Petrogenesis of granitoid rocks of the southwestern Rae Province

M. Cloutier[1], K. Bethune[1], K. Ashton[2]

[1]Department of Geology, University of Regina. Regina, Sk. [2]Saskatchewan Geological Survey, Ministry of the Economy. Regina, Sk.

1. Introduction and Purpose

Historically, the southern Rae has been considered a single cratonic block bounded to the east by the Snowbird Tectonic Zone and to the west by the 2.02 – 1.91 Ga Taltson – Thelon orogen (Hoffman, 1988). However, evidence has accumulated that a vast tract of the western Rae was affected by significant pre-Thelon orogenic event, the 2.5–2.3 Ga Arrowsmith orogeny. The western Rae thus has a longer tectonic history than originally thought and potentially contains older (internal) suture zones that have been obscured by subsequent Thelon-Taltson orogenesis. In the WSW Rae in Saskatchewan, the Nolan-Zemlak domain boundary, juxtaposing highly magnetic granodiorites and derived gneisses of the Zemlak domain (Ashton et al., 2007, Ashton et al., 2014, Van Schmus et al., 1986) against weakly deformed, dominantly ~2.6 Ga granitoid rocks of the Nolan domain potentially represents such a structure.

Aside from a locus high-strain, U-Pb geochronology undertaken to date indicates that this boundary delineates a significant change in the spatial distribution of granitoid rock suites across this region. For example, with rare exceptions, ~2.6 Ga granitoid rocks are restricted to the Nolan domain north of the boundary. In contrast, an older Paleo- to Mesoarchean component variously intermixed with early Paleoproterozoic metaplutonic gneisses of two ages (~2.5 and ~2.3 Ga) characterize the more varied Zemlak domain and correlative rocks of the Beaverlodge domain to the south. Arrowsmith orogenesis is therefore hypothesized (e.g., Ashton et al., 2015) to have involved accretion of a Paleo- to Mesoarchean block, now embedded within the Zemlak-Beaverlodge domain and effectively representing the extension of Taltson basement complex to the west, to a 'proto-Rae' cratonic nucleus dominated by ~2.6 Ga granitoid rocks. The Nolan-Zemlak domain boundary, marking this older internal suture zone, was later severely reworked during 2.0–1.9 Ga Thelon-Taltson orogenesis when a regionally extensive suite of ~1.9 Ga leucogranites, ascribed to crustal anatexis, was emplaced across it.

This study aims to gain a better understanding of the nature of this boundary and test the suture hypothesis through study of the lithological, geochemical and isotopic characteristics of the various granitoid suites at both the regional and local scale. The study will investigate an archival collection of geochemical and isotopic analyses from the SGS. These data, which form the bulk of this poster, will be complemented by investigation of newly collected samples from a field transect across the boundary zone at Tazin Lake.

The primary goal of this research is to better define the igneous petrogenesis and the tectonic setting of emplacement of each suite and evaluate if there are fundamental differences that bear on the existence of an Arrowmith-age suture. Particular attention will be focused on the early Paleoproterozoic granitoids of Zemlak domain. Previous work indicates that the ~2.3 Ga suite was emplaced a syn- to post-collisional setting (Hartlaub et al. 2007); however, very little is known about the chemical and isotopic characteristics of the somewhat older (~2.5 Ga) suite. Archival and new samples of this vintage will therefore be explored to determine if their characteristics are compatible with a subduction-related origin, and, coupled with knowledge of the isotopic characteristics of other suites, to evaluate subduction polarity and how orogenesis may have proceeded until emplacement of 2.3 Ga (syn- to post-collisional) suite.

