# Nature and role of deformation bands in post-Athabasca faulting and genesis of unconformity-related uranium deposits; case study of the C1 fault zone in the eastern Athabasca Basin, northern Saskatchewan


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## 1 Purpose

This study examines deformation bands within the Athabasca Basin in a series of transects across the C1 structural corridor to better understand their genesis and relation to post-depositional fault reactivation as well as the role these structures have in constraining fluids associated with uranium mineralization.

## 2 Regional Geology

The Athabasca Basin, in northern Saskatchewan and Alberta, consists of Paleo- to Mesoproterozoic siliciclastic rocks that unconformably overlie Archean to Paleoproterozoic basement rocks of the Canadian Shield (Jefferson et al., 2007). The eastern portion of the Athabasca Basin unconformably overlies the Hearne Province and is locally divided into the Wollaston and Mudjatik domains. Many unconformity-type uranium deposits of the Athabasca Basin are situated at or close to the Wollaston-Mudjatik Transition Zone and are thought to be directly related to the reactivation of structures within this zone (Jefferson et al., 2007). Three major faults (Offset Fault, Gryphon Fault, and Basal Fault) showing reverse uplift characterize the C1 corridor in which this study is based; these follow the same northeast trend which correlates with the foliation measured in the basement. The Manitou Falls Group comprises a succession of all siliciclastic units above the basement rocks and is sub-divided into four units; the Read (MFA), Bird (MFB), Collins (MFC), and Dunlop-Clampitt (MFD) formations (Ramaekers et al., 2007).

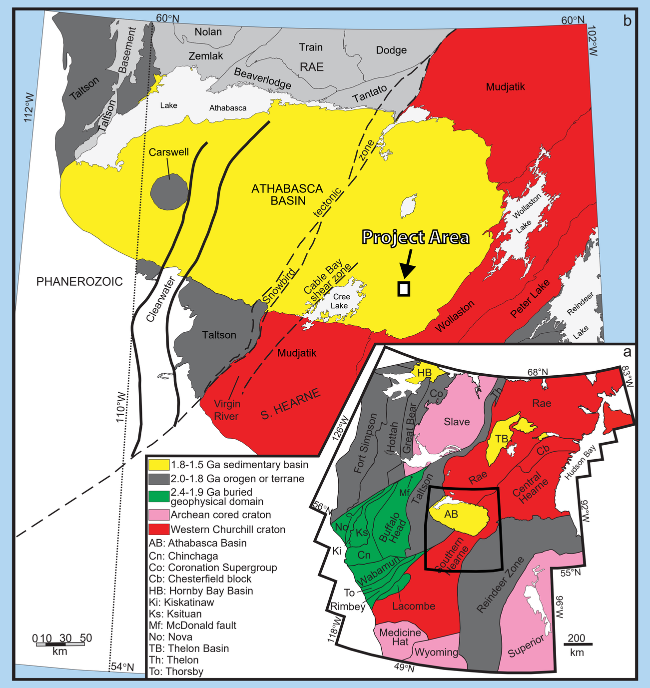



Figure 1 – a) Cratonic map of western Laurentia with the location of the Precambrian domain map outlined in black b) Precambrian Lithotectonic domain map of northern Saskatchewan and northeastern Alberta with project area highlighted. Modified after Card et al. (2018).

