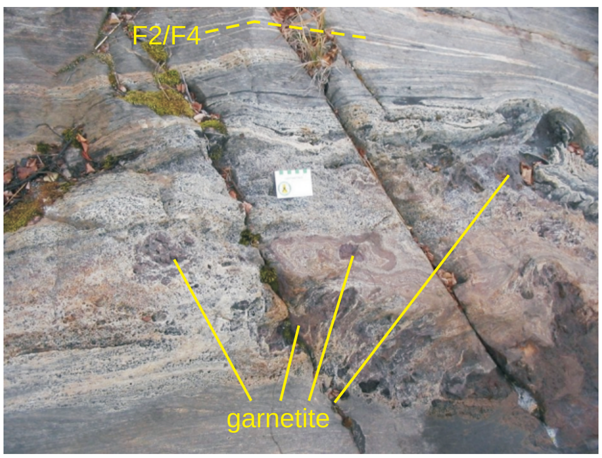


Figure 14 - Pod of garnetiferous melt and garnetite apparently derived by melting of a norite(?) dyke; in garnetiferous granite-tonalite (Egt) within Grease River Shear Zone; from station 4707-5001 located 10 km east of Fond-du-Lac (UTM 385444 m E, 6578974 m N). Note isoclinal F_2 or tightened F_4 fold.

Post-Tectonic Rocks

Pale pink to cream-grey, medium-grained to pegmatitic **muscovite-biotite-garnet leucogranite (Lg)** forms several ridges and hills throughout the north (Figure 6). Most of these small stocks are massive, but they have been affected by late brittle-ductile shearing. These larger bodies contain about 5% biotite **(unit Lgb)** with local muscovite and garnet. **Muscovite-garnet leucogranite dykes** include medium-grained, pegmatitic, and zoned varieties, the latter with pegmatitic cores and medium-grained margins. They appear randomly oriented and locally form stockworks. Most are characterized by centimetre-scale clots of muscovite and minor garnet; biotite is not common. The muscovite-garnet leucogranite dykes extend throughout the southeastern part of the Beaverlodge Domain mapped, and were recognized in the lowest grade part of the Grease River Shear Zone, but were not recognized farther east in the Tantato Domain. This muscovite-garnet leucogranite suite was also observed throughout the Beaverlodge Domain farther north, where it predates *ca.* 1.82 Ga biotite granites, but does not appear to extend into the Train Lake Domain (Card, 2001). Since it postdates the main *ca.* 1.9 Ga metamorphic and deformational events, the **muscovite-biotite-garnet leucogranite suite** is most likely a manifestation of the Trans-Hudson orogeny.

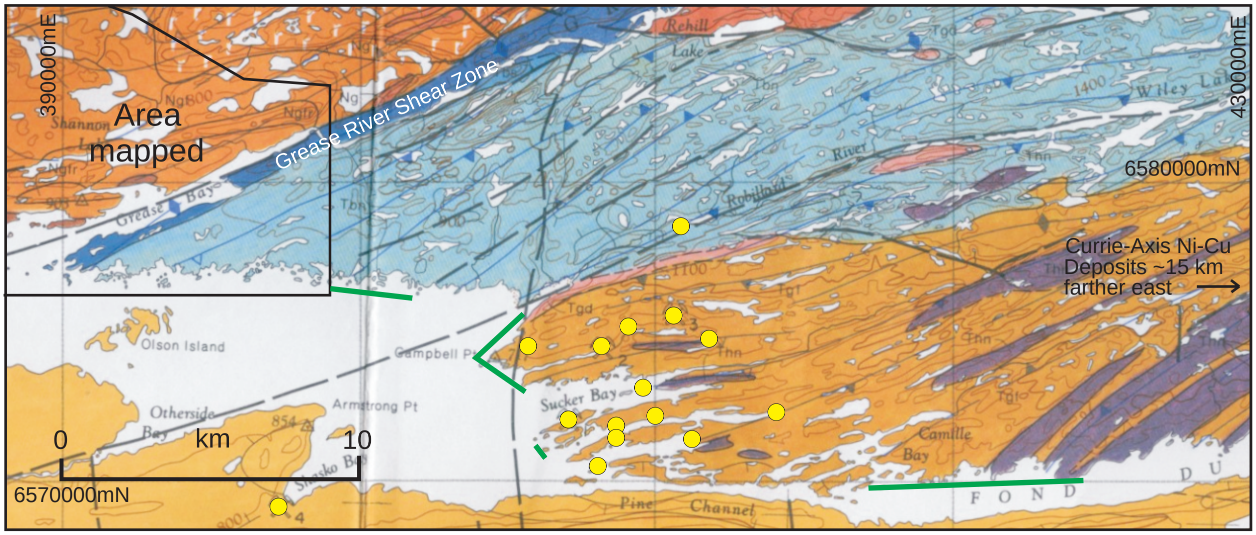
Lamprophyre dykes similar to those in the Fond du Lac west area (Ashton *et al.*, 2006) are less common east of Fond-du-Lac and the associated granite-aplite-felsite suite was not recognized. They contain 5 to 10% phlogopite and rare pyroxene/amphibole phenocrysts up to 3 mm in diameter in a brown to pink, fine- to medium-grained matrix. Most of the lamprophyres are straight-sided dykes with sharp contacts, and range from massive to weakly foliated; however, the foliation may be inclined by as much as 20° to the dyke contact, making it unclear whether it is an igneous or tectonic fabric. The dykes are typically 1 to 2 m thick, but can range up to about 10 m. Several irregularly shaped masses of lamprophyre were also noted in the area north of Grease Bay.