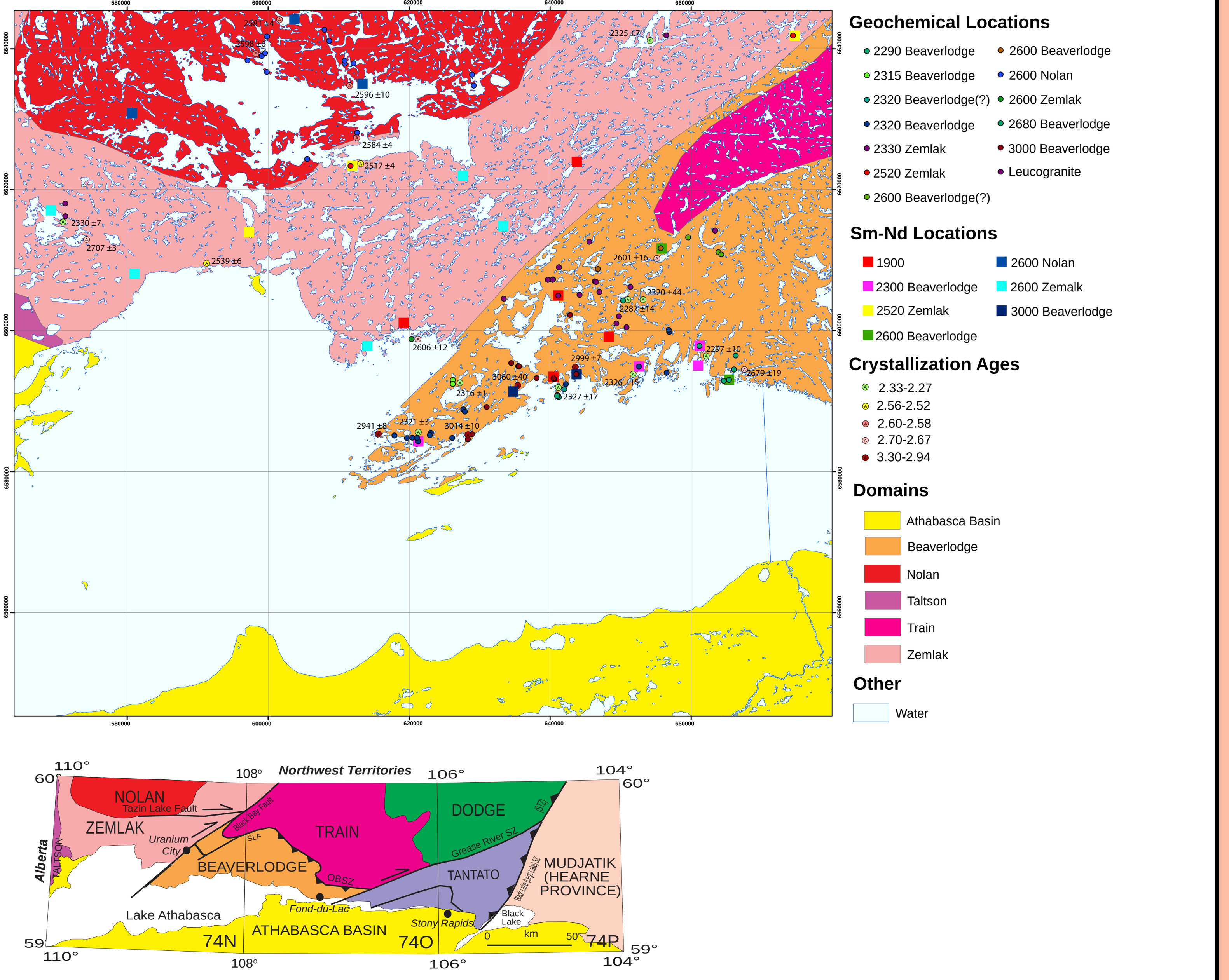

Geochemical Locations
2290 Beaverlodge
2600 Beaverlodge
2315 Beaverlodge
2600 Nolan
2320 Beaverlodge(?)
2600 Zemlak
2320 Beaverlodge
2680 Beaverlodge
2330 Zemlak
3000 Beaverlodge
2520 Zemlak
Leucogranite
2600 Beaverlodge(?)
Sm-Nd Locations
1900
2600 Nolan
2300 Beaverlodge
2600 Zemalk
2520 Zemlak
3000 Beaverlodge
2600 Beaverlodge
Crystallization Ages
2.33-2.27
2.56-2.52
2.60-2.58
2.70-2.67
3.30-2.94
Domains
Athabasca Basin
Beaverlodge
Nolan
Taltson
Train
Zemlak
Other
Water
Northwest Territories
NOLAN
ZEMLAK
TRAIN
DODGE
BEAVERLODGE
TANTATO
MUDJATIK (HEARNE PROVINCE)
Alberta
Lake Athabasca
ATHABASCA BASIN
74N
74O
74P

Figure 1: A) Geological domain map of northwest Saskatchewan. Locations of geochemical samples, Sm – Nd samples and crystallization ages are plotted. B) Lithotectonic map of northern Saskatchewan showing domains of the southern Rae province (Ashton et al., 2005).

