A Geochemical and Petrological Comparison of Felsic Igneous Rocks from the Beaulieu River Volcanic Belt, Northwest Territories (NTS 16/85I)

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Introduction

The Beaulieu River volcanic belt is located approximately 110 km NE of Yellowknife, Northwest Territories in the Archean Slave craton. The study area is composed of rocks of the Beaulieu Group and the Amacher Granite[1,2]. Plutonism related to the Amacher Granite has a proposed spatio-temporal and cogenetic relationship with felsic volcanics of the Beaulieu River volcanic belt[1,2]. To test if the Amacher Granite served as the upper-crustal volcanic plumbing system responsible for the Neoarchean volcanism that produced felsic volcanics of the Beaulieu Group, rhyolites of the volcanic belt, the Amacher granite, and felsic dykes were investigated. Field relationships, petrography, and whole rock major oxide and trace element geochemistry of thirteen samples were compared.

Regional and Local Geology

The Slave craton is an Archean craton located in northwestern Canada[3,4,5]. Rocks of the ca. 3.0-2.8 Ga Central Slave Basement Complex including the Sleepy Dragon Complex, reflect tonalite-trondhjemite-granodiorite plutonism[4]. Overlying the Central Slave Basement Complex is a 2.85-2.80 Ga volcaniclastic and clastic cover sequence termed the Central Slave Cover Group[5]. Numerous volcanic were subsequently deposited between 2.73-2.66 Ga[1,5,6]. The Yellowknife Supergroup consists of the basal Kam Group (2.73-2.70 Ga mafic volcanic flows and minor felsic volcanic horizons), the bimodal Banting Group (2.69-2.66 Ga calc-alkaline felsic and mafic volcanic rocks), and the Duncan Lake Group (2.67-2.61 Ga thick greywacke-mudstone packages) which includes the Burwash Formation[5,6]. Volcanic packages from all over the Slave, including the Beaulieu Group, are considered to be the equivalents to the Kam and Banting Groups[1,2]. A number of plutonic suites intruded greenstone belt supracrustal rocks across the Slave craton, including the 2.70-2.66 Ga synvolcanic granitoids, the 2.64-2.62 Ga Defeat Suite rocks, the 2.62-2.61 Ga Concession Suite rocks, and the 2.60-2.58 Ga Prosperous-Morose Suite granites[5] (Figure 1).

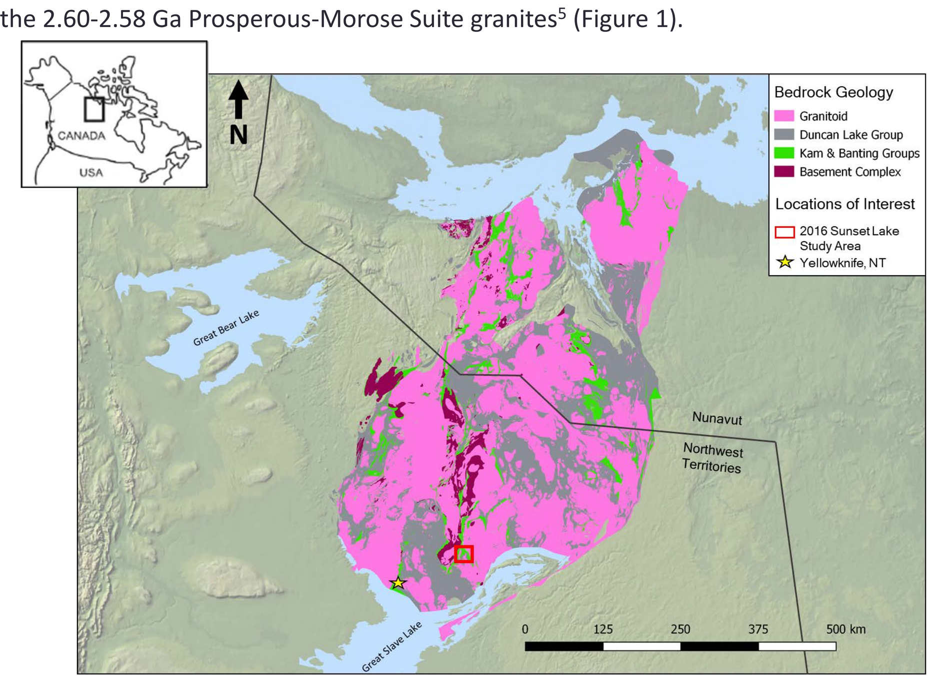

Fig 1. Simplified geological map of the Archean Slave craton, Northwest Territories and Nunavut, Canada modified from Stubley (2005). A yellow star denotes the location of the city of Yellowknife, Northwest Territories. A red square shows the approximate extent of the 2016 Sunset Lake study area.