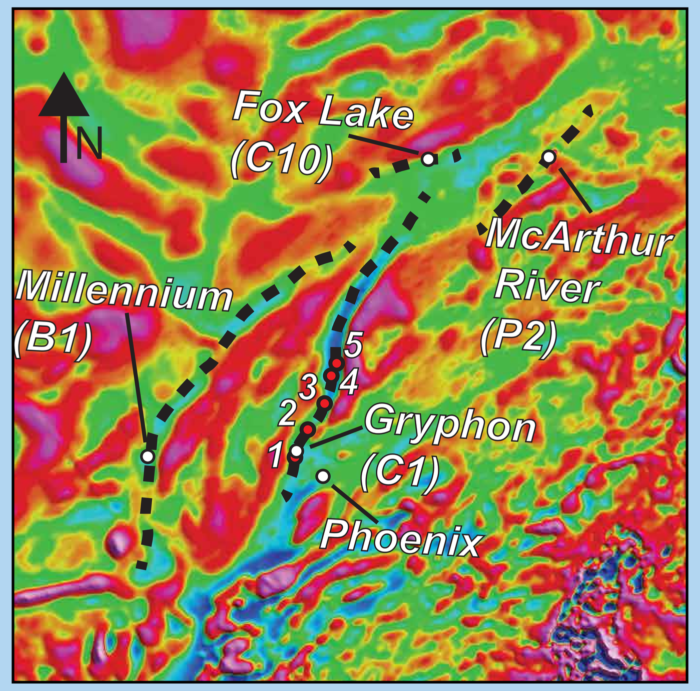



Figure 2 – First vertical derivative magnetic susceptibility map of the project area focusing on the C1 and related fault corridors of the eastern basin. White dots mark major uranium deposits while red dots mark drill core fences studied this summer. 1- Wheeler River, 2- Hughes Lake Fence #1, 3- Hughes Lake Fence #2, 4- Hughes Lake Fence #3, 5- Mann Lake Fence. Modified after Rodgers et al. (2017).

## 3 Methods

- Fieldwork was carried out over ~six weeks in the summer of 2018.
- 15 sandstone and nine basement drill cores were studied.
- All structures were observed and recorded, including those of basement rocks, although the primary focus was on documenting the types and orientations of deformation bands in the Manitou Falls Group.
- Alpha and beta measurements were taken of structures with a hand-held goniometer (roll-tool).
- Structural data was compiled on cross sections, stereonets, and histograms.
- Data and figures of two drill hole fences comprising six holes are presented in Figure 5.

## 4 Deformation Bands

According to Fossen et al. (2007) "deformation bands are the most common strain localization feature found in deformed porous sandstones and sediments". These bands commonly have the appearance of raised white ribs in the host rock due to a resistance to weathering, attributed to a function of strain hardening during formation. Formation of deformation bands, particularly ones involving catalasis, occur proximal to faults and are more abundant between the depths of one to three kilometers. Owing to change in porosity due to grain rotation and flow, deformation bands have the potential to act as fluid baffles or conduits.

The deformation bands in this study were observed and categorized into three main types:

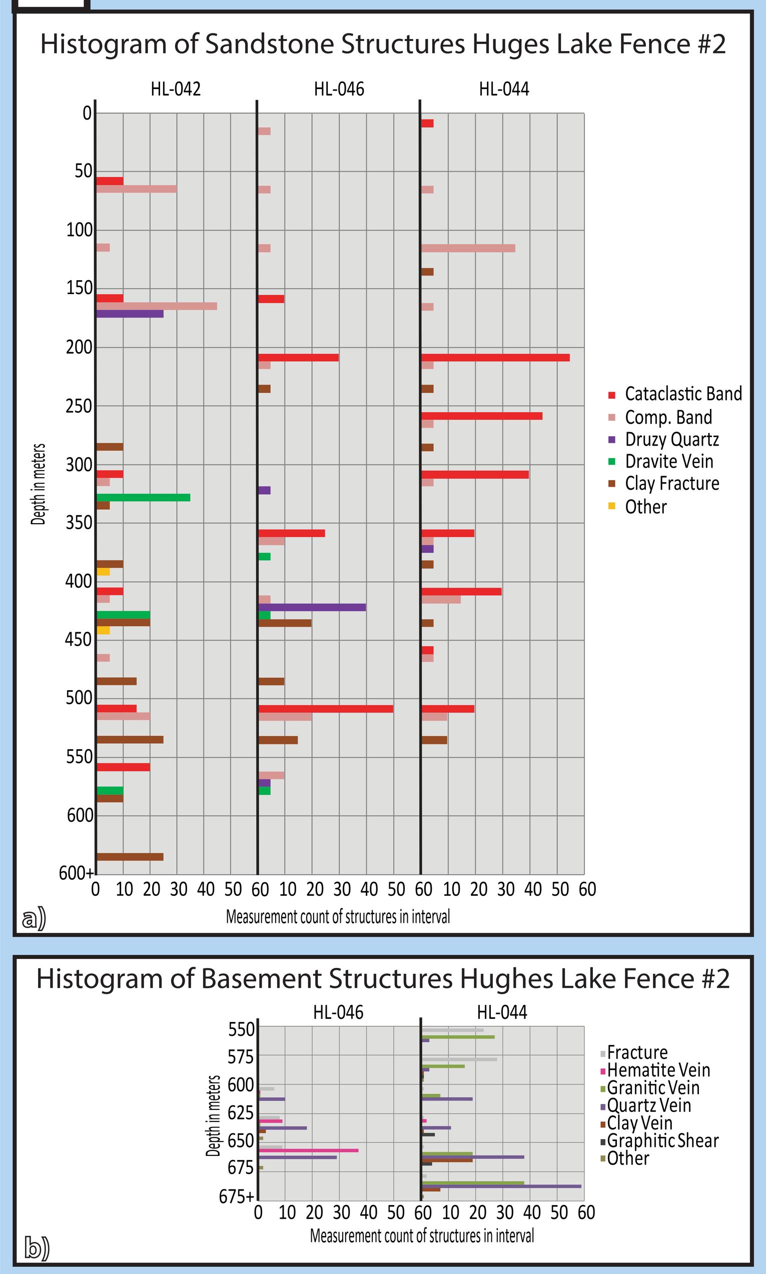
**Compaction** – Reduction of porosity within the band compared to host rock