2. Geochemistry

Figure 2

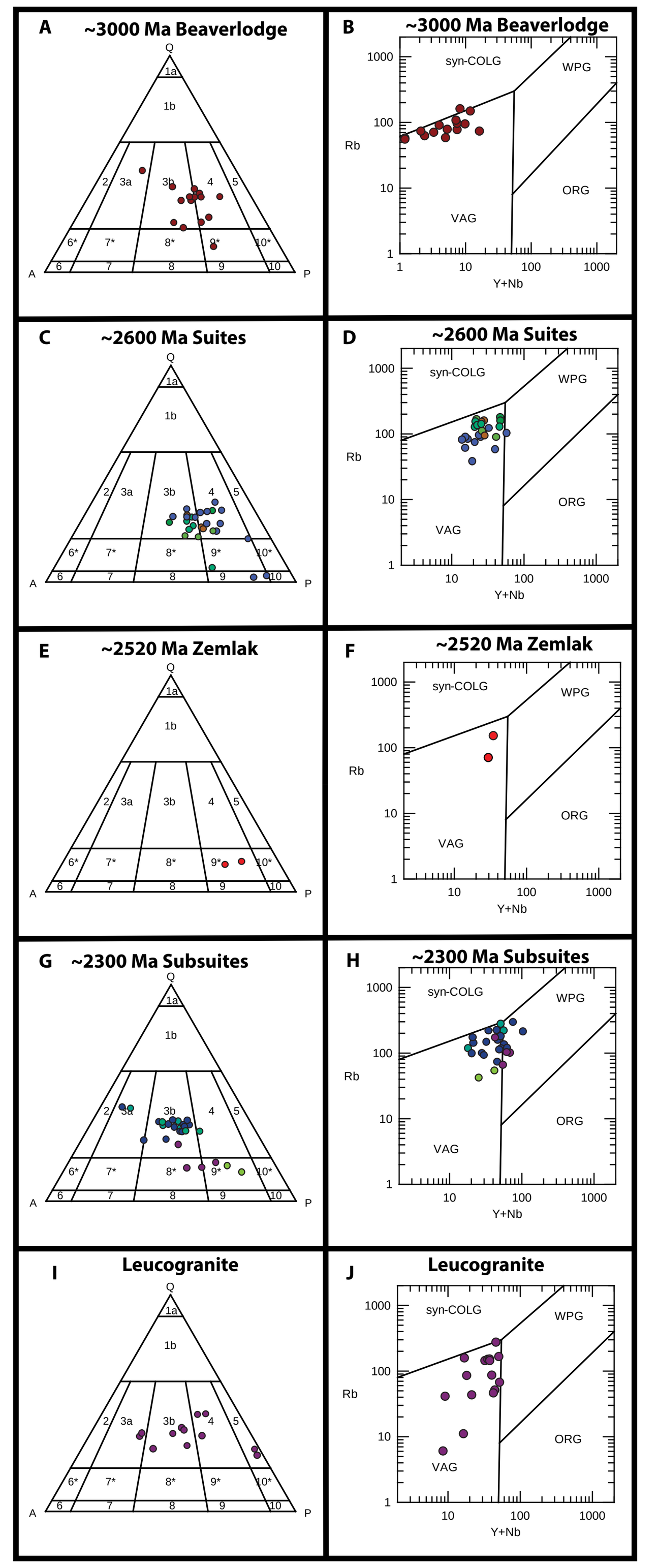
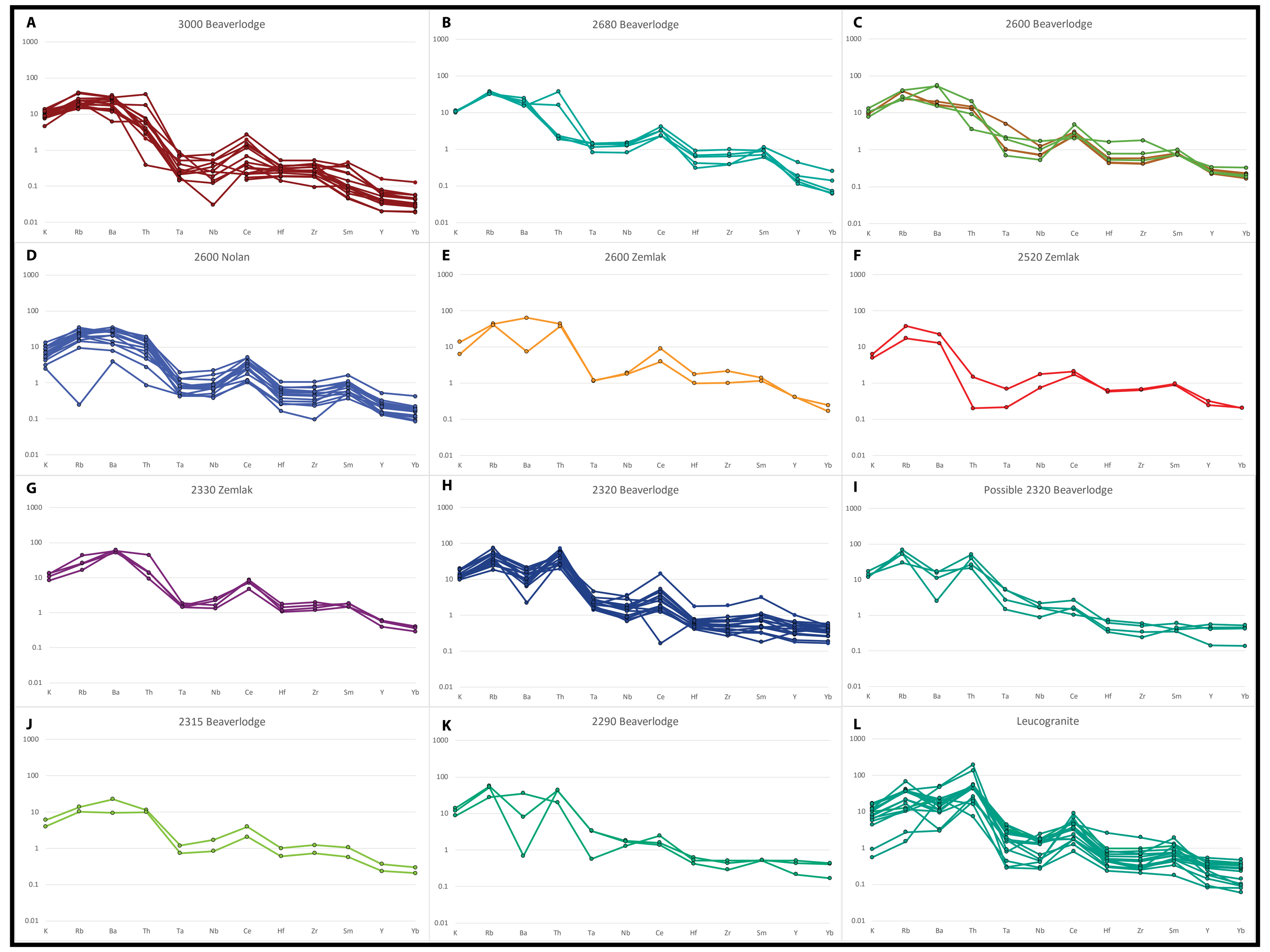