Tantato Domain

The southwestern Tantato Domain (Figure 15) was structurally divided into a ‘lower deck’ and an ‘upper deck’ by Hanmer (1997), who summarized them as follows. The lower deck includes granitoid rocks and a mafic plutonic complex, both of which have yielded inferred U-Pb zircon crystallization ages of 2.62 to 2.60 Ga, and pelitic diatexites containing *ca.* 2.62 Ga old monazite. The upper deck is dominated by pelitic diatexite and *ca.* 2.6 Ga mafic granulite, and was initially emplaced along a discrete basal thrust fault that incorporates lenses of eclogite-facies mafic rocks. The thrust has been subsequently re-activated as an extensional shear zone. Although most of these rocks were not systematically mapped during this study, they were briefly visited to facilitate comparison with rocks of the Beaverlodge Domain.

Lower Deck

The main unit within the mapped southwestern part of the Tantato Domain (Figure 6, Figure 15) is a variably mylonitized, porphyroclastic foliate termed the **Mary Granite (Tgm)**, that has yielded a U-Pb zircon crystallization age of 2606 +13/-11 Ma (Hanmer, 1997). Typical rocks are dark grey with white feldspar porphyroclasts ranging up to 0.5 cm in size (Figure 16), homogeneous, and streaky with a well-developed stretching lineation. Biotite, altered pyroxene and/or hornblende, and rarely preserved garnet form 10 to 30% of most rocks. Hanmer (1997) subdivided



Athabasca Group
Mylonite
Beaverlodge Domain
Psammopelitic to pelitic gneiss and Eastern Plutonic Complex
Tantato Domain
Robillard granite
Mary Granite
Axis mafic granulite
Garnetiferous felsic gneiss
'Pine Channel' gold showings

Figure 15 - Simplified geological map of the southwestern Tantato Domain showing area mapped during this project (box) and parts of the northern shore of Lake Athabasca observed during a three-day reconnaissance (green lines); taken from Slimmon (1989).

this unit into 'Mary garnet-hornblende-two pyroxene granite mylonite' and 'Turcotte biotite-garnet-hornblende granite', although the two are very similar in appearance and the mineralogical differences could result from differences in the degree of shearing than compositional variation. The mylonitization responsible for the porphyroclastic character developed in a heterogeneous fashion, locally resulting in ultramylonite zones up to tens of metres thick characterized by garnet blastesis. On average, the Mary Granite is slightly more radiogenic than rocks of the Eastern Plutonic Complex (Table 1), and is weakly to non-magnetic.

South of Robillard Bay, about 5 km east of the systematically mapped area (Figure 15), the Mary Granite was intruded by a pink-grey leucocratic granitoid ('granodiorite' of Slimmon and Macdonald, 1987; 'Robillard coarse granite orthogneiss' of Hanmer, 1997) prior to mylonitization. This non-magnetic **Robillard granite** has yielded a *ca.* 1910 Ma U-Pb zircon crystallization age (Hanmer, 1997), establishing a maximum age for at least some of the mylonitization.

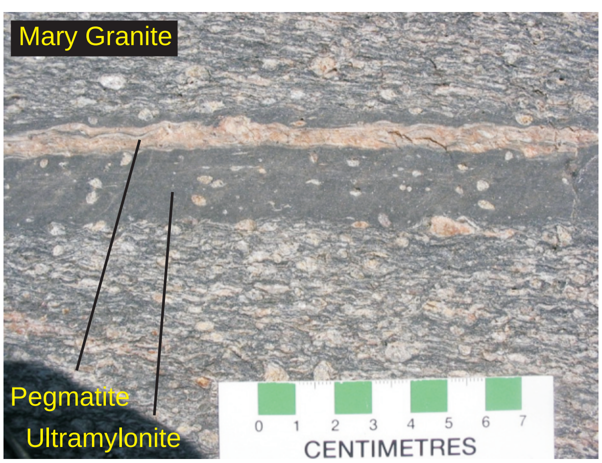


Figure 16 - Porphyroclastic texture of mylonitic Mary Granite from station 4707-0042 located 8.5 km east of mouth of Grease River (UTM 397613 m E, 6577182 m N). Note thin zone of ultramylonite mantling crosscutting pink pegmatite dyke.

The Mary Granite has also been intruded by a set of pink aplite-pegmatite dykes. In parts of the granite not subjected to the ultramylonitic overprint, the dykes are near massive and cut the mylonitic foliation, but within the zones of ultramylonitized Mary Granite, they are strongly lineated and variably dismembered, so that only porphyroclastic remnants of the dykes remain. At several outcrops, zones of ultramylonite mantle attenuated and lineated pegmatites, suggesting that the dykes either facilitated shearing or were emplaced along zones of weakness within developing shear zones (Figure 16). The dykes have been deformed by late northeast-trending F_4 folds along with their mylonitic host. At one locality, a dyke of this suite was folded by a northwest-trending phase (F_3?) as well as a northeast-trending F_4 fold.

Upper Deck

The 'garnet-sillimanite-orthopyroxene diatexites' of Hanmer's (1997) 'upper deck' (**garnetiferous felsic gneisses** of Slimmon and Macdonald, 1987) are layered, heterogeneous, and pervasively garnetiferous. Most exposures are dominated by white-cream to grey, fine- to medium-grained garnetiferous gneiss that probably includes both granitic phases derived by partial melting and minor paleosome. Much of this material exhibits centimetre-scale leucosome and contains 10 to 30% garnet, although most is now replaced by biotite or cordierite(?), along with minor sulphide. A sedimentary origin for at least some of these garnetiferous gneisses is suggested by rare pelitic(?) layers about 1 m thick that contain up to 50% centimetre-scale pseudomorphs of cordierite(?) after garnet (Figure 17). In some of the easternmost exposures visited, sillimanite is present in the melanosome, leucosome, and rimming some garnet (Figure 18). Its random orientation suggests growth or recrystallization after D_1 to D_2 and the main shearing event(s). Orthopyroxene and either magnetite or ilmenite are also present in many of these eastern exposures.