The Beaulieu River volcanic belt contains a variety of volcanic rocks, ranging from basalt, to dacites, rhyolites, and variable volcaniclastic deposits all belonging to the Beaulieu Group[1,2]. Lambert (1988) proposed that the development of the Beaulieu River volcanic belt required a number of phases, including (i) the simultaneous extension of submerged sialic crust, regional volcanism, the emplacement of mafic dykes, as well as active sedimentation. This would be subsequently followed by (ii) the deformation of supracrustal rocks by tectonic shortening and thrusting, (iii) amphibolite grade metamorphism as a result of major fold deformation, (iv) potential granitic plutonism from the late stages of volcanism, followed by the emplacement of Proterozoic dykes, and late stage faulting[2]. Sometime during this sequence of events, uplift of the granitic basement complex resulted in the deformation of supracrustal rocks[1,2].

Analytical Methods and Techniques

Field work was conducted from July to August of 2016, and a total of thirteen hand samples were collected (Figure 2). The samples consist of the Amacher Granite, rhyolites of the Beaulieu Group and felsic dykes found within the study area. Hand samples were cut and sent to Vancouver Petrographics in Vancouver, BC to produce thin sections. For each hand sample, a sample of fresh surface rock chips was collected to be geochemically analyzed for major oxides and trace elements by Acme Labs in Vancouver, BC. Geochemistry for felsic volcanics from Sharrie and Turnback Lakes of the Tumpline Lake area of the Beaulieu River volcanic belt[7] were incorporated in this study to provide a regional comparison to rhyolites of the Beaulieu Group.

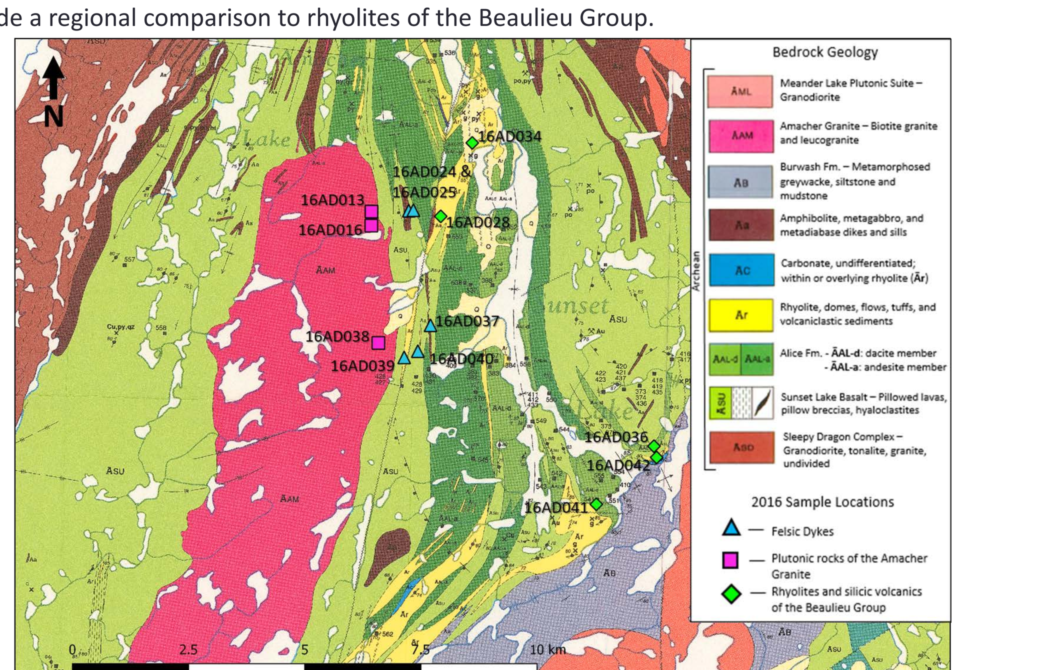

Fig. 2. Simplified bedrock geology map of the Sunset Lake area of the Beaulieu River volcanic belt, Northwest Territories, modified from Lambert (1988). 2016 sample locations are indicated by blue triangles, pink squares, and green diamonds.