Figure 3



- 2290 Beaverlodge
- 2600 Beaverlodge
- 2315 Beaverlodge
- 2600 Nolan
- 2320 Beaverlodge(?)
- 2600 Zemlak
- 2320 Beaverlodge
- 2680 Beaverlodge
- 2330 Zemlak
- 3000 Beaverlodge
- 2520 Zemlak
- Leucogranite
- 2600 Beaverlodge(?)

Figure 4: Symbols for geochemical charts.

Figure 2 Left: QAP diagrams and tectonic distimigraion diagrams (Pearce et al., 1984) of suites from across the southern Rae. 2A & 2B) ~3000 Ma suite 2B & 2D) ~2600 Ma suites 2E & 2F) ~2520 suite 2G & 2H) ~2300 Ma suites 2I & 2J) Leucogranite.

Figure 3 Above: Spider diagrams normalized to ocean ridge granite (Pearce et al., 1984). A) 3000 Ma Beaverlodge B) 2680 Ma Beaverlodge C) 2600 Ma Beaverlodge D) 2600 Ma Nolan E) 2600 Ma Zemlak F) 2520 Ma Zemlak G) 2330 Ma Zemlak H) 2320 Ma Beaverlodge I) Possible 2320 Beaverlodge J) 2315 Ma Beaverlodge K) 2290 Ma Beaverlodge L) leucogranite of unknown age

Samples were divided into the various suites based on their field and petrographic characteristics. The analyses were plotted on an IUGS QAP diagram, on spider diagrams normalized against a hypothetical ocean ridge granite composition (Pearce et al., 1984) and on the Y+Nb versus Rb tectonic discrimination diagram of Pearce et al. (1984)

The ~3000 Ma Beaverlodge suite is enriched in K, Rb, Ba and Th while being depleted in Y and Yb, characteristics typical of a volcanic arc setting (Figure 3A). The suite also plots in the volcanic arc area of the Y+Nb versus Rb tectonic discrimination diagram (Figure 2B).

The ~2680 Ma Beaverlodge suite is enriched in K, Rb, Ba and Th, with Ba slightly depleted relative to Rb and Th. The suite is also depleted in Y and Yb when normalized against ocean ridge granite, suggesting a volcanic arc or syn-collisional tectonic setting (Figure 3B). Samples plot on the boundary between volcanic arc and syn-collisional type granites (Figure 2D).

The ~2600 Ma Beaverlodge suite has the enriched K, Rb, Ba and Th, coupled with depleted Y and Yb, typical of a volcanic arc (Figure 3C); however, on the tectonic discrimination diagram analyses lie near the triple point of volcanic arc, syn-collisional and within-plate granite, suggesting a syn to post-collisional setting (Figure 2D).