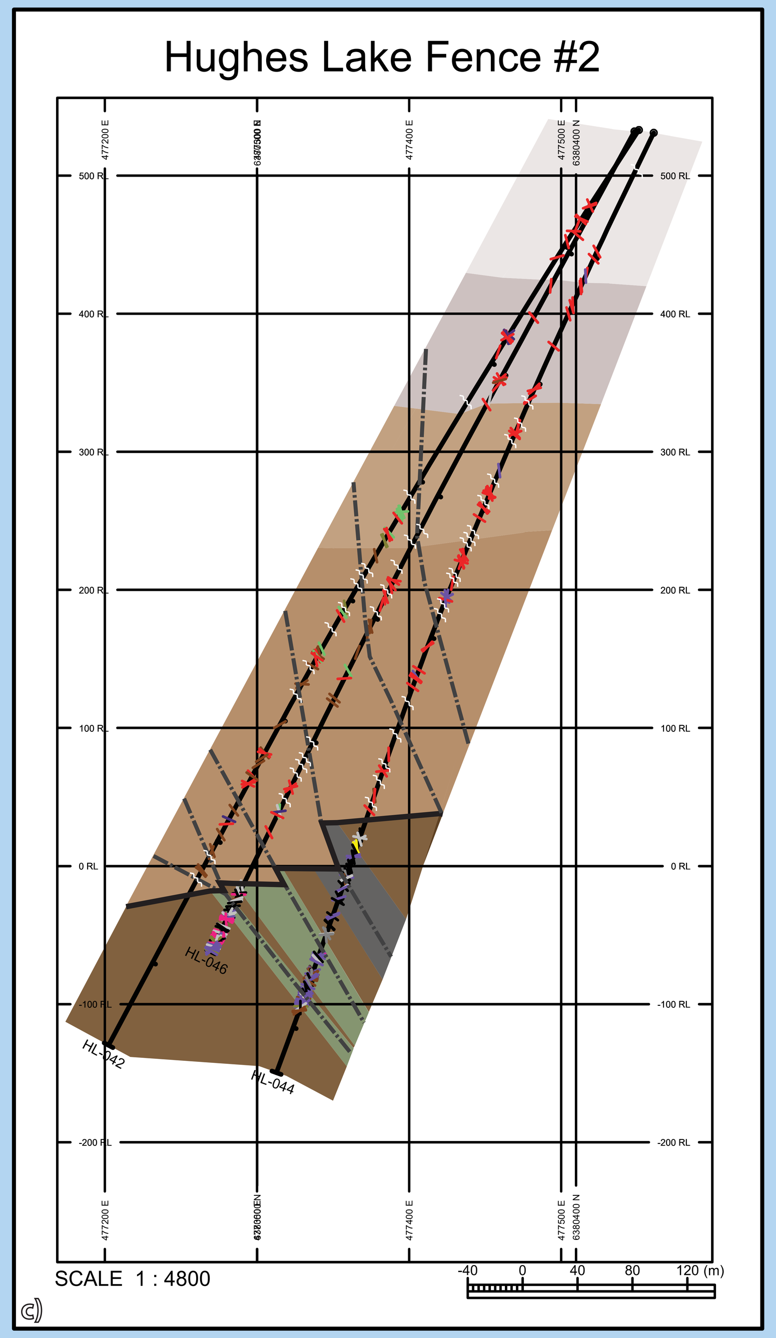
**Shear** – Particle/granular flow causing offset in the rock