Petrography and Unit Descriptions

Rhyolite & Silicic Volcanics of the Beaulieu Group

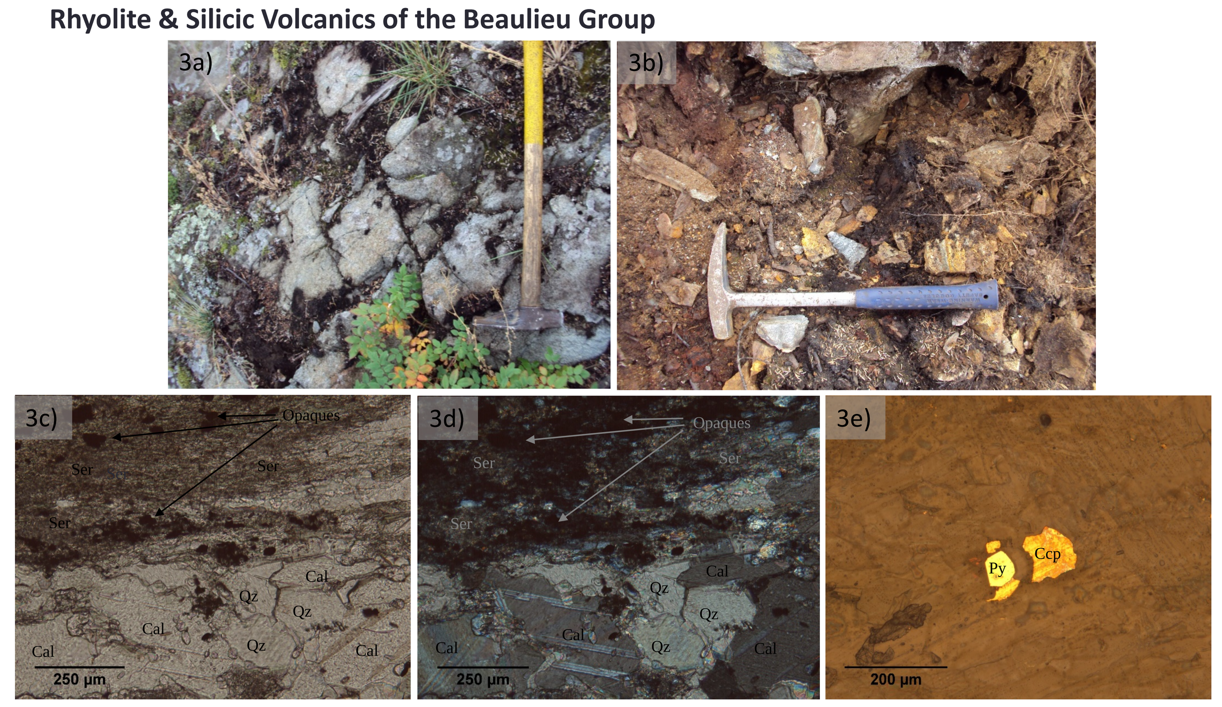

Fig 3. Rhyolite, quartz-phyric rhyolite and silicic volcanic rocks have a very fine grained matrix, are grey in colour and weather light grey to light green. Phenocrysts consist of quartz and feldspar (0.09-2.38 mm). Outcrops are massive (Fig. 3a) to well foliated. Locally, gossans can be observed (Fig. 3b). The groundmass consists of very fine grains of interlocking quartz (43-45%), K-feldspar (32-38%) and plagioclase (16-18%). About 5% of the feldspar content has been altered to sericite along grain boundaries and within fractures. Calcite crystals ranging from 0.12-0.47 mm (1-2%) are observed locally (Fig. 3c & 3d). Opaque minerals (< 2%) were observed in two of the five samples (Fig. 3c & 3d), consisting of chalcopyrite and pyrite (Fig. 3e). These rocks host volcanogenic massive sulphide (VMS) mineralization[2]. Mineral abbreviations: Bt – Biotite; Cal – Calcite; Ccp – Chalcopyrite; Kfs – K-Feldspar; Pl – Plagioclase; Py – Pyrite; Qz – Quartz; Ser - Sericite