The ~2600 Ma Nolan suite is characterized by enrichment in K, Rb, Ba, Th and Ce and depletion in Y and Yb associated with volcanic arc granites (Figure 3D). The analyses also plot well within the volcanic arc portion of the tectonic discrimination diagram (Figure 2D).

The ~2600 Ma Zemlak suite also displays enriched K, Rb, Ba and Th and depleted Y and Yb typical of a volcanic arc (Figure 3E); however, on the tectonic discrimination diagram it is situated near the triple point of volcanic arc, syn-collisional and within-plate granite, in keeping with a syn to post-collisional setting (Figure 2D).

The ~2520 Ma Zemlak suite displays enriched K, Rb and Ba as well as the depleted Y and Yb typical of a volcanic arc environment, but shows an anomalous depletion in Th, differentiating it from the ~2600 Nolan suite (Figure 3F). The suite plots well within the volcanic arc portion of the tectonic discrimination diagram (Figure 2F).

The ~2.3 granite suite, encompassing ages from 2330 to 2290 Ma, was sub-divided into a number of 'sub-suites' on the basis of slight differences in character that appear to correlate with location and (or) age.

The ~2330 Ma Zemlak sub-suite of the 2.3 Ga granite suite is enriched in K, Rb, Ba, Th and Ce but depleted in Y and Yb which is typical of volcanic arcs (Figure 3G); however on the tectonic discrimination diagram it plots near the triple point of volcanic arc, syn-collisional and within-plate granite, suggesting a syn- to post-collisional setting (Figure 2H).

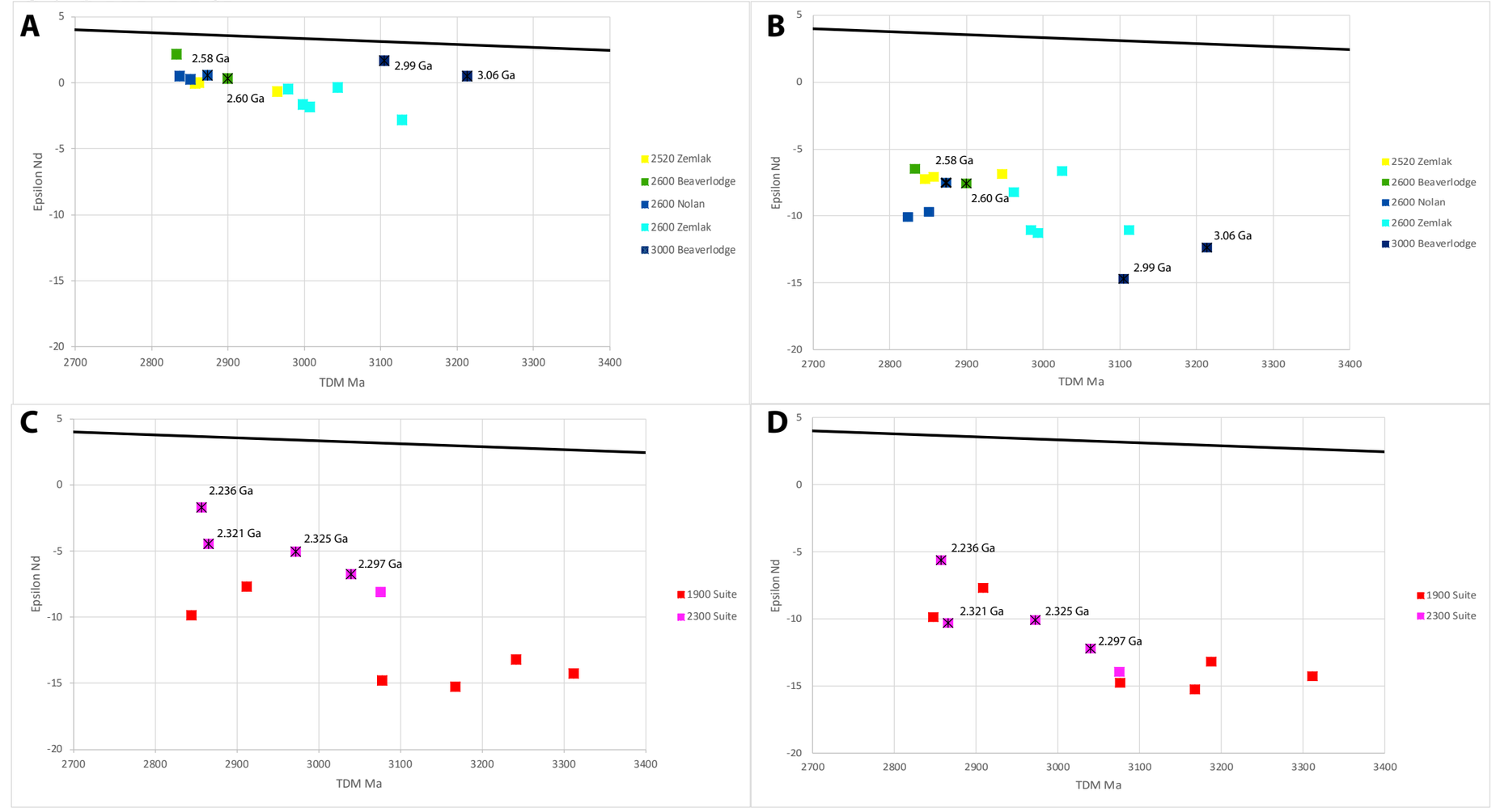
The ~2320 Ma Beaverlodge sub-suite is enriched K, Rb, and Th with a relative depletion of Ba (Figures 3H & 3I). The analyses plot near the triple point of the tectonic discrimination diagram diagnostic of a syn- to post-collisional tectonic setting (Figure 2H).