Although the well-layered character, rare garnet-rich layers, and generally peraluminous composition of these rocks suggest that at least some are of sedimentary origin, determination of their protoliths is not straightforward. Graphite, which is common in highly metamorphosed pelitic gneisses, was not recognized. Secondly, the high garnet content of these rocks may be the result of extremely high-metamorphic temperatures and pressures as opposed to particularly aluminous compositions (as appears to be the case for the garnetiferous granite-tonalite of the Beaverlodge Domain); and thirdly, their peraluminous compositions could result from the withdrawal of multiple, high-percentage partial melts (*i.e.*, these rocks are effectively restites). These rocks generally contain less K, U, and Th than the psammopelitic to pelitic gneiss of the Beaverlodge Domain (Table 1), although this may also be attributable to the apparently higher degree of partial melting that they have experienced. Ultimately, these garnetiferous migmatites likely include a mixture of presently indistinguishable sedimentary and granitoid rocks similar to the intercalated psammopelitic to pelitic gneiss and Eastern Plutonic Complex of the Beaverlodge Domain.

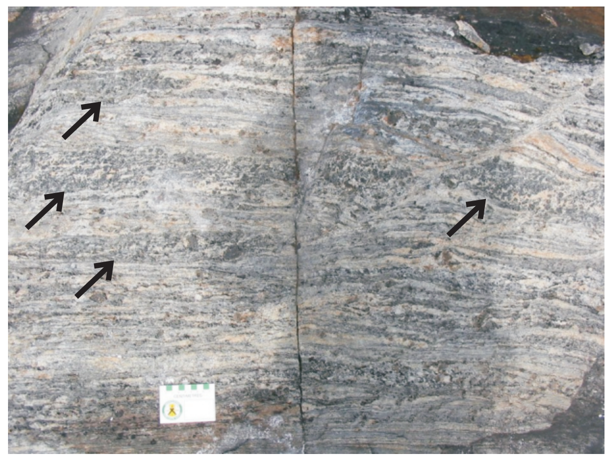


Figure 17 - Grey garnetiferous gneiss exhibiting pelitic(?) layers (arrows) characterized by up to 50% centimetre-scale garnet porphyroblasts pseudomorphed by cordierite(?); from station 4707-0051 located 2 km south of Robillard Bay (UTM 404390 m E, 6573945 m N).

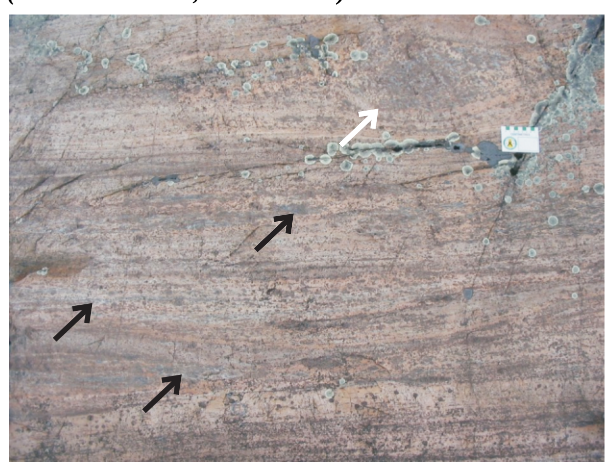


Figure 18 - Typical layering in garnetiferous migmatite; from station 4707-0064 located 15 km east of the mouth of Pine Channel (UTM 421031 m E, 6570327 m N). Note blue-grey colour imparted by randomly oriented sillimanite associated with garnetite restite in upper right (white arrow) and in layers of melanosome (black arrows).

The Axis **mafic granulite** ('Mafic pyroxene gneiss' of Slimmon and Macdonald, 1987; 'Axis two pyroxene ±garnet granulite mafic mylonite' of Hanmer, 1994) is intercalated with the garnetiferous felsic gneiss throughout the upper deck. Near Camille Bay, about 25 km east of the mapped area, it is an extensive and homogeneous pyroxene-plagioclase ±garnet gabbroic rock. It is grey-brown, medium grained, subtly layered locally, and commonly exhibits a stretching lineation. Typical samples contain 30 to 60% pyroxene, minor magnetite, and local garnet. In the Pine Channel–Sucker Bay area (Figure 15), the mafic granulite is intercalated with the pelitic diatexite as grey-brown to green-black sheets only a few metres thick. Rare, dark green, fine-grained mafic boudins in the Mary Granite exhibit a pockmarked surface attributed to biotite alteration and preferential weathering.

Centimetre- to decimetre-scale pegmatite dykes, presumably belonging to the same suite that was emplaced in the Mary Granite of the lower deck, were also noted in the Axis mafic granulite, where they have been attenuated and folded during D_4.

b) Structure

D_1-D_2

The earliest recognizable tectonic fabric is an S_1 foliation defined by the leucosomes of partially melted rocks and by biotite. The D_2 event produced tight to isoclinal folding of the S_1 foliation, resulting in a broadly west-northwest–striking regional foliation. This composite S_1-S_2 fabric is thought to have developed at about 1.91 Ga based on the age of the syn-D_2 granitic sheet in the 2006 map area. Tectonic stretching lineations (Figure 11), observed in both the Beaverlodge and Tantato domains, are thought to have developed at this time, although most have been variably rotated by subsequent folding. In the north, many of these L_2 stretching lineations have down-dip orientations, consistent with development during early thrust displacement along the Oldman-Bulyea Shear Zone (Harper, 1986; Ashton and Card, 1998; Card, 2001).