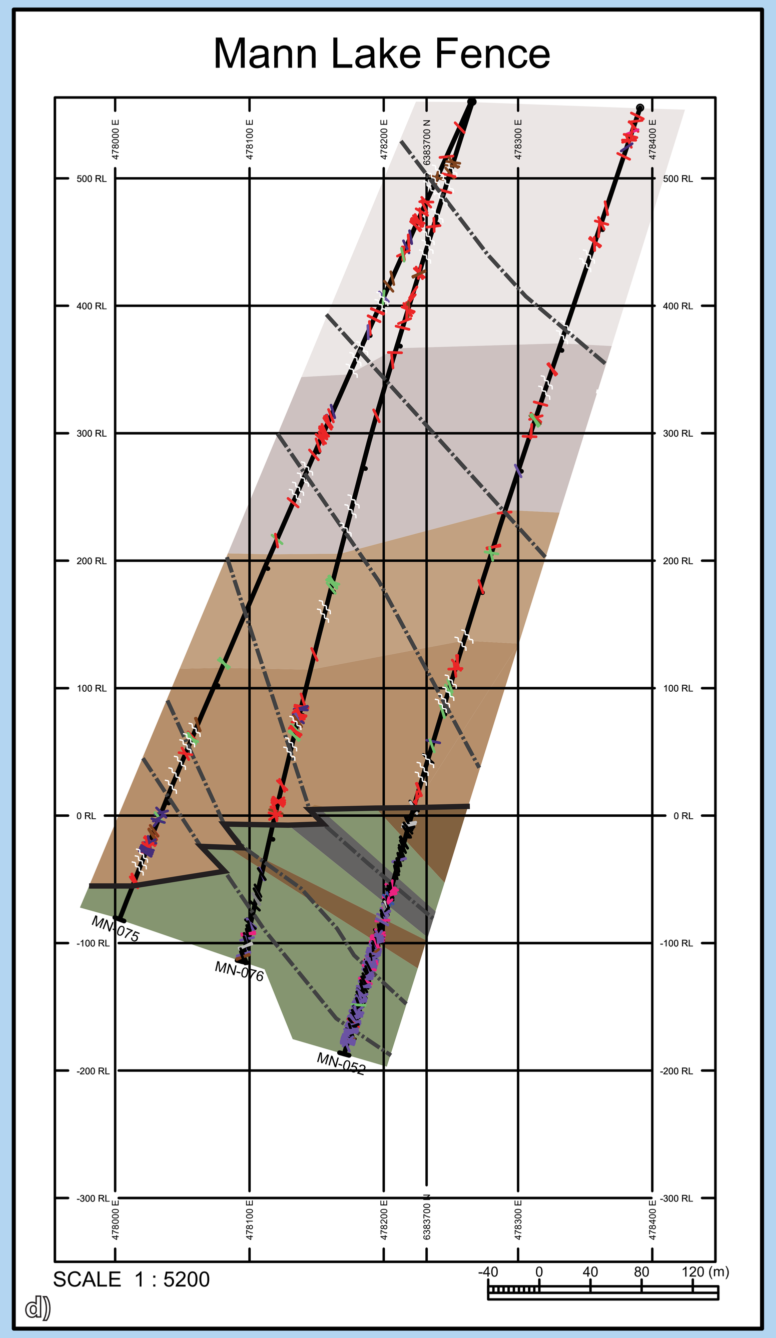
**Cataclastic** – Grain sliding and rotation leading to grain crushing greatly reducing porosity


Figure 3 – a) Photo of a compaction deformation band from drill core HL-042 at 66.1m; b) Photo of a shear band, direction of offset is marked in red, from drill core HL-087 at 546.6m; c) Photo of a cataclastic band, note the breaking along larger grains in the sandstone, from drill core WR-566 at 480.3m.