The ~2315 Ma Beaverlodge sub-suite has enriched K, Rb, Ba and Th associated with volcanic arc and collisional environments (Figure 3J).

The ~2290 Ma Beaverlodge sub-suite has enriched K, Rb, and Th, along with highly variable Ba (Figure 3K). On the tectonic discrimination diagram (Figure 2H), two of the analyses plot at the triple point of volcanic arc, syn-collisional and within-plate granite, whereas the third analysis plots well within the volcanic arc setting, suggesting a syn- to post-collisional environment.

The leucogranites of unknown age, but suspected to be Taltson-related (~1900 Ma; Ashton et al., in press), tend to show more variability in composition. General trends are: 1) an enrichment of K, Rb, and Th with a slight depletion of Ba relative to Rb and Th; and 2) an overall depletion of Y and Yb consistent with within-plate granites derived from attenuated crust (Figure 3L). The leucogranites plot within the volcanic arc granite area as well as along the boundaries of the within-plate granite and syn-collisional granite fields (Figure 2J).

3. Sm-Nd



The author investigated twenty-four currently available Sm-Nd analyses from across the region. TDM ages and εNd values are presented in Figure 4. εNd values are calculated for both crystallization age (Figures 5a, 5c; Ashton et al., 2007, Ashton et al., 2014, Hartlaub et al., 2005, Bethune et al., 2013), and at a common age of 1900 Ma (Figures 5b, 5d).

Neoarchean (~2600 Ma) samples from the Nolan domain have TDMs of 2900 Ma or less and juvenile crystallization age - εNd values that are slightly positive, whereas Archean samples from the Zemlak and western Beaverlodge domains have TDMs greater than 2950 Ma and crystallization age - εNd values that are: 1) slightly positive for the 3000 Ma Beaverlodge suite; and 2) slightly negative for the 2600 Ma Zemlak suite. Samples from the ~2520 Ma Zemlak suite have slightly negative εNd values at their crystallization age and TDMs ranging from 2970 Ma to 2850 Ma, consistent with minor crustal contamination. Both the ~2300 Ma samples and the ~1900 Ma samples have TDMs ranging from ~3300 Ma to ~2850 Ma and negative εNd values, consistent with large amounts of crustal contamination.

Figure 5: TDM ages plotted against calculated epsilon Nd values. Symbols marked with black star indicate samples of known age. Black line shows feplted mantle based on Goldstein et al., 1984. 5a & 5c) Epsilon Nd values calculated at crystallization ages of the individual suites. 5b & 5d) Epsilon Nd values calculated at 1900 Ma.

4. Occurence of Ultramafic Rocks

Ashton et al., 2005 identified a suite of ultramafic and associated gabbroic rocks on an island between Laird Island and the southern shore of Tazin Lake (see Deane et al., this session). These rocks were mapped as an intrusive unit of unknown age within the Nolan granite. New mapping undertaken during the 2016 field season has found this suite to be in contact with both a highly magnetic ~2520 Ma gneissic granodiorite of the Zemlak Domain to the southeast and a mylonitized ~2600 Ma Nolan granite to the northwest. The suite grades from a massive course-grained pyroxenite(?) at the center outwards into a weakly foliated fine- to medium-grained gabbro/diorite. The contact with adjacent granitoid units (Nolan, Zemlak) are highly deformed casting doubt on its interpretation (e.g., Ashton et al., 2005) as an intrusive unit. Geochemical samples of the ultramafic unit and the outer gabbroic rocks, as well as a geochronological sample of gabbro along the northwest contact, were collected for further investigation into the source of the suite.

