New Insights into the Structural Geology and Tectonic Setting of the Uranium City area, Northwestern Saskatchewan

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Kraus, J. and Ashton, K.E. (2000): New insights into the structural geology and tectonic setting of the Uranium City area, northwestern Saskatchewan; *in* Summary of Investigations 2000, Volume 2, Saskatchewan Geological Survey, Sask. Energy Mines, Misc. Rep. 2000-4.2.

Abstract

The Uranium City area, in the south-central Rae province of northwestern Saskatchewan, records a protracted deformation history from the Neoarchean to the Paleoproterozoic. Five generations of structures (F_1 to F_5) related to four compressive deformation events (D_1 to D_4) have been identified in the Murmac Bay Group, a Neoarchean rift sequence or basin deposit. Three structural domains (A to C) have been distinguished on the basis of variation in bulk deformation paths and deformation histories. D_1 and/or D_2, although partly obscured by subsequent deformation, appear to be characterized by overthrusting accommodated by thick fold nappes. Models for D_3, the last regionally significant event, are presented according to which the rocks of the Uranium City area were subjected to dextral shearing (with or without a transpressive component) resulting in a large Z-asymmetrical fold structure and related faults. D_4, which is expressed by small-scale structures only, may have recorded weak sinistral shearing during the waning stages of deformation.

1. Introduction

Mapping at 1:20 000 scale was conducted in the Uranium City area during the first field season of a three-year collaborative project between the Saskatchewan Geological Survey and the Geological Survey of Canada. The area is located in the south-central Archean Rae province (Figures 1 and 2). The southern Rae portion is welded to the Buffalo Head terrane in the west, and to the Hearne province in the east by the Taltson magmatic arc and the Snowbird tectonic zone, respectively (e.g. Hoffman, 1988, 1989). The lithological units exposed around Uranium City are described in detail in a companion paper (Ashton *et al.*, this volume). In brief, the study area hosts a possible passive continental margin (or intracratonic basin) sequence of weakly to highly metamorphosed supracrustal Archean rocks of the Murmac Bay Group, which unconformably overlie ca. 3.0 Ga Archean granitic basement (Figure 3) (Tremblay, 1972; Macdonald, 1983; Van Schmus *et al.*, 1986; Hartlaub and Ashton, 1998, Hartlaub, 1999, Ashton *et al.*, this volume). Both contain several suites of felsic and mafic intrusive rocks. The Murmac Bay Group is unconformably overlain by weakly deformed and essentially unmetamorphosed sediments of the Paleoproterozoic Martin Group. The whole sequence is unconformably overlain by largely undeformed Paleoproterozoic Athabasca sandstone. There is evidence that the Archean rocks experienced deformation in at least two and possibly three events: first, in the Neoarchean and subsequently during the Paleoproterozoic. Here, we present a preliminary synthesis of the structural and tectonic history of this small part of the Rae province.

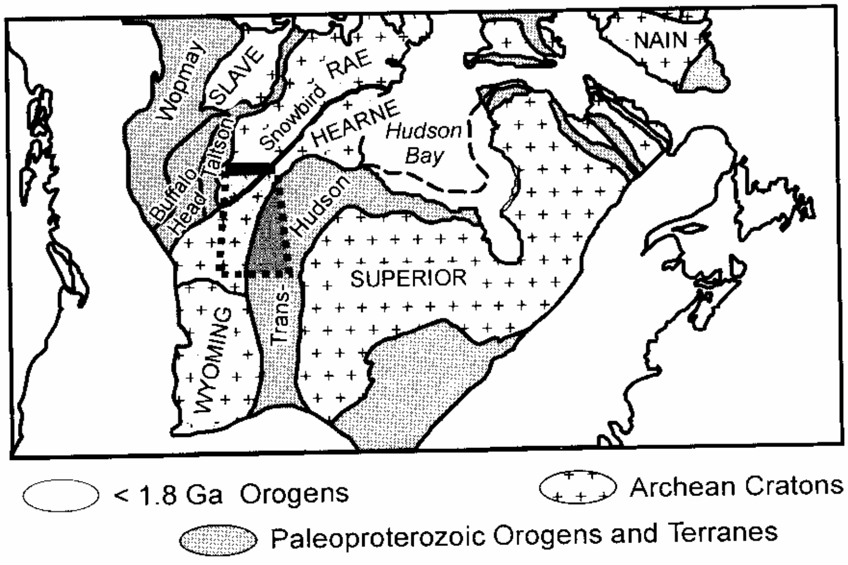

Figure 1 - Simplified map of the tectonic elements of Laurentia. Saskatchewan is outlined by dotted line and the black rectangle refers to the area of Figure 2 (after Hoffman, 1988).

2. Previous Work

A few regional scale structural analyses of the Uranium City area have been conducted, the most important of which are summarized as follows.

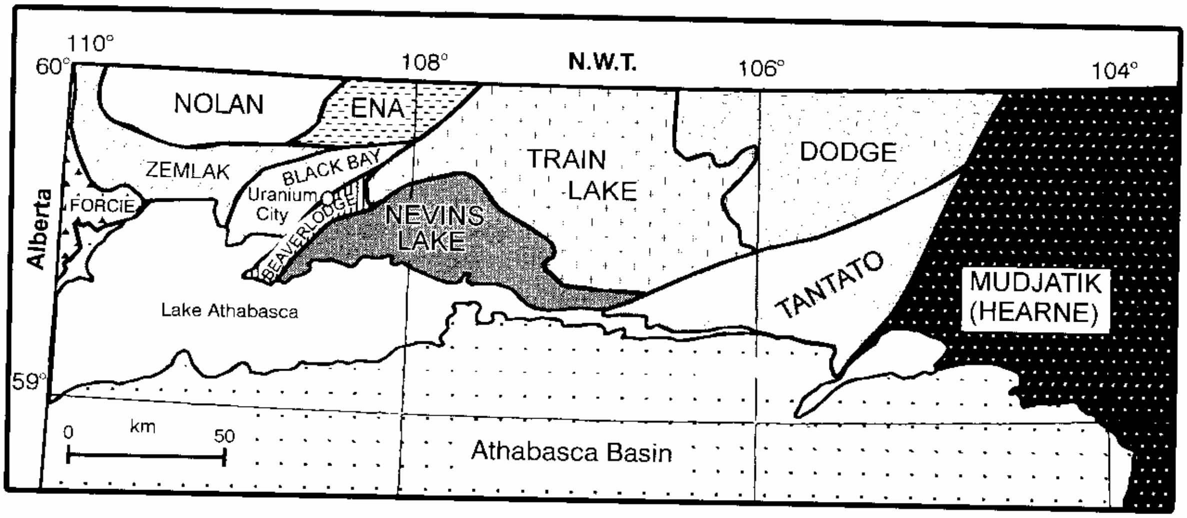

Figure 2 - Regional geology of the Rae province in northwestern Saskatchewan.