Amacher Granite

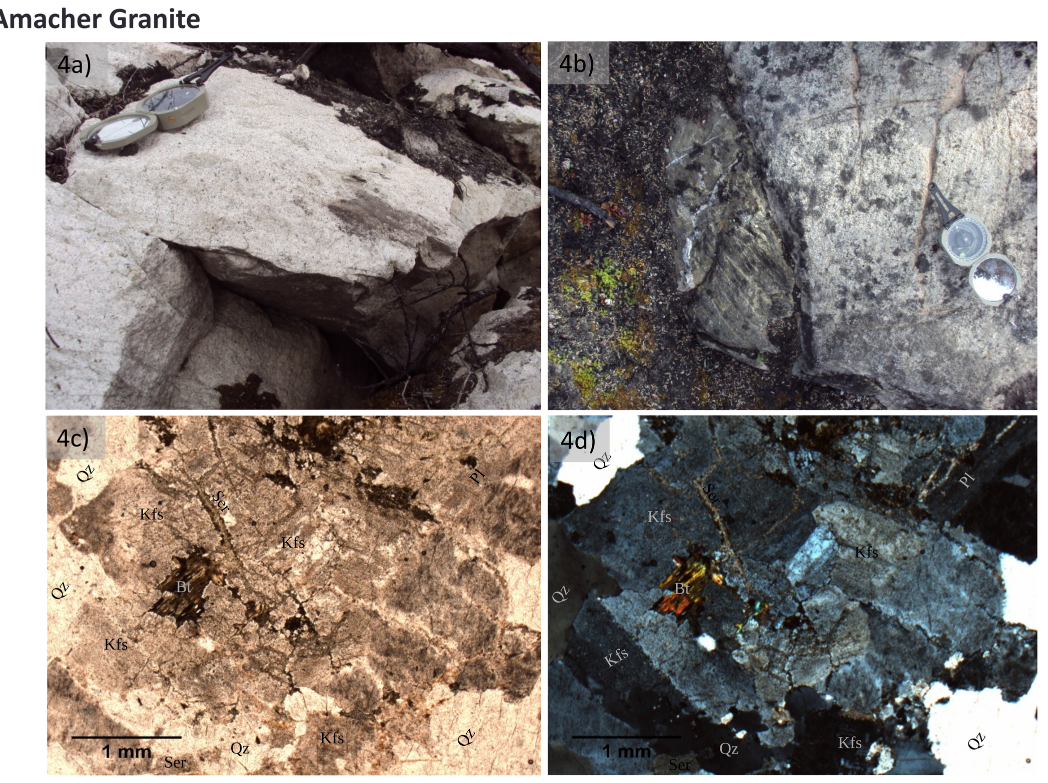

Fig 4. The Amacher Granite is a homogeneous, medium grained biotite-bearing syeno-granite or leucogranite. It has a white to light pink fresh surface and weathers to a dull grey (Fig. 4a) or pink. It is massive to weakly foliated. Outcrops have sharp intrusive contacts with the surrounding volcanics and block-sized xenoliths of country rock can be observed along the granite margins (Fig. 4b). Quartz crystals (43-46%) range in size from 0.1-5 mm and display undulatory extinction. K-feldspar crystals (34-39%) ranging in size from 0.1-4 mm exhibit perthitic textures. Plagioclase crystals between 0.1-1.5 mm (12-19%) commonly display lamellar twinning. Feldspar crystals have been altered to sericite along grain boundaries and fracture planes of feldspar grains. This unit contains 3-4% biotite (0.06-2.2 mm; Fig. 4c & 4d).

Felsic Dykes

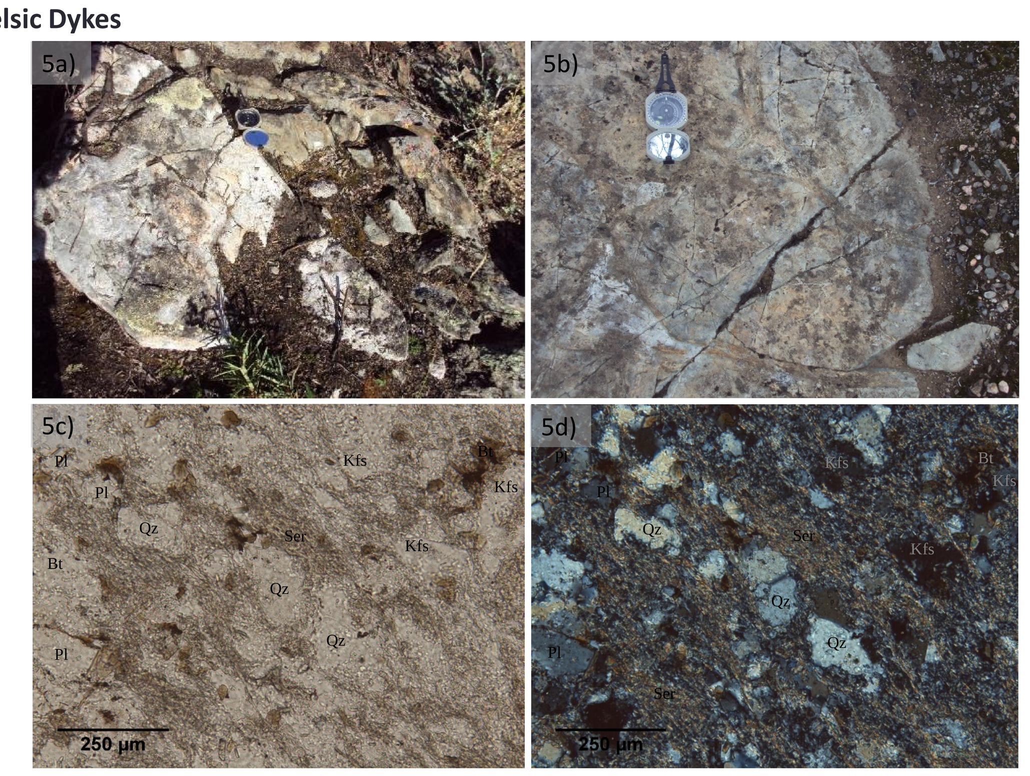

Fig 5. A series of heterogeneous quartz-feldspar porphyritic dykes cross-cut intermediate to mafic volcanics. The rocks are dark grey on the fresh surface and weather light grey to white, and locally light pink. The dykes have relatively sharp contacts with intermediate to mafic volcanics (Fig. 5a). Locally, the contacts are irregular (Fig. 5b). The dykes have a very fine grained groundmass of interlocking quartz and feldspar crystals with sericitic alteration along grain boundaries and within fractures (Fig. 5c & 5d). Quartz and feldspar phenocrysts (0.09-0.82 mm) display undulatory extinction, but feldspar grains are often mottled and lack twins (Fig. 5c & 5d). Biotite crystals (2-8%) range in size from 0.02-0.3 mm (Fig. 5c & 5d).