In the Tantato Domain, the mylonitic foliation developed within the porphyroclastic Mary Granite carries a strong, originally down-dip, stretching lineation. A co-linear stretching lineation is developed in the intrusive pegmatite dykes that are locally associated with zones of ultramylonite (Figure 16). Thus, the main east-trending regional foliation is characterized by the mylonitic foliation and stretching lineation developed in the porphyroclastic granite, the variably mylonitized pegmatite dykes and the zones of ultramylonite. This composite fabric is subsequently folded by northeast-trending F_4 folds (Figure 19), suggesting that it is older. Since the pegmatites are also deformed by rare F_3 folds, the main east-trending foliation is thought to have developed during D_2. Rare isoclinal folding of the ultramylonitic fabric (Figure 20) is similarly thought to have taken place late in the D_2 event. Intensity of the east-trending mylonitic foliation appears to generally increase towards, and extend about 1 km beyond, the contact between the Mary Granite and the diatexites farther east (*i.e.*, the contact between the upper and lower decks). Beyond that, it drops significantly throughout the rest of the Tantato Domain observed, suggesting that this inferred D_2 mylonitic foliation developed during juxtaposition of the upper and lower decks. Hanmer (1997) thought that the upper and lower decks were juxtaposed along a high-temperature normal fault based on an analysis of shear bands at the northeastern apex of the upper deck. Alternatively, this normal sense of displacement could represent re-activation of a thrust fault, as recognized on the Oldman-Bulyea Shear Zone (Card, 2001).

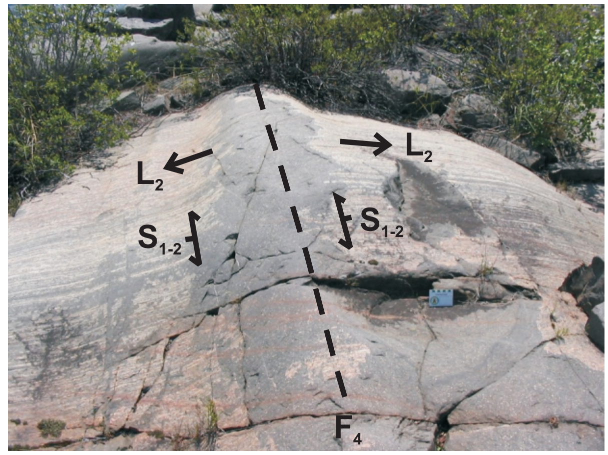


Figure 19 - Thin (only several millimetres thick), strongly lineated (arrows denote folding of lineation) and mylonitized pink pegmatite folded along with host mylonitic Mary Granite by near-upright F_4 antiform (trace denoted by dashed line); from station 4707-0043 located 0.5 km west of eastern map boundary (UTM 398616 m E, 6576964 m N). Note down-dip orientation of lineation.


Figure 20 - F_2(?) isoclinal folding of ultramylonite developed in Mary Granite; from station 4707-0048 located 2.75 km east of eastern map boundary (UTM 401694 m E, 6576507 m N).

D_3

In the Mackenzie Lake area and farther north (Figure 2), close to rarely isoclinal F_3 folding accentuated the northwest-striking overprint of the composite S_1-S_2 foliation. Minor F_3 folds have steeply southwest-dipping axial planes that are broadly parallel to the Oldman-Bulyea Shear Zone (Figure 1), which has been interpreted as a northeast-verging thrust fault to the north (Harper, 1986; Card, 2001). This phase of regional folding is quite common north of this study area (Harper, 1986), but was not recognized during mapping to the west (Ashton *et al.*, 2006). Tight, horseshoe-shaped, east-west fold closures defined by the boundary between the central supracrustal zone and the Eastern Plutonic Complex to the west and the Beaverlodge-Train Lake domain boundary to the east (Slimmon, 1989; Ashton *et al.*, 2006) may be ramifications of D_3. A northwest-trending ptygmatic fold defined by a biotite pegmatite that intruded the Mary Granite suggests that the D_3 event also affected rocks of the Tantato Domain.

D_4

Intense F_4 folding imposed a strong northeast-trending regional fabric in both the Beaverlodge and Tantato domains, and variably overprinted the northwest-trending fabric established by D_2-D_3 in the north (Figure 6). Outcrop-scale F_4 folds are generally open to close (Figure 11), have steeply dipping axial planes and plunge gently to moderately either to the southwest or northeast. In pre- to syn-tectonic rocks, an axial planar S_4 foliation is commonly defined by flattened garnet, pyroxene, and/or their alteration products (Figure 8, Figure 10), whereas in the biotite-garnet pegmatites, it is defined by the alignment of quartz and/or biotite. Rare type-2 fold interference patterns resulting from the refolding of northwest-trending F_3 folds by northeast-trending F_4 folds were recognized in the Mackenzie Lake area.

Approaching and within the more than 3 km-wide Grease River Shear Zone (formerly Straight River Fault of Baer, 1969; Figure 6), the F_4 folds are tight to isoclinal and cannot be distinguished from F_2 folds. Axial planes generally dip steeply to the northwest and fold axes plunge more consistently to the southwest. 'Z' fold asymmetry is dominant, consistent with a dextral sense of displacement (Hanmer, 1997; Lafrance and Sibbald, 1997). This is supported by a pervasive, gently southwest-plunging stretching lineation and rare kinematic indicators (Figure 21, Figure 22) that infer a dextral sense of shear with a minor northwest-side-up component. Winged δ-porphyroclasts and the pervasive mylonitic fabric along the northwestern shore of Grease Bay indicate that early shearing took place under ductile conditions. The mylonitized rocks along the southeastern shore of the bay, however, are chloritized and characterized by more brittle textures including dextral shear bands and pseudotachylyte. This greenschist-facies overprint suggests that shearing continued during uplift or that the zone experienced multiple dextral displacements. In a previous study, this greenschist-facies dextral shear was found to deform a *ca.* 1.9 Ga pegmatite dyke (Lafrance *et al.*, 1999; B. Lafrance, pers. comm., 2002), whereas a *ca.* 1.8 Ga leucogranite dyke cut across the mylonitic fabric, establishing Paleoproterozoic age constraints.