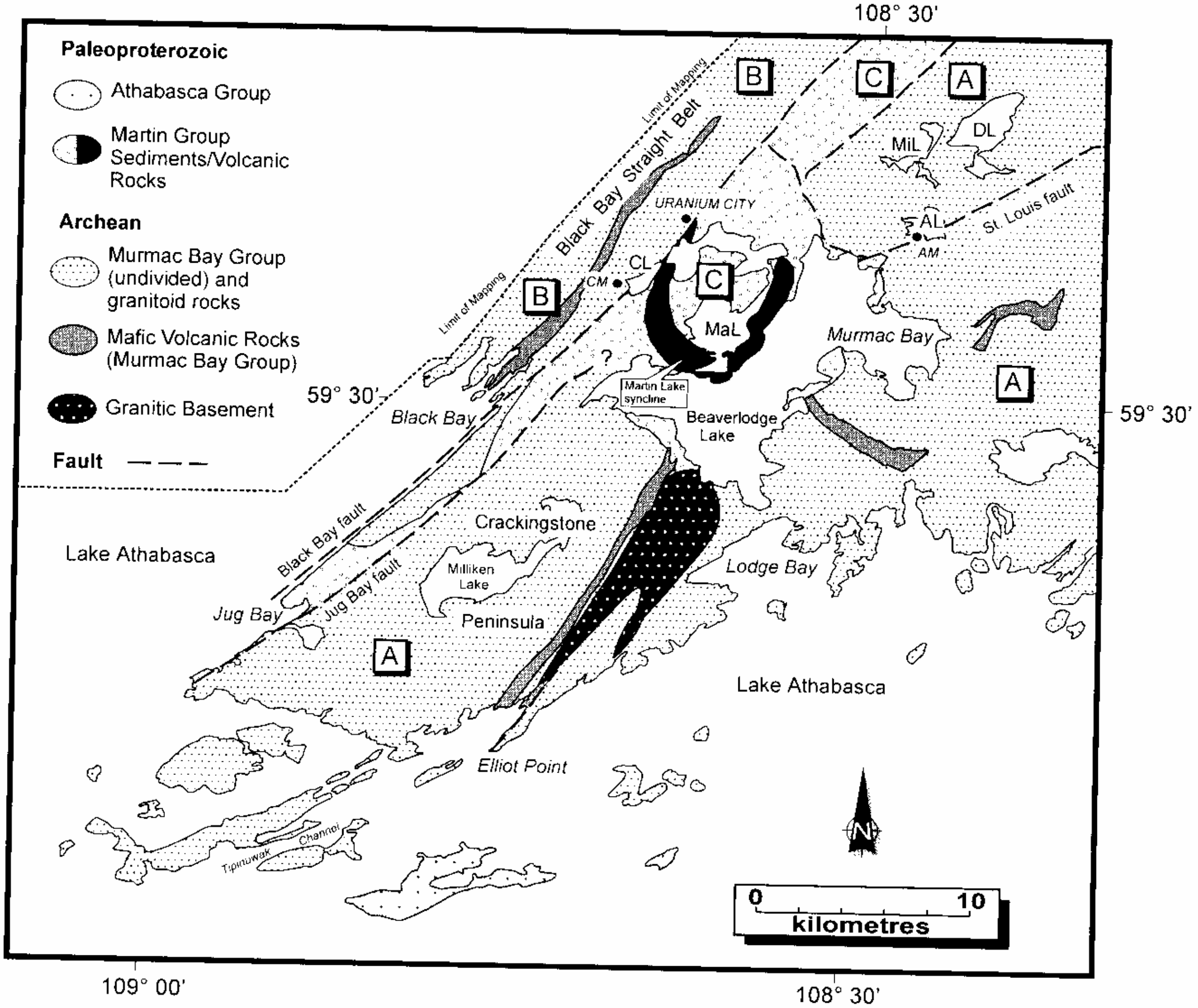

Figure 3 - Simplified geological map of the study area. The letters A, B, and C refer to structural domains (see text for details). AL, Ace Lake; AM, Ace Lake mine; CL, Cinch Lake; CM, Cinch Lake mine; DL, Donaldson Lake; MaL, Martin Lake; and MiL, Mickey Lake.

Tremblay (1972) described two generations of folds in the Beaverlodge Lake area, the first of which affects both the Murmac Bay Group and Martin Group rocks. He attributed the sinuous trace of a large first-generation fold (Martin Lake syncline; Figure 3) to refolding.

Sibbald and Lewry (1980) recognized two generations of structures (F_1 and F_2) for the Lodge Bay area, which they attributed to two episodes of deformation (D_1 and D_2), each of which is characterized by strong variations in strain intensity. They attributed the intercalation of supracrustal and igneous rocks to D_1 folding and thrusting. Minor F_1 folds contain a stretching lineation parallel to their hinges and an axial planar S_1 fabric. The F_1 folds are overprinted by major F_2 folds with steeply east- to southeast-dipping axial surfaces and northerly and southerly plunging axes. The F_2 folds are accompanied by an S_2 axial-plane cleavage.