## 5 Structural Data and Figures



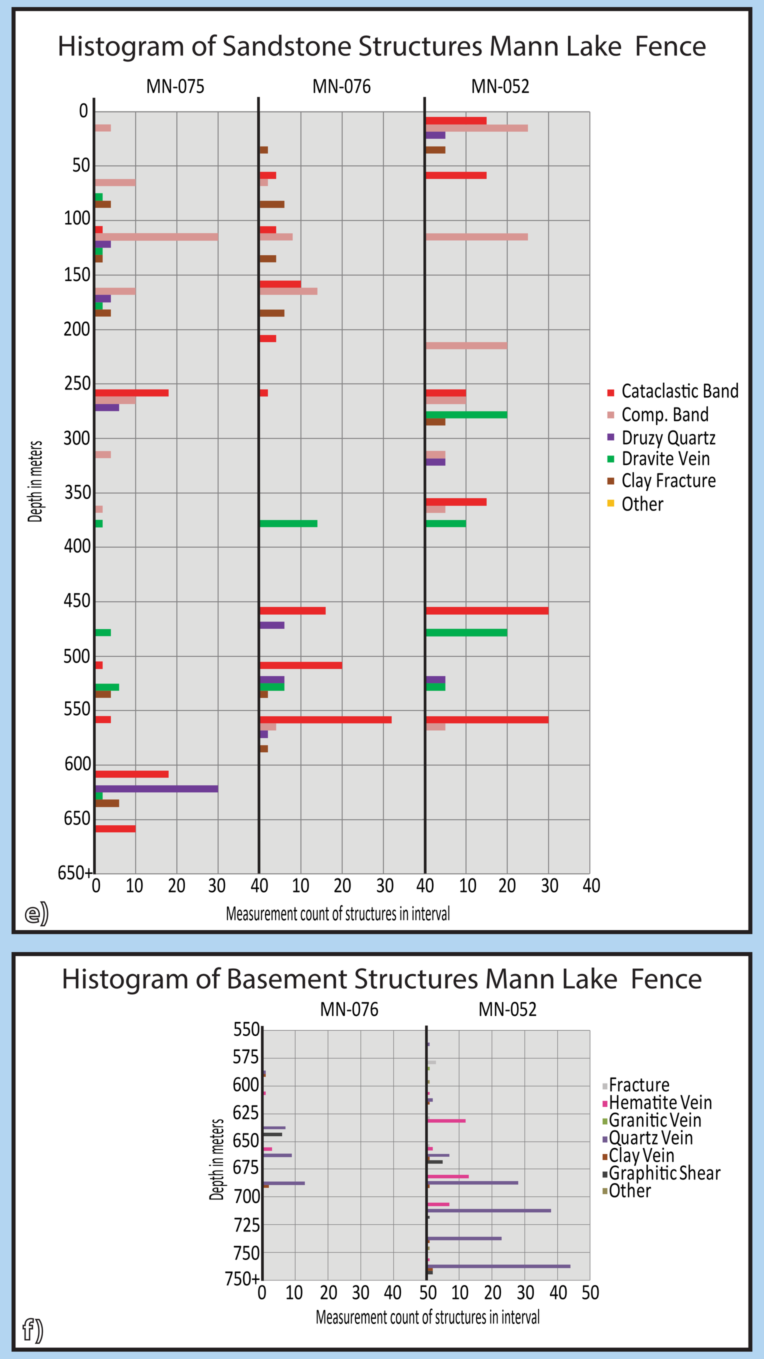