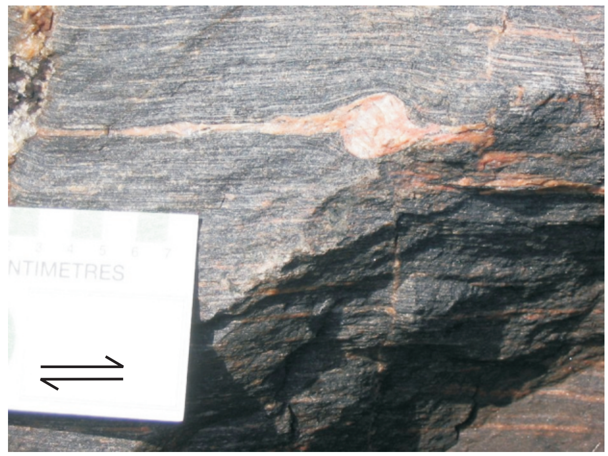


Figure 21 - Steeply north-northwest–dipping mylonite derived from garnetiferous granite-tonalite of the Grease River Shear Zone; looking north-northwestward at near-vertical surface at station 4707-0017 located on the northwestern shore of Grease Bay 5 km from the mouth (UTM 393825 m E, 6579731 m E). Moderately west-plunging stretching lineation (not illustrated) and δ-winged porphyroclast together indicate oblique dextral-reverse sense of displacement.

In the westernmost 3 km of the Tantato Domain, D_4 structures associated with the Grease River Shear Zone have re-oriented the down-dip stretching lineations thought to have developed during D_2. Brittle faulting, associated quartz veining, and kink banding are also common in this eastern part of the Grease River Shear Zone.

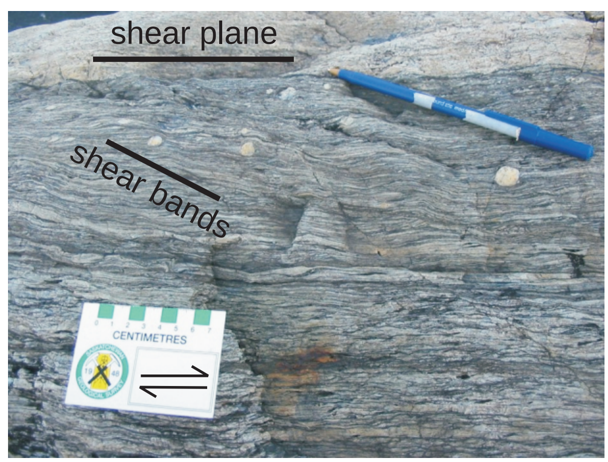


Figure 22 - Dextral shear bands developed in garnetiferous granite-tonalite indicating dextral component of displacement along the Grease River Shear Zone; looking southeastward at near-horizontal surface at station 4707-0019 located along the southeastern shore of the Grease Bay 3 km from the mouth (UTM 391957 m E, 6578174 m N).

Late- to Post-tectonic Structures

Several sets of late- to post-tectonic features were recognized and have been recorded on the accompanying map separates as D5 structures. They include a gentle warping of the regional foliation about a north-northwest trend. This was also noted during mapping of the area west of Fond-du-Lac (Ashton *et al.*, 2006) and broadly correlated with north-trending folds that affect the *ca.* 1.82 Ga Martin Group at Uranium City and the region farther west (*e.g.*, Ashton *et al.*, 2000; Ashton and Hunter, 2004).

Three sets of regional lineaments are obvious on air and satellite photos, and presumably represent relatively young, brittle to brittle-ductile faults. They include: 1) northwest-trending structures parallel, and likely related, to late re-activation along the Oldman-Bulyea Shear Zone; 2) a north-trending 'Airfield Fault' in the west; and 3) east-northeast– to northeast-trending structures parallel, and likely related, to late re-activation of the Grease River Shear Zone (see accompanying map separates). All three are expressed at outcrop scale as centimetre- to metre-scale, brittle-ductile shear zones in the Beaverlodge Domain. The outcrop-scale, northwest-trending, brittle-ductile shear zones were observed northeast of Mackenzie Lake (Figure 6, see accompanying map separates), where they were accompanied by moderately southwest-plunging, down-dip stretching lineations. Since some of these structures are developed in the late muscovite-biotite-garnet leucogranite, they are thought to represent late normal faults developed during a period of post-tectonic extension, rather than early thrust faults. Similar late normal shear zones were observed along the Oldman-Bulyea Shear Zone, where they post-dated emplacement of *ca.* 1815 Ma granite (Card, 2001). The north-trending 'Airfield Fault' in the west (Figure 6) marks an abrupt eastward change from highly fractured (partly by fractures sub-parallel to the 'Airfield Fault'), well-exposed rocks to more massive and drift-covered rocks. It is marked by a prominent scarp on the western side with an adjacent valley extending southward through the area immediately east of the Fond-du-Lac airfield. The broadly east- to northeast-trending regional S_1-S_2 foliation is rotated into a northerly orientation within a zone up to 1 km wide, which is also characterized by the development of phyllonites. The abundance of biotite leucogranite (Pb) in the north suggests that it also acted as a conduit for crustal melts. The sense of displacement along the 'Airfield Fault' was not determined, although related, centimetre-scale, north-trending, brittle-ductile shear zones along the shore of Lake Athabasca about 1 km east of Fond-du-Lac exhibit mainly sinistral apparent offsets. Rare apparent dextral displacements may indicate a component of dip slip or multiple shearing events.

A conjugate set of late, outcrop-scale brittle faults (n=37) is accompanied by quartz veining. The set comprises northeast-trending sinistral and north-northwest–trending dextral structures, apparently developed during a period of north-south shortening.