Geochemistry

2016 Sunset Lake Study Area Dataset, Beaulieu River Volcanic Belt, NT: Felsic Dykes; Amacher Granite; Rhyolites & Silicic Volcanics of the Beaulieu Group

Sharrie Lake and Turnback Lake Datasets, Tumpline Lake Area, Cameron-Beaulieu Volcanic Belts, NT[7]: Rhyolites of Sharrie Lake, Tumpline Lake Area; Rhyolites of Turnback Lake, Tumpline Lake Area

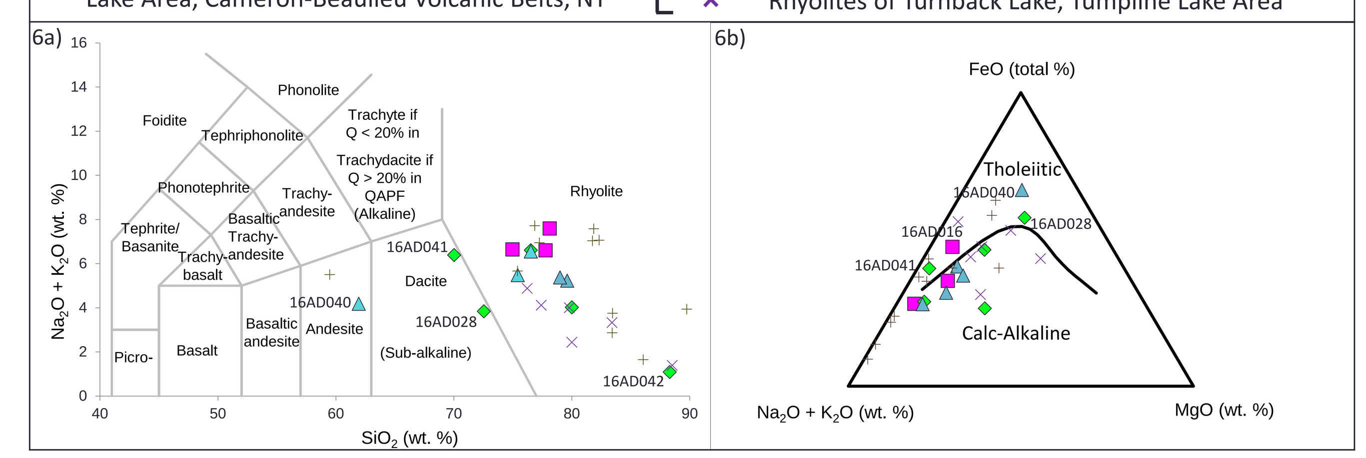

Fig. 6. 6a) Total Alkali-Silica (TAS) diagram[9] - All of the samples collected from the Sunset Lake study area plot as rhyolitic rocks with the exception of felsic dyke sample 16AD040 which compositionally plots as an andesite, and Beaulieu Group volcanic samples 16AD028 and 16AD041 which plot as dacites. **6b)** AFM (Alkali vs. FeOt vs. MgO) diagram[10] - The majority of the samples plot as calc-alkaline rocks, with the exception of felsic dyke sample 16AD040, Amacher Granite sample 16AD016, and Beaulieu Group volcanic samples 16AD028 and 16AD041 which plot as tholeiitic rocks.