Since 1998, there has been renewed mapping activity in the "Rae Northeast" between Uranium City and the Tantato domain (Figure 2) (Ashton and Card, 1998; Hartlaub and Ashton, 1998; Ashton *et al.*, 1999; Hartlaub, 1999, Ashton *et al.*, this volume). Hartlaub and Ashton (1998) reported three fold generations for the north shore of Lake Athabasca immediately east of our study area. Their F_1 folds are tight to isoclinal and associated with an axial-plane S_1 foliation. Close to tight F_2 folds, which contain an S_2 axial plane foliation, plunge shallowly in northerly and southerly directions. The map picture is dominated by shallowly to intermediately south-southwest-plunging open to closed S_3-cleaved F_3 folds with northwest- and southeast-dipping axial planes, which fold F_1 and F_2 structures. This interpretation was also applied to the neighbouring study areas of Ashton and Card (1998) and Hartlaub (1999).

All authors mentioned above reported brittle structures following ductile folding.

3. Structural Generations

The Uranium City area records a protracted deformation history possibly exceeding 0.7 Ga from the Neoarchean to the Paleoproterozoic. At least five generations of structures (F_1 to F_5) exist in the Murmac Bay Group rocks, which we relate to four distinct compressive deformation events (D_1 to D_4) (Table 1). We distinguish three structural domains (A to C) based on variation in bulk deformation paths and deformation histories (Figure 3). The spatial orientations of structural features for each domain are given in Figure 4. **Domain A** comprises the area east of the Jug Bay fault hosting Archean basement, Murmac Bay Group rocks, and intrusive rocks. It is representative for the regional-scale deformation and can therefore be correlated with the adjacent areas investigated by workers mentioned above. **Domain B** constitutes the area west of the Black Bay fault. It hosts essentially the

Table 1 - Tentative summary of the tectonometamorphic history of the Uranium City area.

Deformation		Structures	Magmatic Events	Metamorphism	Speculative Age (Ga)	Tectonic Setting
		Unconformity	Gabbro		? 2.7	Deposition of Murmac Bay Group during rifting of Archean basement
D_1	F_1	Transposed folds; stretching lineation; S_1 parallel to primary layering	Leucogranite	M_1 metamorphism, locally at high grade (anatexis)	? 2.6	Crustal thickening by north-west-directed overthrusting; Rae-Hearne collision?
			Gunnar granite cutting F_1 structures, followed by gabbro dykes and sills			
D_2	F_2	Isoclinal folds; stretching lineation; S_1/S_2 transposition foliation parallel to primary layering	Leucogranite	M_2 metamorphism, locally at high grade (partial melting of post-Gunnar-granite gabbro	? 2.0 to 1.9	East-west shortening related collision with Taltson orogen?
D_3	F_3	North-northwest–northeast-trending dominantly Z-folds at all scales; local S_3; Black Bay straight belt with shallow L parallel to hinges of Z-folds, dextral shear bands	Leucogranite	M_3 metamorphism at lower medium grade		Transpression during approx. east-west shortening related to Rae/Hearne–Superior collision?
					? ca. 1.8	Deposition of Martin Group in dextral pull-apart basin and on erosional surface
	F_4	Dominantly Z-folds; dextral shear bands and refolding of L in Black Bay high-strain zone	Diabase sills; west- to northwest-trending diabase dykes			
D_4	F_5	Gentle folds, box folds, and kink bands			post-1.8	
						Deposition of Athabasca Group in an intracratonic basin