Of the approximately 800 measured joints, there is a weak dominance of nearly orthogonal northwestern and east-northeastern trends, similar to the pattern developed west of Fond-du-Lac (Ashton *et al.*, 2006).

c) Metamorphism and Timing of Deformation

Metamorphic conditions in the area west of Fond-du-Lac were estimated to be 900°C and 8 kbar by Kopf (1999) on the basis of thermobarometry and 770° to 850°C and 5 to 7 kbar by Ashton *et al.* (2006) based on the stability of observed mineral assemblages. High strain and extensive retrogression has hampered determination of the metamorphic history east of Fond-du-Lac, although several relevant observations, together with recent, independent work conducted in the Tantato Domain, demonstrate an eastward increase in temperature and pressure conditions. The S_1 fabric is partly defined by melt leucosome and appears to wrap around much of the garnet, consistent with the observation that garnet was early and deformed by F_2 folds west of Fond-du-Lac (Ashton *et al.*, 2006). The presence of metamorphic orthopyroxene in rocks of diverse igneous composition indicates conditions in the granulite facies, and the apparent stability of abundant garnet suggests relatively high-pressure. There may also be eastward transition from orthopyroxene-bearing to clinopyroxene-bearing assemblages (Figure 6), although this apparent trend may be an artifact of the widespread retrogression of metamorphic minerals. In metabasites, higher pressure is suggested by the change from orthopyroxene-clinopyroxene-hornblende assemblages west of Fond-du-Lac (Ashton *et al.*, 2006) to assemblages involving pyroxene and garnet east of town. With increasing pressure, clinopyroxene-garnet-quartz assemblages become stable relative to orthopyroxene-plagioclase in the 5 to 7 kbar range (Bucher and Frey, 1994).

Metamorphic conditions in the Tantato Domain have been investigated at the northern apex of the upper deck, about 50 km east of the study area and directly along strike of garnetiferous felsic gneiss (*i.e.*, diatexite of Hanmer, 1994) and mafic granulite units visited during the shoreline reconnaissance. Some of the mafic granulite there, proved to be eclogite (Snoeyenbos *et al.*, 1995) metamorphosed under 750°C and 16 kb conditions at 1904 to 1905 Ma (Baldwin *et al.*, 2007). Adjacent garnetiferous felsic gneisses contain high-pressure minerals including kyanite, sapphirine, corundum, and spinel. Early metamorphic conditions of 775°C and 10 kb (Baldwin *et al.*, 2003) were derived from the Godfrey Granite, a 2601 ±4 Ma old (Hanmer, 1997), variably mylonitic, 'garnet-hornblende ±clinopyroxene granite' belonging to the same lower deck suite as the Mary Granite. These conditions were thought to have developed during granite emplacement or during an early 2.55 to 2.52 Ga metamorphic event, and were superseded by 860°C and 12 kb conditions during the *ca.* 1.9 Ga event that produced the eclogite (Baldwin *et al.*, 2003). It was further noted that this type of high-pressure metamorphism is typically associated with collisional orogenesis (Baldwin *et al.*, 2003).

Although an Archean metamorphic event may well have affected these Tantato Domain rocks, it is unclear whether that was the time at which the earliest-recognized, broadly east-west regional fabric was formed. The mineral assemblages from which at least some of the highest pressure metamorphic conditions have been derived help to define this early east-west fabric, which was subsequently folded by F_4. This early fabric could, alternatively, be equivalent to the composite S_1-S_2-S_3 foliation in the Beaverlodge Domain, the S_2 component of which is thought to have formed at about 1910 ±6 Ma (see above). Also of note is the similarity between the 1904 to 1905 Ma (Baldwin *et al.*, 2007) age determined for metamorphism in the Tantato Domain and the three 1907 to 1910 Ma metamorphic ages from independent samples in the central Beaverlodge Domain recorded in this study.

The S_3 foliation developed north of Mackenzie Lake is defined by biotite replacing garnet and by quartz flattening. D_3 deformation probably developed under the same stress regime as D_2, but at lower metamorphic grade, perhaps during regional uplift. The only evidence of D_3 encountered in the Tantato Domain during this study was the northwest-trending ptygmatic folding of a pegmatite dyke that cut the mylonitic foliation within the Mary Granite.

The S_4 foliation is generally much better developed throughout both the Beaverlodge (Ashton *et al.*, 2006, Figure 20; Figure 8, Figure 10) and Tantato (Figure 17) domains and defined by flattened garnet, pyroxene, cordierite(?), and their retrograde replacements. Orthopyroxene-bearing granitic melt rocks emplaced axial planar to F_4 folds suggest that metamorphic conditions were at granulite facies during D_4 time in the area west of Fond-du-Lac (Ashton *et al.*, 2006).

d) Economic Potential

One of the main goals of this project was to aid in the exploration for unconformity-type uranium deposits by determining the geological history of basement rocks exposed along the northern margin of the Athabasca Basin. The nearest known uranium mineralization (Fond du Lac Uranium Deposit; Saskatchewan Mineral Deposit Index #1572) is located on the southern side of Lake Athabasca about 2 km southeast of the hamlet of Fond-du-Lac (see accompanying map separate). It was identified by tracing a 10 km long train of uraniferous Athabasca sandstone boulders trending 255°. Camok Limited listed reserves for the underlying unconformity deposit of 450 000 kg at an average grade of 0.25% U_3O_8 in 1970 (Saskatchewan Mineral Deposit Index #1572). Interestingly, the deposit is located at the extrapolated intersections of both the Airfield Fault (Figure 6) and lineaments that parallel the Grease River Shear Zone (Figure 6 and accompanying map separate). The Airfield Fault in particular would have been a zone of relatively high fluid flow and may have contributed to development of the deposit. The property has recently been acquired by CanAlaska Uranium Limited.

No uranium showings are known from the area mapped, nor were any outliers of Athabasca Group rocks identified north of Lake Athabasca. Hematitic alteration (Figure 23) thought to have developed at/near the Athabasca Group unconformity was noted at several basement outcrops, where the channel separating the northern and southern shores of Lake Athabasca are very narrow (*i.e.*, Fond-du-Lac area and Fond du Lac River east of the mapped area). Spectrometer measurements obtained from four stations in the eastern zone of local hematite alteration (all within 1 km east of the hamlet) show a weak enrichment of U (1.5 to 3.3 ppm) in the hematized zones and fractures relative to the host psammopelitic to pelitic gneiss and pyroxene granite-tonalite (0 to 0.4 ppm). The absence of such alteration elsewhere suggests that the unconformity surface to the north was well above present-day bedrock exposure prior to erosion.