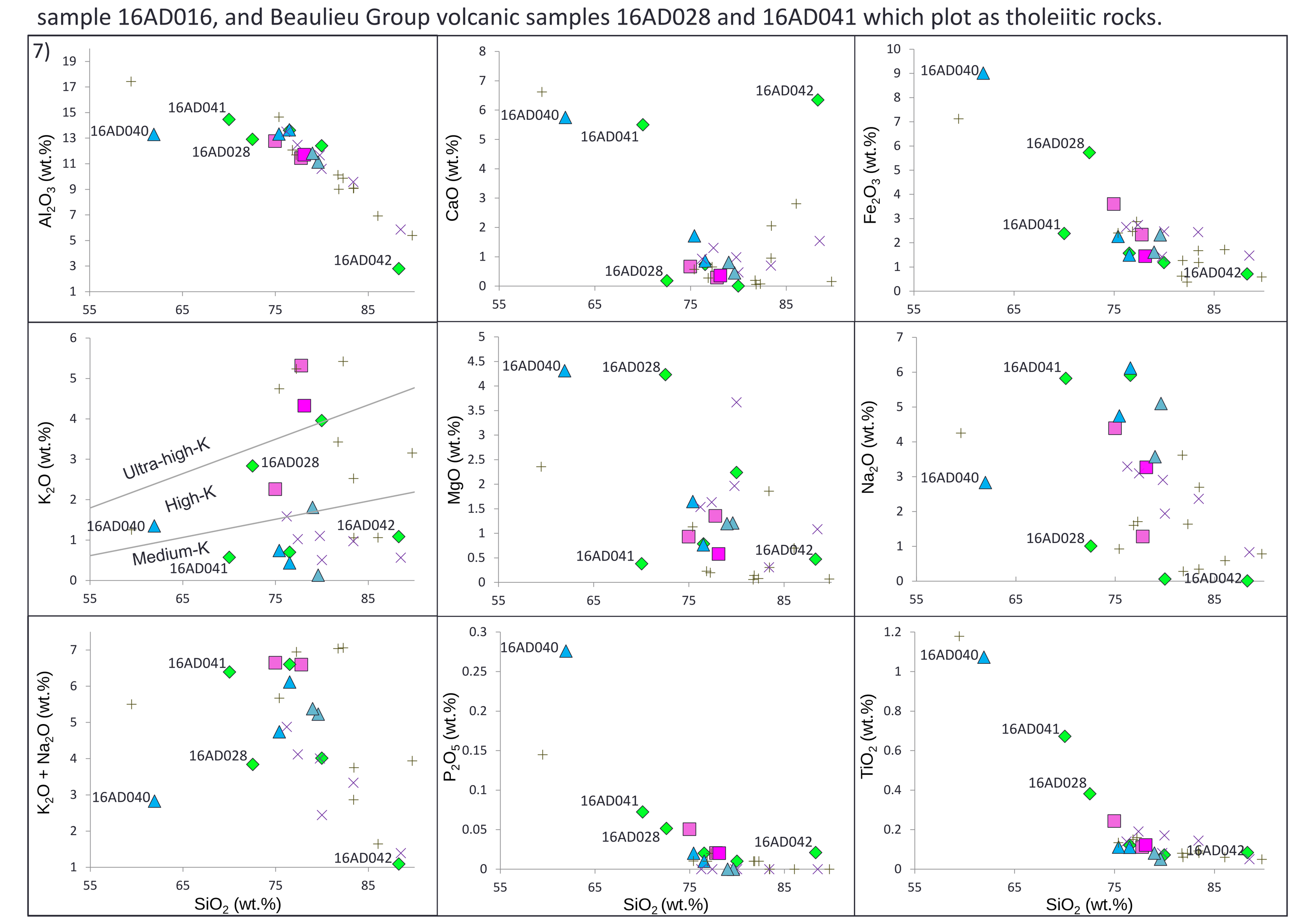

Fig. 7. A series of major oxide Harker diagrams – All of the Sunset Lake samples plot with an Al_2O_3 content of 11.0-14.5 wt. % with the exception of Beaulieu Group volcanic sample 16AD042. CaO values are typically between 0.01-1.72 wt. %, but felsic dyke sample 16AD040 and volcanic samples 16AD041 and 16AD042 contain relatively higher proportions. Fe_2O_3 values for the rocks tend to range from 0.72-3.60 wt. % with the exception of felsic dyke sample 16AD040 and volcanic sample 16AD028. The majority of samples plot with an MgO content of 0.38-2.24 wt. % except for felsic dyke sample 16AD040 and volcanic sample 16AD028. The majority of samples plot with a P_2O_5 content of 0-0.072 wt. %, with the exception of felsic dyke sample 16AD040. TiO_2 content ranges from 0.05-0.24 wt. % with the exception of felsic dyke sample 16AD040, and volcanic samples 16AD028 and 16AD041. K_2O, Na_2O and $K_2O + Na_2O$ values are relatively variable among all samples from the Sunset Lake study area.

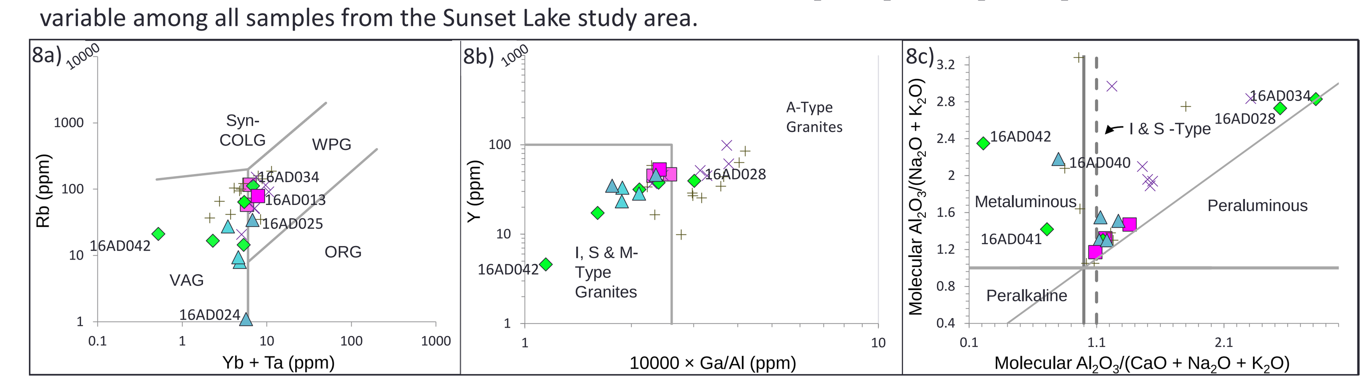

Fig. 8. 8a) Geotectonic discrimination diagram for granitic rocks[11] – The majority of Sunset Lake samples plot as volcanic arc granites (VAG), with a cluster of data points around the volcanic arc granite-within plate granite (WPG) boundary. Felsic dyke sample 16AD025, Amacher Granite samples 16AD013 and 16AD038, and volcanic sample 16AD034 plot along the WPG side of the boundary. **8b)** Granite-Type (I, S, or M vs. A) discrimination diagram[12] - All samples plot as I, S & M-Type granites with the exception of volcanic sample 16AD028. **8c)** A/NK vs. A/CNK diagram[13] – The majority of samples plot as peraluminous granites, but rhyolitic and silicic volcanic samples tend to be more variable, with two of five samples plotting as metaluminous (16AD041 and 16AD042) and two as peraluminous with much higher A/NK and A/CNK values. Felsic dyke sample 16AD040 also plots as a metaluminous granite.