5. Preliminary Findings:

- The 3000 Ma Beaverlodge granites have an arc-like geochemical signature with positive εNd indicating juvenile crustal production.
- The ~2600 Ma Nolan suite is characterized by an arc-type signature with negative εNd indicating juvenile crustal production. It is distinguished from the adjacent 2600 Ma Zemlak granitoids that have post-collisional geochemical signatures, older TDMs and more evolved εNd values and from the 2520 Ma Zemlak granodiorites that have more evolved εNd values.
- Geochemical analysis of the 2520 Ma samples suggest that the respective granitoids were emplaced in a volcanic arc setting. εNd values calculated for time of crystallization are slightly negative, implying minor crustal contamination of the melt.
- Analyses of the ~2300 Ma samples agrees with previous interpretations (e.g. Hartlaub et al., 2007) that the granitoids were emplaced in a syn- to post-collisional tectonic setting. εNd values calculated at time of crystallization are negative, indicating an evolved source with crustal influence.
- The leucogranites of suspected Taltson-age (~1900 Ma) are more highly variable in composition but the general trends (enrichment of K, Rb, and Th with a slight depletion of Ba relative to Rb and Th; depletion of Y and Yb) are consistent with within-plate granites derived from attenuated crust. The leucogranites plot within the volcanic arc granite area as well al along the boundaries of within-plate granite and syn-collisional granite. TDM ages range from 3310 Ma to 2840 Ma Ga suggesting melting of multiple sources. εNd values calculated at 1900 Ma (late Taltson) indicate an evolved system consistent with anatectic melting.
- A distinctive body of ultramafic and related gabbroic rocks situated right along the Nolan – Zemlak boundary requires further geochemical, isotopic and geochronological characterization.

6. Future Work:

33 new samples acquired during the 2016 field season have been sent for whole-rock geochemical analysis, along with corresponding samples for thin-section study. These will be analyzed to further define igneous petrogenesis and the tectonic setting of emplacement of the suites along the Nolan – Zemlak boundary.

Zircon mounts of 7 archival samples, that have been previously dated using the SHRIMP method, will be reanalyzed using a laser ablation split stream inductively coupled plasma mass spectrometry (LASS-ICPMS) technique for new U-Pb and Lu-Hf measurements. The U-Pb and Lu-Hf measurements will be used to further constrain the degree of crust-mantle interaction.

Four samples from different map units were selected this summer for geochronological testing. These four samples are:

- A previously undocumented grey gneiss (Figures 6A and 6B) located in Abitau Bay well inboard of the Nolan – Zemlak boundary. The gneiss is of tonalitic - granodioritic composition with a well-defined gneissosity. The grey gneiss is located within relatively undeformed megacrystic granitoids of the Nolan domain.
- A mylonitic granite from the southern shore of Tazin Lake (Figures 6C and 6D) inferred to be of Nolan affinity. This mylonitic granite is directly adjacent to the newly mapped Nolan – Zelmak boundary (See Deane et al., 2016).
- A leucogranite located on southern Laird Island (Figures 6E and 6F) (within the mylonitic portion of the Nolan domain that displays little to no ductile deformation.
- A gabbroic unit of the mafic – ultramafic suite found directly in contact with both Nolan granites and Zemlak granodiorites. Previous mapping of the region interpreted this suite to be intrusive, but newly mapped field relationships call this relationship into question.