The 266 gamma and neutron radiation spectrometer readings taken over the summer were used to establish minimum, maximum, and average concentrations of K, U, and Th for all of the major rock types (Table 1). For reference, analyses were also obtained from two uranium showings in felsite and lamprophyre dykes known from west of Fond-du-Lac (Ashton *et al.*, 2006). Both felsites and lamprophyres recorded U concentrations in the 15 to 35 ppm range at these showings. Values from three lamprophyres elsewhere ranged from 2 to 15 ppm, suggesting that this rock type is naturally enriched. The 251 measurements from the area mapped this summer ranged from 0 to 12 ppm, with an overall average of 1.74 ppm. The psammopelitic to pelitic gneiss of the Beaverlodge Domain registered slightly higher U and Th values (2.0 ppm U based on n=97) than rocks of the Eastern Plutonic Complex (average 1.5 ppm U based on n=127), presumably due to the concentration of accessory minerals during transport and deposition. Partitioning of these elements during late crustal melting has also produced relatively elevated values (3.8 ppm average U based on n=3) in the late muscovite-garnet-biotite leucogranite.

Widespread gold mineralization in the Tantato Domain is centred in the Pine Channel area of Lake Athabasca (Figure 15; Saskatchewan Mineral Deposit Index #1574 to 1576, 1581, 2175 to 2178, 2182 to 2188, 2328, and 2329), about 10 km southeast of the mapped area. It is hosted by quartz veins associated with brittle, locally graphitic, northwest- and north-trending fractures and faults, and is locally concentrated where these late faults intersect contacts between the garnetiferous felsic gneiss and mafic granulite (Lafrance, 1997). Magmatic nickel and copper mineralization in the mafic granulite unit of the Tantato Domain is also well known in the Currie-Axis lakes area, centred about 45 km east of the study area

Figure 23 - Hematitic alteration related to the Athabasca Group unconformity, in pyroxene granite-tonalite at station 4707-0007 located 1 km east of Fond-du-Lac (UTM 375886 m E, 6577447 m N).

(Coombe Geoconsultants Ltd., 1991; Saskatchewan Mineral Deposit Index #1583 to 1587, 2608, 2610, 2614, and 2718).

The only reported mineral occurrence in the area mapped is a Pb showing (Saskatchewan Mineral Deposit Index #1571) within the Fond-du-Lac town site. It was described over 70 years ago as consisting of jamesonite along with minor stibnite, sphalerite, chalcopyrite, and arsenopyrite in a small quartz vein (Alcock, 1936). Its precise location is unknown.

4. Discussion and Conclusions

a) Stratigraphic Relationships

A distinctive, multi-phase magnetic unit within the Eastern Plutonic Complex west of Fond-du-Lac has yielded a 2345 ±11 Ma crystallization age, suggesting that it is related to the Arrowsmith Orogen. Since it appears to broadly crosscut the regional fabric, the host granitoid rocks of the Eastern Plutonic Complex are inferred to be Archean. A psammopelitic gneiss from the central supracrustal belt of the south-central Beaverlodge Domain west of Fond-du-Lac has a maximum depositional age of 2030 ±16 Ma based on the youngest detrital zircon age. Its minimum age is constrained by two independent 1909 to 1907 Ma metamorphic ages.

The southeastern Beaverlodge Domain comprises granulite-facies granitoid rocks of the Eastern Plutonic Complex representing an eastward extension of units recognized west of Fond-du-Lac, and psammopelitic to pelitic gneiss, which was previously referred to as garnetiferous quartzofeldspathic gneiss and grouped with the Eastern Plutonic Complex (Ashton *et al.*, 2006). The age relationship between this eastern psammopelitic to pelitic gneiss and that dated in the central supracrustal belt to the west is unknown. Late lamprophyre dykes and muscovite-biotite-garnet leucogranite stocks and dykes are probably manifestations of the Trans-Hudson Orogen.

The westernmost Tantato Domain is dominated by the *ca.* 2.6 Ga Mary porphyroclastic granite. At least some of the garnetiferous felsic gneisses farther east appear to have been derived from siliciclastic sedimentary rocks, although others may have granitoid precursors. These gneisses are similar in appearance to the psammopelitic to pelitic gneisses and Eastern Plutonic Complex of the southeastern Beaverlodge Domain and may be broadly correlative. Mafic granulite sheets/dykes intruded into the Beaverlodge gneisses are also similar in appearance to the *ca.* 2.6 Ga mafic granulites intercalated with the garnetiferous felsic gneisses of the Tantato Domain.

b) Structural/Tectonic Relationships

Development of the early, broadly east-west S_2 fabric in the Beaverlodge Domain took place at about 1.91 Ga and is tentatively thought to correlate with the similarly oriented early fabric in the Tantato Domain. Northeast-vergent thrusting along the Oldman-Bulyea Shear Zone is probably correlative. The boundary separating the upper and lower decks of the Tantato Domain may also have originated as a northeast-vergent thrust at this time and may represent an eastern extension of the Oldman-Bulyea Shear Zone. Continued northeast-southwest shortening produced northwest-trending F_3 folds in the hanging wall of the Oldman-Bulyea thrust and are potentially preserved in the Tantato Domain as rare ptygmatic folds in pegmatite dykes within the Mary Granite. Northeast-trending F_4 minor folds in the southeastern Beaverlodge Domain, together with the dextral Grease River Shear Zone, probably formed during transpression resulting from west-northwest to east-southeast shortening. A pre-existing mylonitic D_2(?) fabric that is attributed to juxtaposition of the upper and lower decks in the Tantato Domain, together with variably mylonitized pegmatite dykes, is also folded by northeast-trending F_4 folds. This model infers that the early, east-west fabric in the Tantato Domain is Paleoproterozoic in age and correlative with that seen throughout the Beaverlodge, Zemlak, and Lloyd domains.