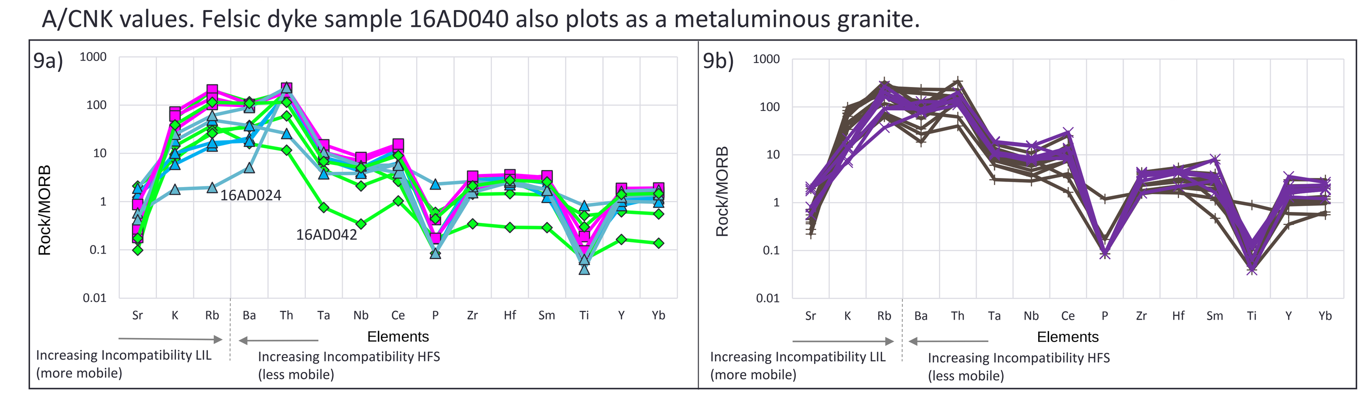

Fig. 9. Spider diagrams[14] of incompatible elements. Data has been normalized to mid ocean ridge basalt (MORB) values[15] for these diagrams – **9a)** Spider diagram of rocks from the Sunset Lake study area. All rocks have very similar trends, with the exception of felsic dyke sample 16AD024 and volcanic sample 16AD042. **9b)** Spider diagram for the Sharrie and Turnback Lakes volcanics datasets. Note the comparable trend between the study area and two additional locations.

Discussion and Interpretations

Petrographic analyses and geochemical signatures of rocks belonging to the Amacher Granite and local felsic dykes show an affinity to rhyolitic rocks of the Beaulieu River volcanic belt. This is observable through spatio-temporal relationships; comparable mineralogies, and major oxide and trace element geochemistry. This does not imply a direct relationship, as granites are considered the coarse grained intrusive equivalents to rhyolitic volcanic rocks. Geochemical trends provide insight into the ways in which these rocks may or may not be related (Table 1).

Geochemical Plot	Sample Trend	Interpretation
Rock Classification (TAS, AFM)	Predominantly rhyolite (with the exception of 16AD040, 16AD028 & 16AD041); and predominantly calc-alkaline magma series (with the exception of 16AD040, 16AD016, 16AD028 & 16AD041).	• 16AD040 → Andesitic dyke of Alice Fm. • 16AD028 & 16AD041 → Dacite of Alice Fm. • 16AD016 → Evolution from tholeiitic basalt to A-Type Granite or the assimilation of metasediments or mafic magma Tholeiitic magma series → Mid ocean ridge volcanism • Rhyolite, Amacher Granite & Felsic Dykes Calc-alkaline magma series → Subduction related volcanism → Comparable to Banting Group rocks[1]
Harker Diagrams	Comparable ranges of major oxides, with more evolved end members (rhyolites/granites) plotting with higher degrees of fractional crystallization	• 16AD040, 16AD028 & 16AD041 → Not Granitic or Rhyolitic → Ineffective indicators of a comagmatic relationship. • K_2O & Na_2O → Mobilized by alteration and metamorphism → Not reliable indicators of a comagmatic relationship. • Samples form distinct clusters → Potential comagmatic relationship.
Granite Discrimination Diagrams	VAG-WPG environments; I, S, or M-Type with the exception of 16AD028; and metaluminous and peraluminous	• Predominantly VAG, coinciding with calc-alkaline signatures. Few samples plot as WPG, suggesting A-Type plutonism, but also plot as I, S or M-Type Granites on the Granitoid-Type diagram. • 16AD028 plots as an A-Type Granite as it is dacitic in composition. • Samples plot as metaluminous and peraluminous, and 16AD013 plots within the I- or S-Type Granite region.
Spider Plots	Comparable concentrations of incompatible elements and similar trends for all units, including the felsic volcanics of the neighbouring Tumpline Lake area	• Samples show very similar trends in concentrations of incompatible elements unlikely to be mobilized during magmatic events or by processes of alteration and metamorphism → Indicative of comagmatic relationship. • Trends of Tumpline Lake data suggest similar petrogenetic processes.