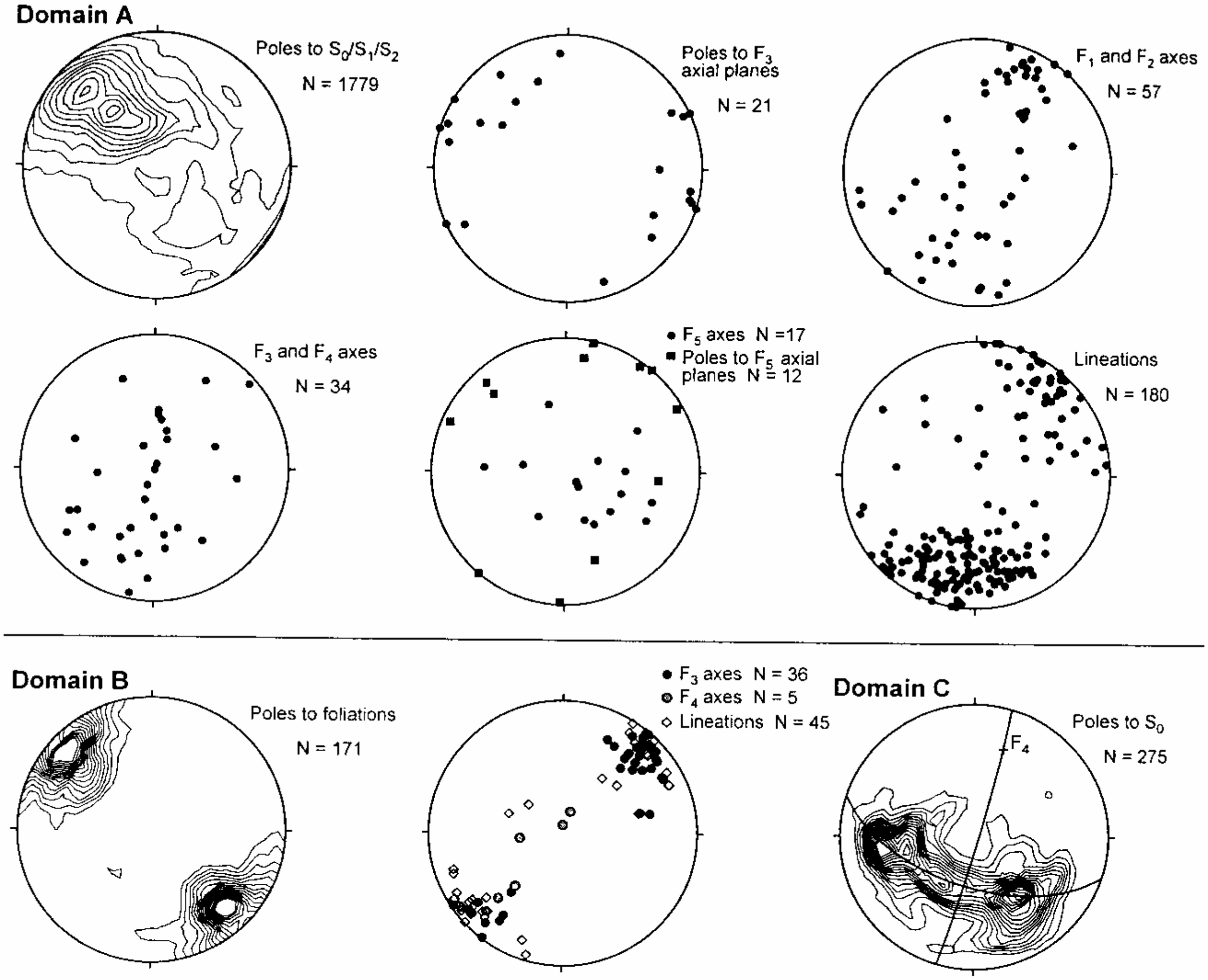

Figure 4 - Equal-area projections (lower hemisphere, Schmidt net) of structural data for the three structural domains. Contours at 0.5, 1.0, 1.5,...8.0 (multiples of random distribution). In domain C, the pole to the great-circle girdle defined by bedding poles is the axis of the F$_4$ Martin Lake syncline. The great circle containing the F$_4$ axis constitutes the syncline's axial plane.

same rocks as domain A, but it has experienced much higher F$_3$ strains so that Macdonald (1983) referred to it as the 'Black Bay straight belt'. **Domain C** is a lithological domain as well in that it hosts only Martin Group sediments and late mafic volcanic rocks. These rocks postdate F$_2$ and M$_2$ and thus do not record the early deformation history of the Murmac Bay Group.

a) Domain A

F$_1$ and F$_2$ Folds and Related Thrusts

F$_1$ and F$_2$ folds, each of which may represent one or several fold generations, are in most cases indistinguishable in terms of style and orientation. Both are isoclinal to transposed with shallowly to intermediately plunging hinges (Figure 4) and are typically observed at decimetre to metre scale. They can be distinguished where rare overprinting and cross-cutting relationships are preserved: the F$_2$ folds postdate and the F$_1$ folds predate and/or coincide with M$_1$ metamorphism and related granitic magmatism (Ashton *et al.*, this volume). Locally, however, the F$_2$ folds are not as tightly apressed as the F$_1$ folds. Psammite xenoliths in post-F$_1$ Gunnar granite (Ashton *et al.*, this volume) contain an S$_1$ fabric defined by migmatitic schlieren, which is indicative of local partial melting associated with F$_1$ folding. This granite and all other post-F$_1$ granites contain an S$_2$ fabric defined by flattened quartz and feldspar grains enveloped by phyllosilicate grains. S$_2$ is parallel to lithological boundaries. In the Murmac Bay Group supracrustal rocks, the main planar fabric is an S$_1$/S$_2$ transposition foliation, which is parallel to primary layering on the F$_1$/F$_2$ fold limbs (Figure 4). This fabric is defined by aligned hornblende grains in mafic rocks, by gneissic layering in psammites, by aligned phyllosilicates in pelites, and as a fracture cleavage in quartzites. In psammites, at several locations around Milliken Lake, this fabric envelops sillimanite faserkiesel (Figure 5). The poles to $S_0/S_1/S_2$ plot on a broad girdle (Figure 4), which is composed of a number of northwest-southeast-trending great-circle girdles. The poles to these great-circle girdles represent the large F_3 fold axes, and the broad girdle reflects the variation in F_3 axis orientations. The maximum of $S_0/S_1/S_2$ poles in the northwest quadrant of the stereonet reflects the prevailing southeasterly dips on the Crackingstone Peninsula.

Relict crenulations of S_1 are preserved in insular domains within the S_1/S_2 transposition fabric at Beaverlodge Lake. In F_1/F_2 hinges in sedimentary rocks, an axial-plane cleavage is restricted to phyllosilicate-rich layers. Minor F_2 folds are rare. They occur, for example, as transposed leucogranite stringers in Gunnar granite or as isoclinal structures in siltstone. F_2 folds appear to be associated with M_2 metamorphism, which culminated in partial melting of all rocks including post-F_1/pre-F_2 gabbro dykes and sills (Figure 6; Table 1; Ashton *et al.*, this volume).

Owing to the strong degree of transposition followed by granite intrusion, few large-scale F_1 folds (but no large F_2 folds) have been identified. On the northeastern Crackingstone Peninsula, a kilometre-scale, northwesterly verging F_1 anticlinorium cored by granitic basement reveals a shallow, slightly curvilinear fold axis. The strain increases dramatically to the western termination of the basement, where northwest-vergent drag folds are developed, too. This zone of elevated strain may be the base of an F_1 fold nappe juxtaposing basement rocks over its Murmac Bay Group cover. Shear bands and CS fabrics observed elsewhere, as well as near-down-dip stretching lineations, may constitute another piece of evidence for early northwest-directed transport.

Figure 5 - Faserkiesel enveloped by the S_1/S_2 transposition foliation at southwestern Milliken Lake.

Figure 6 - Patches of M_2 leucosome in post-F_1 gabbro sill, Black Bay.

F_3 to F_5 Folds

Open to tight, northerly trending (in northeast-trending rocks) mainly Z-asymmetrical F_3 folds are ubiquitous at all scales in the Uranium City area (Figures 4 and 7). They have rather mildly thickened hinges compared to the F_1 and F_2 folds. Minor F_3 folds appear to be related to a map-scale fold with its hinge in the Beaverlodge Lake Lodge Bay area (Figure 3), which is responsible for a change in structural grain from northeasterly on the Crackingstone Peninsula to east-southeasterly farther east. On a regional scale, the structure appears to be a large Z-fold. An axial-plane S_3 fabric is developed in rocks which contain phyllosilicates. At one location at Beaverlodge Lake, $S_{1/2}$ and S_3 alternate in adjacent beds, displaying a chevron pattern in a way described by Henderson (1997). In some places, the S_1/S_2 transposition foliation is crenulated but did not develop into a new cleavage.