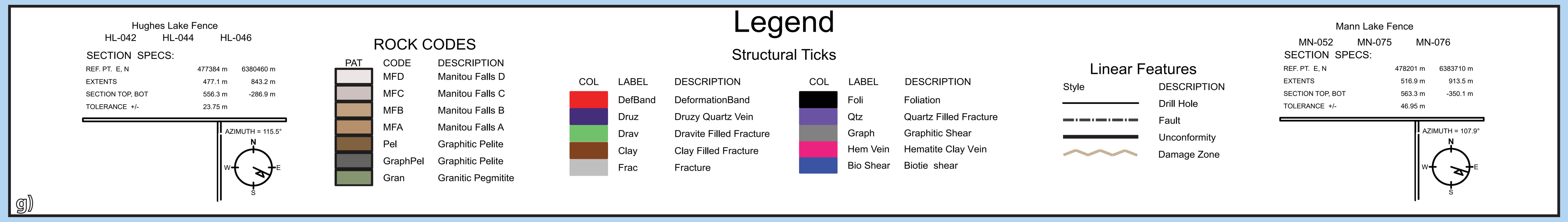
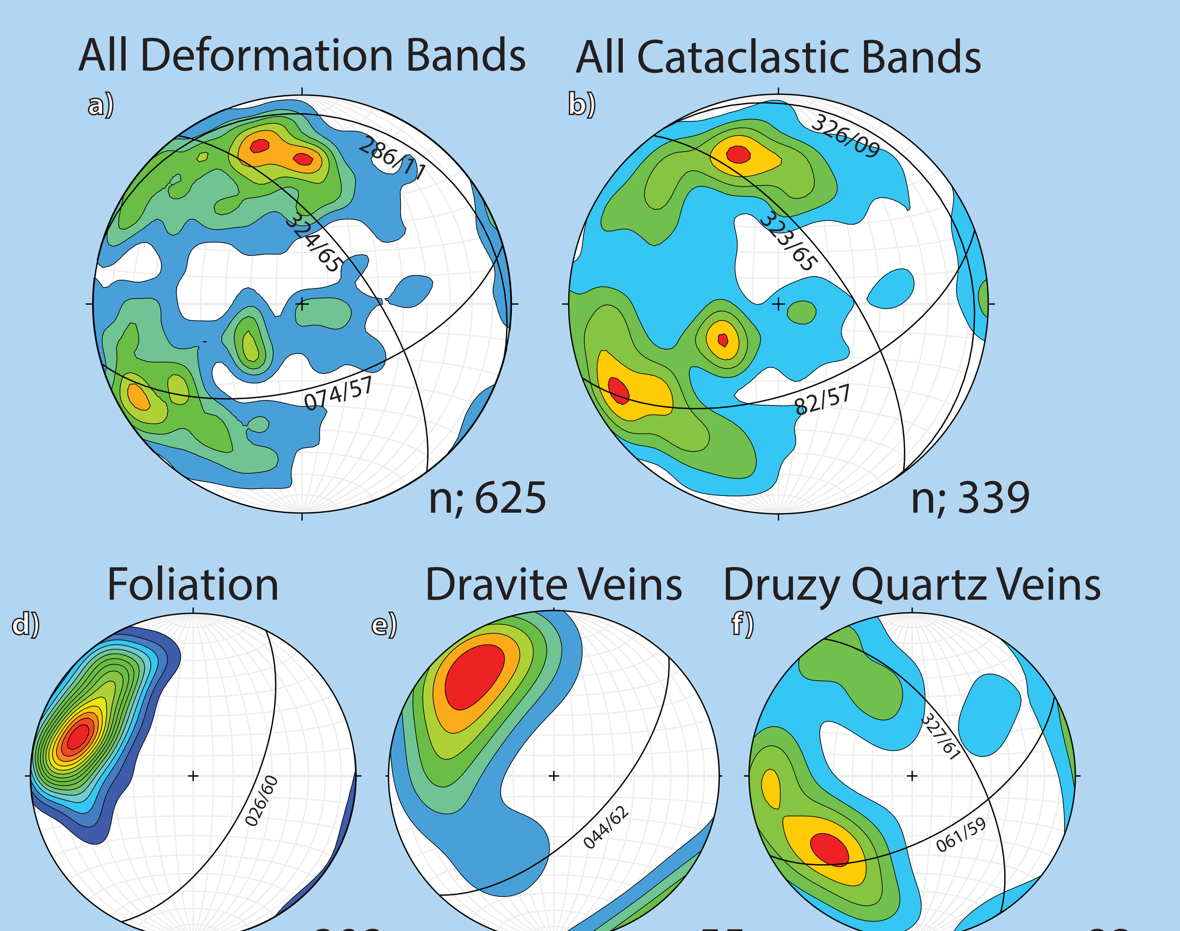