c) Extrapolation of Exposed Units Southward Underneath the Athabasca Basin

Aeromagnetic anomalies do not correlate particularly well with specific lithological units in the area east of Fond-du-Lac (Figure 6, Figure 24). Some rocks of the Eastern Plutonic Complex northeast of Mackenzie and Spence lakes are sufficiently magnetic to produce relative ‘highs’; otherwise the Beaverlodge and western Tantato (the part underlain by the Mary Granite) domains have similar, weakly magnetic signatures. The Grease River Shear Zone does not show up as an obvious tectonic discontinuity in the area mapped (Figure 24). The contact between the weakly magnetic Mary Granite of the lower deck and the non-magnetic garnetiferous felsic gneiss to the east in the upper deck, however, is obvious and can be traced southwestward across Lake Athabasca and beyond. The highly magnetic mafic granulites are also sufficiently distinctive to be traced across the lake, although their discontinuous nature hampers extrapolation beneath the Athabasca Basin beyond about 10 km from the southern shore.

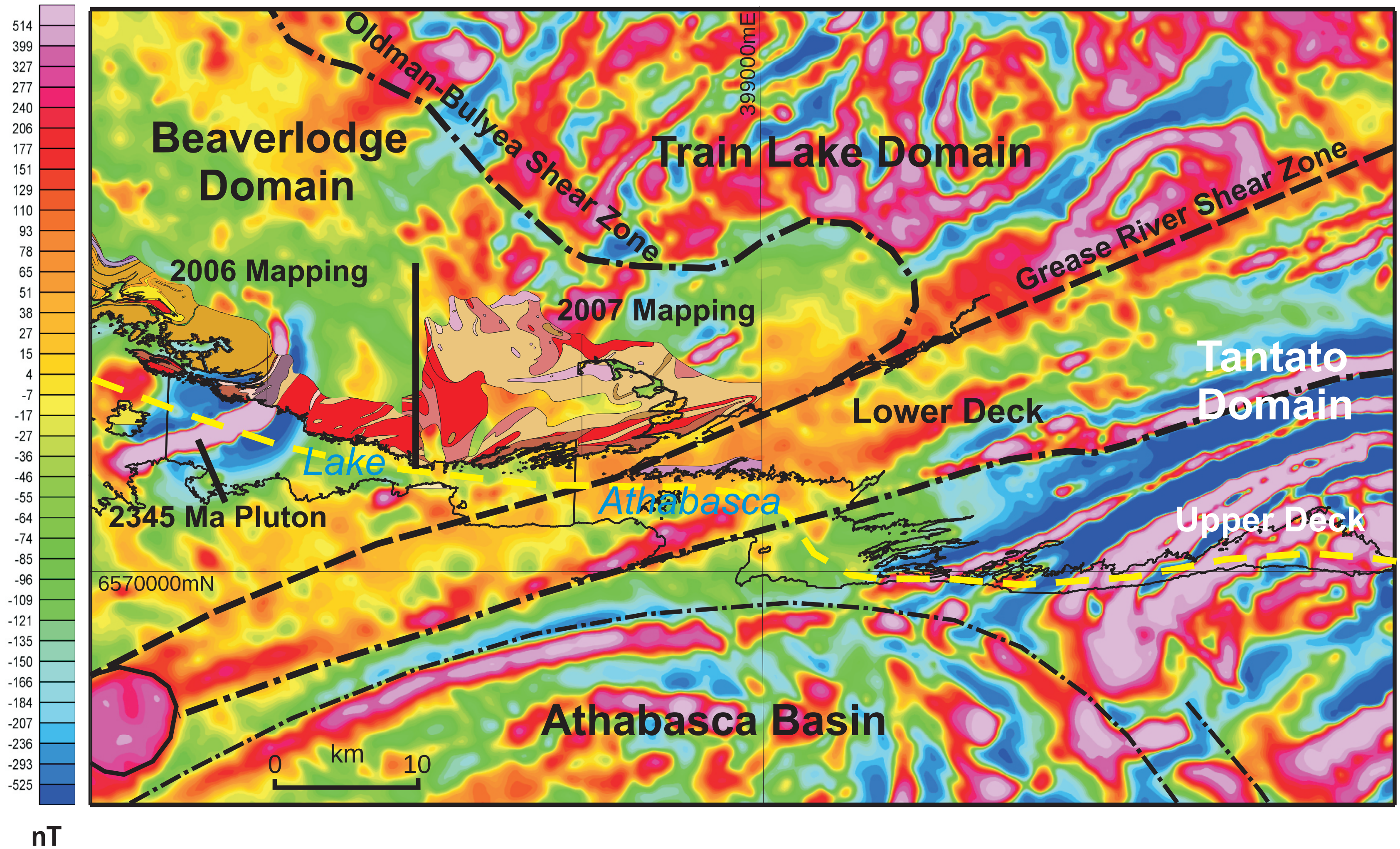


Figure 24 - First vertical derivative aeromagnetic map (Geological Survey of Canada, 1987) with new simplified geological map superimposed showing continuation of weak positive anomalies related to the Mary Granite in the western Tantato Domain and strong positive anomalies related to the mafic granulites farther east.

5. Acknowledgments

The field work was made possible by the cheerful and capable assistance of Richard From, Jessica Pitre, Adam Putz, and Emily Monahan. The bedrock mapping was complemented by a Quaternary study led by Janet Campbell, Saskatchewan Ministry of Energy and Resources (see Campbell *et al.*, this volume). Thanks to John Camier of CanAlaska Uranium Ltd. for graciously providing helicopter time that enabled us to access some of the central parts of the area. We greatly benefited from discussions with Mike Williams and Greg Dumond of the University of Massachusetts during a two-day field trip through the Beaverlodge and Tantato domains, and with Gary Delaney (Saskatchewan Ministry of Energy and Resources) during a one-day visit to the area in late July.

The original manuscript was much improved thanks to constructive reviews by Ralf Maxeiner and Colin Card.

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