F_4 folds, which are Z-asymmetrical on the Crackingstone Peninsula, are in most cases impossible to tell apart from F_3 folds (Figure 4). The F_4 folds may be more open than their F_3 counterparts. Both generations may have formed in essentially the same tectonic regime, but not simultaneously (see below). Along the eastern shore of the Crackingstone

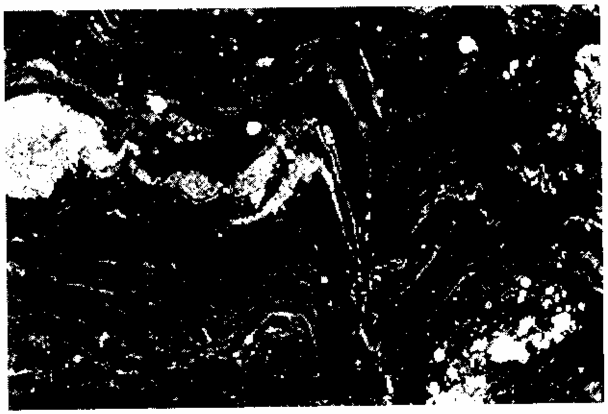

Figure 7 - Train of mildly Z-asymmetrical F_3 folds with varying degrees of tightness in Murmac Bay Group siltstone near Elliot Point. This pattern is a microcosm of the regional scale F_3 folds along the north shore of Lake Athabasca, east of Lodge Bay (see Figure 3 and the compilation map of Macdonald and Slimmon, 1985). Note the folded F_2-boudinaged conformable leucogranite stringers.

Peninsula, between Lodge Bay and Elliot Point, conglomeratic horizons in the basal quartzite locally contain a foliation defined by a shape fabric in the quartz clasts. The intersection of this shape fabric with S_0 yields a dextral asymmetry in all places (Figure 8). Based on the consistent asymmetry and northerly trend, we believe that this fabric constitutes an S_3 or an S_4, despite the lack of minor folds in those outcrops.

The waning stages of deformation are manifested by gentle, small-scale, mostly S-asymmetric chevron-type F_5 folds, box folds, and kink bands. These structures are not significant at the map scale.

Lineations

There is a variety of lineations of different ages in both the Murmac Bay Group and intrusive rocks, defined by stretched quartz grains, quartz rods, clasts, crenulations, and preferred mineral orientations. In a few places, where two different kinds of lineation appear together, they are approximately parallel. The early near-down-dip stretching lineations (see above) appear to be related to early thrusting, but not all early lineations are near down-dip. For example, in southeasterly dipping psammites in one outcrop on Milliken Lake (Figure 3), F_1-related faserkiesel define a lineation, which ranges from subhorizontal to intermediately plunging. Further, a quartz-stretching lineation in the generally shallow F_1 and F_2 folds is parallel to their hinges. The best-developed stretching lineations are parallel to the subhorizontal axes of hundreds-of-metres- to kilometre-scale northeasterly trending open folds, one through Milliken Lake and a trail of them through a group of islands east of Elliot Point (Figure 3). Although there is no unambiguous evidence whether these folds are F_2 or F_3 structures, their relatively large interlimb angles (varying between 60° and 90°) and some small open parasitic folds on Milliken Lake, which deform the transposition foliation (and also contain the shallow, hinge-parallel stretching lineation) suggest that they are F_3 structures. Hence, this lineation is likely an L_3, which formed during stretching of the F_3 fold hinges (see last section for a detailed explanation). In summary, the lineations in the study area are of different ages, but no overprinting relationships were observed.

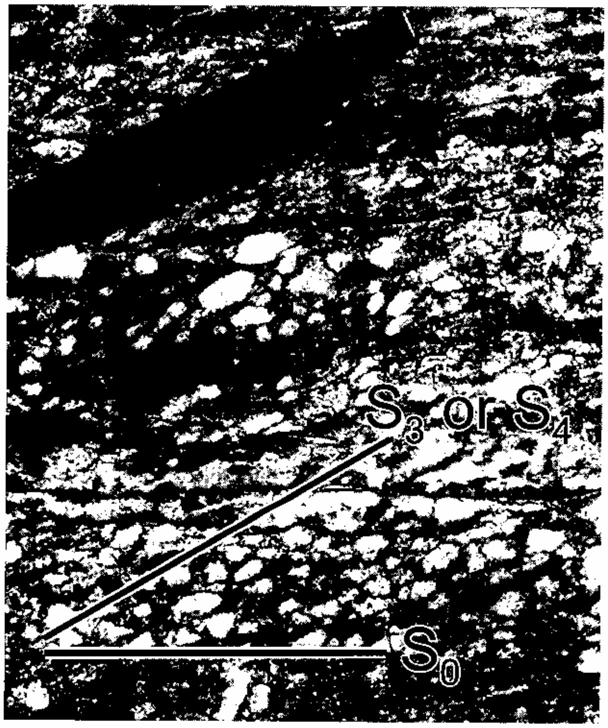

Figure 8 - Shape fabric of clasts defining an S_3 or S_4 in conglomeratic portions of the basal quartzite, Lodge Bay. Note the dextral asymmetry of bedding and cleavage.

Shear Zones and Faults

St. Louis Fault

The St. Louis fault is a complicated structure exhibiting low-temperature mylonitization and later cataclastic deformation (Krupicka and Sassano, 1972). We examined the kinematics of an east-northeast-trending segment of the structure in two locations: east of Donaldson Lake and on the Ace Lake mine (Figure 3), but our results are inconclusive and microstructural work is needed. A complicating factor is that the structure appears to be gently folded by F_3 and/or F_4.