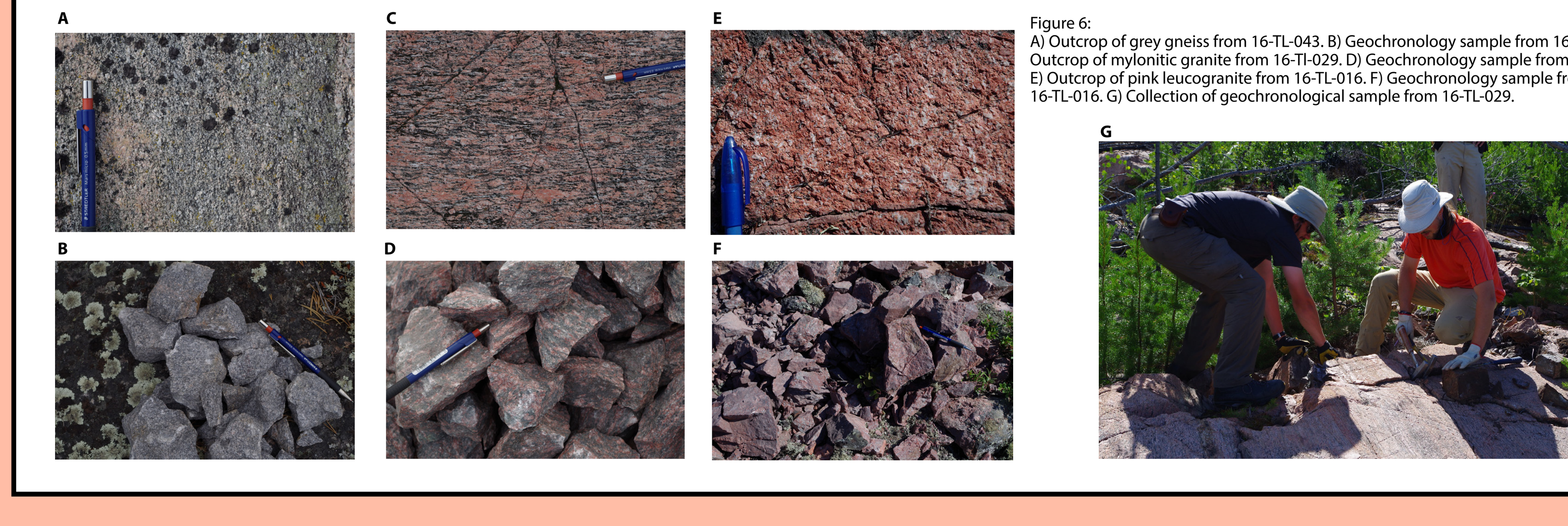


Figure 6:
A) Outcrop of grey gneiss from 16-TL-043. B) Geochronology sample from 16-TL-043. C) Outcrop of mylonitic granite from 16-Tl-029. D) Geochronology sample from 16-TL-029. E) Outcrop of pink leucogranite from 16-TL-016. F) Geochronology sample from 16-TL-016. G) Collection of geochronological sample from 16-TL-029.

7. References:
Ashton, K.E., Card, C.D., Modeland, S., (2005). Geological reconnaissance of the north-ern Tazin Lake map area (NTS 74N), including parts of the Ena, Nolan, Zemlak, and Taltson domains, Rae Province. Summary of Investigations 2005, vol. 2. Saskatchewan. Geological. Survey. Sask. Industry Resources, Misc. Rep. 2005-4.2. Pap. A-1, 24.
Ashton, K.E., Card, C.D., Davis, W., Heaman, L.M. (2007). New U-Pb zircon age dates from the Tazin Lake map area (NTS 74N). Summary of Investigations 2007, vol. 2. Saskatchewan Geological Survey, Saskatchewan Ministry of Energy and Resources, Misc. Rep 2007-4.2, Paper A-11, 8.
Ashton, K.E., Rayner, N.M., Bethune, K.M. (2009). Meso- and Neoarchean granitic magmatism, Paleoproterozoic (2.37 Ga and 1.93 Ga) Metamorphism and 2.17 Ga provenance ages in a Murmac Bay group pelite; U-Pb SHRIMP ages from the Uranium City area. Summary of Investigations 2009, vol. 2. Saskatchewan Geological Survey, Sask. Ministry of Energy and Resources, Misc. Rep. 2009-4.2, Paper A-5, 9.Ashton, K.E., Rayner, N.M., Heaman, L.M., Creaser, R.A. (2014). New Sm-Nd and U-Pb ages from the Zemlak and south central Beaverlodge domains: a case for amalgamated Taltson basement complex and proto-Rae cratonic blocks within the Rae Province of northwestern Saskatchewan. Summary of Investigations 2014, vol. 2. Saskatchewan Geological Survey, Sask. Ministry of the Economy, Misc. Rep. 2014-4.2, Paper A-6, 28.
Bethune, K., Berman, R., Rayner, N., Ashton, K., (2013). Structural, petrological and U-Pb SHRIMP geochronological study of the western Beaverlodge domain: Implications for the crustal architecture, multi-stage orogenesis and the extent of the Taltson orogen in the SW Rae craton, Canadian Shield. Precambrian Research. 232. 89–118.
Hartlaub, R.P., Chacko, T., Heaman, L.M., Creaser, R.A., Ashton, K.E., Simmonetti, T. (2005). Ancient (Meso- to Paleoarchean) crust in the Rae Province, Canada: evidence from Sm-Nd and U-Pb constraints; Precambrian Research., vol. 141, p 137-153
Hoffman, P.F. (1988). United Plate of America, the birth of a craton: Early Proterozoic assembly and growth of Laurentia. Annual Reviews in Earth and Planetary Science. 16. 545-603
Van Schmus, W.R., Persons, S.S., Macdonald, R., Sibbald, T.I.I. (1986). Preliminary results from U-Pb zircon geochronology of the Uranium City region, northwestern Saskatchewan. Summary of Investigations 1986. Saskatchewan Geological Survey, Sask. Energy Mines, Misc. Rep. 86-4, p108-111

8. Acknowledgements:
This project is funded by an NRCANADA GEM-2 Research Grant provided to Dr. K. Bethune. I would like to sincerely thank the Saskatchewan Geological Survey for providing knowledge, data, and technical assistance related to this project.