Figure 4 – a) Histogram of the structures measured in sandstone drill core across Hughes Lake Fence #2; b) Histogram of the structures measured in basement drill core across Hughes Lake Fence#2; c) Cross section of Hughes Lake Fence #2 created using measurements taken from drill core during the Summer 2017 field season; d) Cross section of the Mann Lake Fence created using measurements taken from drill core during the Summer 2017 field season; e) Histogram of the structures measured in sandstone drill core across the Mann Lake Fence; f) Histogram of the structures measured in basement drill core across the Mann Lake Fence; g) Legend for Figures 6 b and c.




## 6 Regional Structural Trends



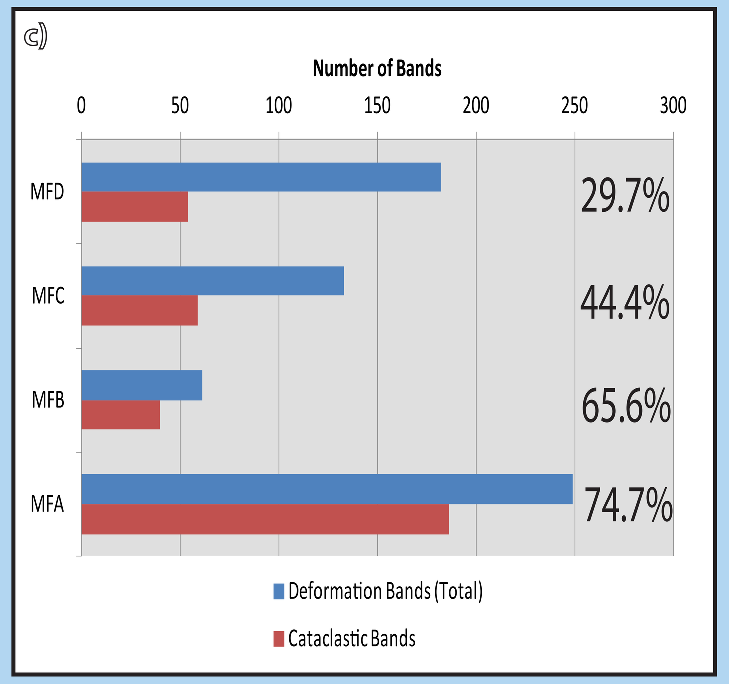




Figure 5 - All stereonets represent contoured poles to planes of all, average orientations are in black, kamb contoured with an interval of 2σ and significance level of 3σ; a) all measured deformation bands; b) all measured cataclastic deformation bands; c) Histogram comparing quantity of all deformation bands vs only cataclastic bands, plotted in descending stratigraphic order, values are % of total bands that are cataclastic; d) all measured foliations in the basement; e) all measured dravite veins across all holes in the sandstone; f) all measured druzy quartz veins across all holes in the sandstone.

## 7 Paleo-Stress Analysis

1. The three main faults of the C1 trend (oriented 020°/50°) show reverse displacement with related offset of the unconformity.

2. The deformation bands have three main orientations, two of which (NE – 074°/57° and NW – 324°/65°) have a conjugate relationship (~70°), allowing derivation of the stress field. The maximum stress bisects the two conjugates (σ1 44->286); the intermediate stress occurs at their intersection (σ 2 45->116) and the minimum stress is situated in the M-plane at 90° to σ1 (σ3 05->021).

3. As can be seen in Fig. 8 which shows the typical stress fields associated with reverse and strike-slip faulting (Fossen, 2016), the stress fields for the reverse fault movement and the deformation bands are incongruent.