Other Shear Zones

Low-temperature, retrograde mylonite zones, commonly several tens to a few hundred metres wide, are common in the leucogranites of the Mickey Lake–Donaldson Lake area (Figure 3). These mylonites are typically characterized by quartz ribbons with aspect ratios of up to 1:50 and locally show some brittle-ductile overprinting. Some of these ribbon mylonites are bleached and so fine grained, that they had been mistaken for quartzites in previous mapping. Others are strongly sericitic and had therefore been mapped as sericite schists. These late mylonite zones, particularly the overprinted ones, are commonly accompanied by strong chloritization. Owing to their fine grain size and the lack of visible kinematic indicators, the determination of shear sense will rely on our forthcoming microstructural study. At present we can only report that some brittle-ductile shear bands indicate a predominantly apparent sinistral shear sense.

b) Domain B

Domain B is the eastern part of the Black Bay straight belt (Figures 3, 4, and 9). The straight belt constitutes an at least 10 km wide, northeast-trending corridor of intensely deformed and attenuated Murmac Bay Group rocks and intrusive rocks. It is bounded by the Black Bay fault to the east.

Our mapping covered the eastern part of the straight belt (Figure 3). Here, M_1 and M_2 metamorphic grades are indistinguishable, but the combined grade is

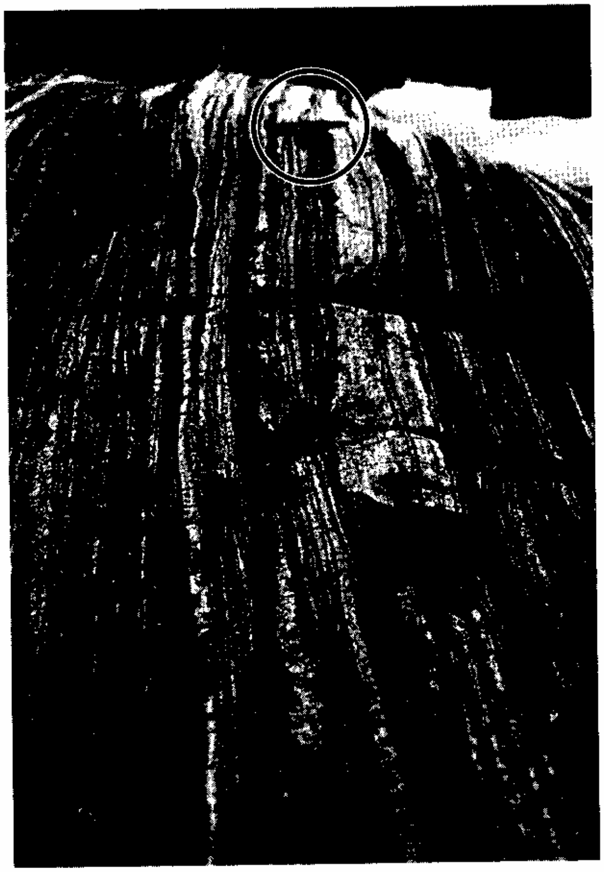

Figure 9 - Attenuated, highly strained high-grade gneisses in the Black Bay straight belt. Hammer (circled) for scale.

characterized by partial melting (Figure 6) and leucogranite injection. The following post-M_2 structural features have been observed (Figure 4):

1) Shearing was accommodated along the gneissic layering, which dips steeply towards the northwest and southeast (Figure 4). These dip reversals occur at all scales and appear to be the result of shallow boudinage together with relatively open folding.

2) Abundant close to transposed Z-asymmetrical folds with shallowly northerly plunging axes both deform the shear-zone fabric and, with increasing tightness, contain the shear-zone fabric along their axial-planes. The F_3 axial planes appear rotated towards the shear fabric with increasing tightness. A strong, gently northeast- and southwest-plunging stretching lineation is developed parallel to the fold axes. In some locations, both curve through the horizontal. Some of these folds have been intruded by synkinematic leucogranite both along and across their axial planes. In the first situation, the stringers are undeformed to slightly boudinaged (Figure 10), because they remained in the extensional sector throughout folding whereas, in the second situation, the stringers were irregularly folded during tightening of the host fold. There are also a few S-folds, mainly plunging shallowly southwesterly, and some earlier rootless folds. We correlate both the Z-folds and shearing with the ubiquitous F_3 Z-folds outside the shear zone, and interpret the granite intrusion as related to the M_3 event.

3) Open, more brittle style F_4 Z-folds have typically intermediately plunging axes and they are locally dismembered by brittle faults parallel to the shear-zone fabric (Figure 11). They deform boudinaged conformable granite stringers and the shallow stretching lineation.

4) Other F_3 and/or F_4 structures such as ubiquitous decimetre-scale brittle to brittle-ductile shear bands, asymmetrical boudinage (with steep boudin axes; Figure 12), and asymmetrical granite fish are all indicative of a component of dextral shear.

At Cinch Lake mine (Figure 3), the S_3 mylonitic fabric in leucogranite dips steeply northwestward and the stretching lineation plunges shallowly southwest. This is consistent with shallowly oblique dextral reverse movement of the west side over the east side.

Figure 10 - Z-asymmetrical F_3 fold in Black Bay straight belt with syn-F_3 axial-planar leucogranite intrusion in plan view.

Figure 11 - Z-asymmetrical F_4 fold that has been dismembered by shearing along its long limb. In contrast to the F_3 fold in Figure 10, this one folds the shallow L_3 lineation.

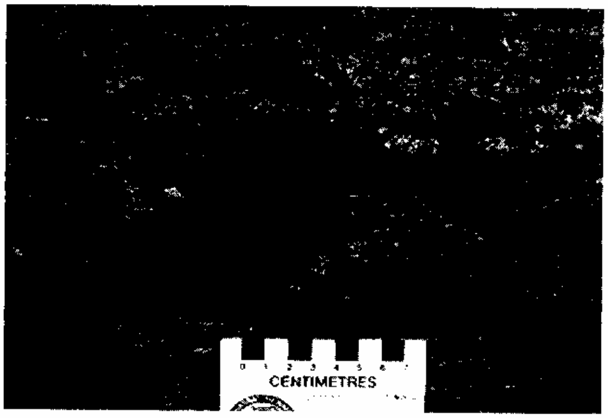

Figure 12 - Shear bands indicating dextral movement in the Black Bay straight belt (plan view).