Table 1. Summary table of geochemical plots and their implication for understanding the proposed syn-volcanic/comagmatic relationship between the Amacher Granite and Rhyolites of the Beaulieu Group.

Conclusion

The Amacher Granite and local felsic dykes show a distinct compositional affinity to felsic volcanics of the Beaulieu River volcanic belt. Mineralogies, textures, and geochemical signatures support the hypothesis that the Amacher Granite is a subvolcanic body, comagmatic with felsic volcanic phases that occur relatively high in the volcanic sequence[1,2]. Spatio-temporal relationships and relative dating techniques, combined with petrographic and geochemical analyses suggest that rhyolites of the Beaulieu Group formed as a result of melt-rich regions being erupted from a crystal-rich reservoir (mush), which later crystallized to form the Amacher Granite[1,2,16]. These events likely took place in a volcanic arc setting[1].

Recommendations for future work include a geochronological study of the Amacher Granite and rhyolites of the Beaulieu River volcanic belt to obtain an absolute age for both units. Further geochemical analyses may also reinforce the findings of this study, and assist geoscientists in developing a model for volcanic-plutonic relationships within the Slave craton.

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References

1.) Henderson, J. B. (1985). Geology of the Yellowknife-Hearne Lake area, district of Mackenzie: a segment across an Archean basement. *Geological Survey of Canada, Memoir 414.*

2.) Lambert, M. B. (1988). Cameron River and Beaulieu River volcanic belts of the Archean Yellowknife Supergroup, district of Mackenzie, Northwest Territories. *Geological Survey of Canada, Bulletin 382.*

3.) Davis, W. J., Jones, A. G., Bleeker, W., & Grütter, H. (2003). Lithosphere development in the Slave craton: A linked crustal and mantle perspective. *Lithos, 71*(2), 575-589.

4.) Ketchum, J. W. F., Bleeker, W., & Stern, R. A. (2004). Evolution of an Archean basement complex and its autochthonous cover, southern Slave province, Canada. *Precambrian Research, 135*(3), 149-176.

5.) Heaman, L. M., & Pearson, D. G. (2010). Nature and evolution of the Slave province subcontinental lithospheric mantle. *Canadian Journal of Earth Sciences, 47*(4), 369-388.

6.) Helmstaedt, H. H., & Pehrsson, S. J. (2012). Geology and tectonic evolution of the Slave province – a post-lithoprobe perspective. *Tectonic Styles in Canada: The Lithoprobe Perspective*, 379-466.

7.) Berger, A. J. (2015). Stratigraphy, geochemistry, isotopic signatures and vms potential of late Archean volcanic rocks from the southern Slave craton, Northwest Territories – regional comparison to Sharrie Lake and Turnback Lake volcanic belts. *Carleton University.*

8.) Stubley, M. P. (2005) Slave craton: Interpretive bedrock compilation *NWT-NU. NWT-NU Open file.*

9.) Le Bas, M. J., & Streckeinsen, A. L. (1991). The IUGS systematics of igneous rocks. *London, England: Journal of the Geological Society, 148*(5), 825-833.

10.) Irvine, T. N., & Baragar, W. R. A. (1971). A guide to the chemical classification of the common volcanic rocks. *Canadian Journal of Earth Sciences, 8*(5), 523-548.

11.) Pearce, J. A., Harris, N. B., & Tindle, A. G. (1984). Trace element discrimination diagrams for the tectonic interpretation of granitic rocks. *Journal of Petrology, 25*(4), 956-983.

12.) Whalen, J. B., Currie, K. L., & Chappell, B. W. (1987). A-type granites: geochemical characteristics, discrimination and petrogenesis. *Contributions to Mineralogy and Petrology, 95*(4), 407-419.

13.) Barbarin, B. (1999). A review of the relationships between granitoid types, their origins and their geodynamic environments. *Lithos, 46*(3), 605-626.

14.) Pearce, J. A. (1983). Role of the sub-continental lithosphere in magma genesis at active continental margin. *Continental Basalts and Mantle Xenoliths, Shiva, Nantwich,* 230-249.

15.) Sun, S. -s., & McDonough, W. S. (1989). Chemical and isotopic systematics of oceanic basalts: implications for mantle composition and processes. *Geological Society, London, Special Publications, 42*(1), 313-345.

16.) Bachmann, O., Miller, C. F., & de Silva, S. L. (2007). The volcanic–plutonic connection as a stage for understanding crustal magmatism. *Journal of Volcanology and Geothermal Research, 167*(1), 1-23.