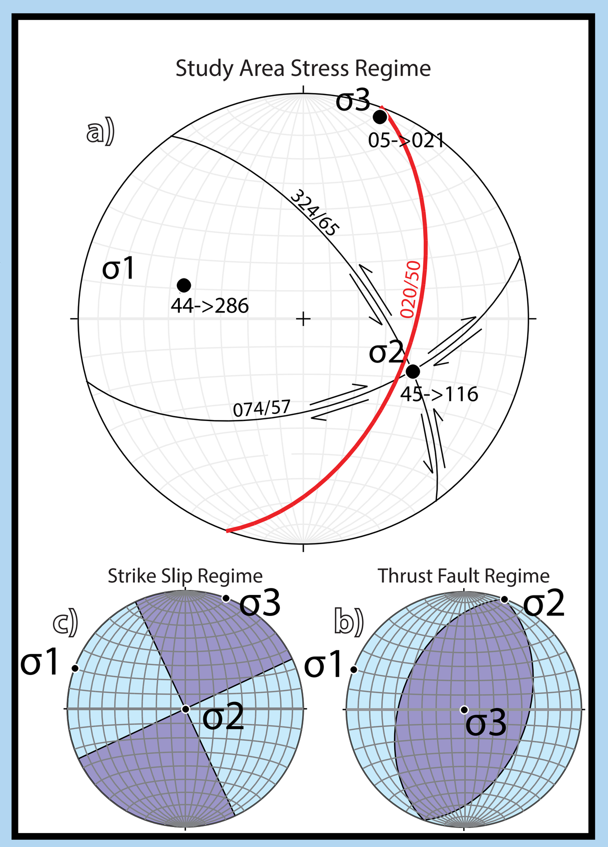



Figure 6 - a) Stereonet of major trends found within the study area, black lines show strike and dip of major deformation band. The red line shows orientation of the C1 trend; b) Stress field associated with reverse faulting modified after Fossen (2016); c) Stress field associated with a strike slip fault modified after Fossen (2016).

## 8 Preliminary Results

1. Three different styles of deformation bands were observed: compaction, shear, and cataclastic.
2. Deformation bands observed conform to three major trends:
   a. A subhorizontal trend 286°/11°
   b. A northeast trend 074°/57°
   c. A northwest trend 324°/65°
3. The northeast- and northwest-trending sets appear to have a conjugate relationship.
4. The three deformation band trends are apparent within each sandstone formation, but abundance of bands fluctuates, with MFD and MFA having the greatest number.
5. With increasing depth, cataclastic bands become more abundant.
6. From the basement, C1 faults appear to project into the sandstone where they are marked by zones of chalky, friable rock interpreted as fault gouge.
7. Druzy quartz veins define the same conjugate relationship as the general population of deformation bands whereas dravite veins preferentially occur along the northeast trend.
8. Foliation orientations (026°/60°) in the basement rocks adhere closely to the orientation of the three main faults of the C1 trend (020°/50°; Offset Fault, Gryphon Fault, and Basal Fault), with the faults collectively displaying reverse displacement in a step-wise pattern.
9. The conjugate relationship between the deformation bands is incompatible with the development of a reverse/thrust fault. Based on Anderson's Theory (Anderson, 1951) the stress regime (σ1 44->286°; σ2 45->116; σ3 05->021) is more indicative of strike-slip faulting. It is therefore highly likely that a SE-dipping, pre-existing, basement-rooted fault zone was reactivated after sandstone deposition under a new stress regime (inferred from the conjugate set).

## 9 Future Work

1. Thin section petrography will be undertaken to investigate the mechanisms and processes at work during the formation of the deformation bands, and their relationship to the surrounding host rocks.
2. Attention will be directed towards evaluating the relative timing and contrasting orientations between different types of bands and other fault related structures, i.e., compaction versus cataclastic, dravite versus druzy quartz etc.
3. The paleostress field derived above implies reverse-dextral-oblique displacement coupled with reverse-sinistral-oblique displacement on the respective conjugates (NE-trending and NW-trending). Further analysis is required to determine if offset observed in bands in the field is compatible with these predicted displacements.

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4) Cameco Corp., Denison Mines Corp., and Orano for allowing access to cores and data pertaining to the Mann Lake project.
5) Denison Mines Corp., and Japan-Canada Uranium Co. Ltd. for allowing access to cores and data pertaining to the Wheeler River project.
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