In summary, this high-strain corridor constitutes a dextrally oblique reverse high-strain zone, possibly with a transpressive component. Considering the combination of shallow stretching lineations, abundant shear bands, and the strong attenuation of the package, the transpressive interpretation appears the more plausible one.

c) Domain C

Domain C comprises the area between the Black Bay fault and Jug Bay fault, and part of the Beaverlodge Lake shore (Figure 3). It hosts only Martin Group sediments and related volcanic rocks, which were deposited after F_2 and M_2, possibly during F_3. Thus, the rocks of domain C do not record the Archean history of the Murmac Bay Group. As evident from the map and the stereographic projection of bedding (Figures 3 and 4; data taken from Tremblay, 1972), the rocks are folded into the tight, shallowly to intermediately north-northeasterly plunging F_4 Martin Lake syncline (e.g. Tremblay, 1972) with a steeply east-southeast-dipping axial plane. The significance of this fold is discussed below. In one location west of Milliken Lake, small Z-asymmetrical F_4 folds with intermediately to steeply northeasterly plunging axes were observed.

The steep Black Bay fault and the parallel, moderately to steeply northwest-dipping Jug Bay fault delimit a narrow, at least 50 km long belt, which we interpret as a dextral pull-apart basin (Figure 3). Both structures appear to be brittle-ductile and have a strong brittle overprint associated with pervasive chloritization in a zone tens of metres wide. We could not gather any kinematic information on the Black Bay fault other than some dextral ductile-brittle shear bands on an adjacent small island, but there is no proof that the shear bands and the fault are related. At Jug Bay, Martin Group siltstones and weakly foliated to massive Gunnar granite are exposed two metres apart, but the faulted contact of the Jug Bay fault is missing. Farther away from the contact, in the granite, there are fault sets near-parallel to the main structure. In their vicinity, the granite is hydrothermally altered, locally beyond recognition. The Jug Bay fault thus appears to represent a set of faults rather than a single discrete structure. The Black Bay fault was active longer than the Jug Bay fault, as the former truncates late easterly trending dykes, whereas these dykes cut across the latter.

d) Correlation with Previous Work

Our sequence of structural generations (Table 1) correlates well with Ashton and Hartlaub (1998) and Hartlaub (1999). As the only difference, we report two additional late fold generations (F_4 and F_5). Sibbald and Lewry (1980) grouped our early F_1 and F_2 folds together so that our F_3 correlates with their F_2. Our interpretations are in stark contrast to Tremblay (1972), whose F_1 is our F_4. Further, the sinusoidal fold-axial plane of the Martin Lake syncline did not result from refolding but is a primary feature common in folds at all scales.

4. Tectonic Synthesis

D_1 is characterized by northwest-directed folding and thrusting (in terms of present day coordinates), as indicated by the northwest vergent F_1 anticlinorium cored by basement on the northeastern Crackingstone Peninsula, and by local near-down-dip stretching lineations in southeasterly dipping rocks. Considering the local high M_1 metamorphic grade which led to partial melting, D_1 deformation was likely not accommodated in a foreland fold-and-thrust belt, but in thick, internally deformed ductile nappes. Preliminary monazite chemical ages from upper medium-grade pelitic rocks sampled 20 km to the east of the study area suggest that D_1 occurred at or close to the Archean-Proterozoic boundary (Hartlaub, pers. comm., 2000). The significance of D_2 is uncertain. F_2 folds are distinguished solely on the basis of their relationships with respect to post-F_1 granites and their accompanying M_2 metamorphism. Considering that F_2 structures did not introduce any complex F_1/F_2 interference patterns, the D_2 and D_1 settings may have been similar. D_2 is likely of Paleoproterozoic age and, so we speculate, it may be related to the collision of the Taltson orogen with the Rae plate at 2.0 to 1.9 Ga.

We present three preliminary models for the D_3 deformation history. In the first model, the large F_3 fold hinge in the Beaverlodge Lake–Lodge Bay area belongs to a symmetrical synform with a steep, northeast-trending axial plane and abundant large M-shaped folds in its hinge area, formed during northwest-southeast shortening. According to this geometry, we expect the sequence exposed on the eastern shore of the Crackingstone Peninsula to re-appear to the east (under the Athabasca sandstone cover and Lake Athabasca). The fold's axis, east of the Crackingstone Peninsula and south of Lodge Bay, must be shallow to subhorizontal in order to be in agreement with the northeasterly trend of the rocks exposed on the peninsula and on the islands to the east of it.

The other two models (Figure 13) consider the large F_3 fold as Z-asymmetrical, with the rocks of the

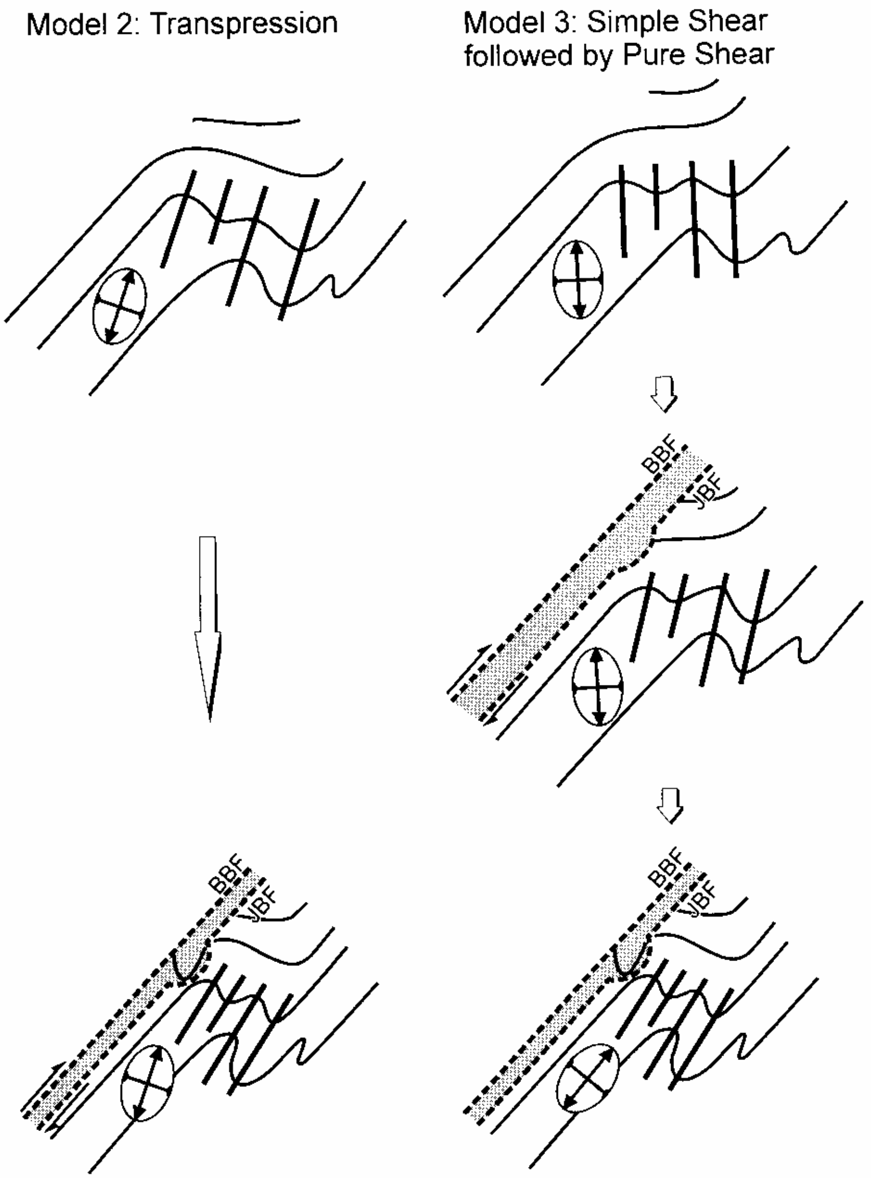

Figure 13- Sequence of diagrams that schematically depict the D_3 history according to models two and three, as discussed in the text. The thick black lines depict fold axial planes and the ellipses indicate the directions of instantaneous maximum and minimum stretching. BBF, Black Bay fault and JBF, Jug Bay fault.

Crackingstone Peninsula being located on one of the long limbs. This is consistent with the structural grain and the prevailing map-scale Z-asymmetrical folds west of Uranium City (see compilation map of Macdonald and Slimmon, 1985).

According to the second model, the Uranium City area was subjected to dextral transpression (i.e. a combination of simple shear and pure shear, which results in thinning of the deformation zone). In this situation, the direction of the maximum shortening direction was at an angle higher than 45° with the then prevalent structural grain (which we assume to have been the same northeast grain as on the present-day Crackingstone Peninsula). In this setting, the F_3 folds formed at an angle to the northeast structural grain in a shear environment that progressively rotated them towards parallelism with this direction. During rotation, the fold hinges were in the extensional sector and a stretching lineation parallel to the fold axes developed. The reason for the locus of the large fold hinge straddling the Beaverlodge Lake area, and the abundance of kilometre-scale parasitic symmetrical folds in this hinge area, may be related to a large-scale flow perturbation initiated around flow-inhibiting voluminous granite bodies. During tightening of the large fold structure, a northeast-trending dextral pull-apart basin developed (shaded area in Figure 13), flanked by the Black Bay shear zone/fault and the Jug Bay fault, the latter of which dismembered the large F_3 fold along its long limb and possibly cut out part of the hinge. While the basin was becoming narrower during transpression, its Martin Group fill was constrained to become folded (Martin Lake syncline; Figures 3 and 4). In the Black Bay straight belt and, to a minor extent in the extended Donaldson Lake area, sets of west- to west-northwest-trending, undeformed late mafic dykes may represent the "frozen" azimuth of the maximum shortening direction at the end of D_3, which is consistent with the transpression interpretation.

Model three is a variation of model two, and considers simple shear and pure shear deformation as not having operated simultaneously. According to this model, the large Z-fold developed as a drag fold in dextral simple shear related to approximately east-west shortening. During continued dextral shearing, the F_3 axial planes rotated towards parallelism with the structural grain and the Martin basin developed as a strike-slip basin developed (shaded area in Figure 13). This was followed by pure shear associated with northwest-southeast shortening, during which the parasitic F_3 folds in the large F_3 hinge area east of Beaverlodge Lake were locally tightened, their axial planes were rotated farther towards parallelism with the northeast structural grain, and the Martin Lake syncline formed.

The fundamental difference between models two and three is that model two does not require a shift in the shortening direction during D_3, and it offers the best explanation for the pervasive, relatively shallow L_3 stretching lineations. Model one may explain the large apparent thickness of the quartzite, but it cannot account for the shallow stretching lineations parallel to the F_3 hinges, nor for the pull-apart basin.

We therefore favour model two at the present stage of investigations in the Uranium City area. After the D_3 deformation outlined in these models, small, gentle, S-asymmetrical folds recorded on the Crackingstone Peninsula, which are frequently associated with kink bands and box folds, are thought to indicate of weak sinistral shearing during D_4. D_4 may represent the waning stages of deformation and, since there are no large-scale D_4 structures, it is rather insignificant. D_3 and D_4 are possibly related to the Hudsonian orogeny, a worldwide event at ca. 1.8 Ga, which, for example, included the Rae/Hearne-Superior collision.

5. Acknowledgments

We thank Russell Hartlaub, Ryan Morelli, Erin Chorney, and Sarah Ehman for acquiring some of the structural data presented in Figure 4. We further acknowledge the dedicated field assistance of Danielle Boivin, Erin Chorney, Sarah Ehman, and Asha Yanko. Discussion in the field with Kathy Bethune, Colin Card, Tom Chacko, Gary Delaney, Charlie Harper, Russell Hartlaub, Larry Heaman, and Ryan Morelli is appreciated.

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