A Geochemical Comparison of Ainsley Beach and Flower Ridge Mafic Volcanic Rocks

G. McMenamin, D. Kinsella, S. Lindberg, T. Samson, K. Roth, and T. Hamre.

Supervised by Sandra Johnstone as part of GEOL 308: Geochemistry, Fall 2017

VIU Create Conference 2018

Introduction

Previous research conducted by Vancouver Island University geology students found discrepancies between the mapped Karmutsen Formation (Km) at Ainsley Beach, Nanoose Bay and the geochemical data from the rocks themselves. The Ainsley Beach (AB) rocks had characteristics of both Km and Sicker Group (SG) in their geochemical data plots. From these results, Cristancho et al.[1] proposed the possibility that the AB rocks could be related to the Flower Ridge Formation (FRF) based on predictions by Juras[2]. **The goal of this project was to use geochemical analysis to identify correlations between the mafic volcanic rocks of Ainsley Beach and Flower Ridge Formation to determine if, although different units, they formed at the same time and/or under similar geologic conditions.** Our predictions for the data include:

If the rocks were formed by similar processes the:	
1	AFM diagram will show Flower Ridge Formation and Ainsley Beach overlap
2	Conserve Trace diagram may show similar trends of Ainsley Beach and Flower Ridge Formation by infilling the bimodal Karmutsen distribution
3	Spider plot will indicate Sr enrichment and Ti depletion for Flower Ridge Formation and Ainsley Beach
4	PER's plot will contain similar fractionation trends between Flower Ridge Formation and Ainsley Beach using olivine and plagioclase

This poster will provide pertinent background geology for the bedrock units in question, a summary of our field and laboratory methods, a discussion of our findings and results, as well as a conclusion with recommendations for future work.

Background Geology

The Wrangellia terrane is comprised of several bedrock formations, all of which record distinctly separate volcanic events. The following map, created using BC MapPlace 2, shows the sampling locations and Wrangellia bedrock formations. The bedrock units included in order of age are:

SG - Sicker Group (Devonian ~380 Ma)
Metamorphosed bedrock interpreted to have formed in an intra-oceanic island arc environment during the mid to upper Devonian Period[3].

FRF - Flower Ridge Formation (~358 Ma)
Potentially an undistinguished portion of the Sicker arc, Flower Ridge Fm was classified as basaltic in composition with amygdaloidal feldspar and lapilli-tuff, tuff-breccia and pyroclastic breccia[2]. It has been hypothesized to be of back-arc origin[2].

Km - Karmutsen Formation (Upper Triassic ~250 Ma)
Characterized by tholeiitic, pillowed, flood basalts[3], as well as a homogenous succession of basaltic lava, comagmatic sills and dykes[4]. The Karmutsen Fm formed in either a normal mid-oceanic ridge (N-MORB), or a plume mid-oceanic ridge (E-MORB)[5].

AB - Ainsley Beach, Nanoose Bay (~200-250 Ma)
Ainsley Beach is composed of basaltic rock with visible pillows and minor brecciation, however, ambiguously associated with the Nanoose Complex. The area was previously mapped as part of the Karmutsen Fm, independent of the surrounding rock units[3].

Field and Analytical Methods

Field Work:

- Rock samples were collected from field locations (10 Flower Ridge, 6 Ainsley Beach) see map locations below
- Sample locations geo-referenced to Google Earth and BC MapPlace for future creation of study area maps

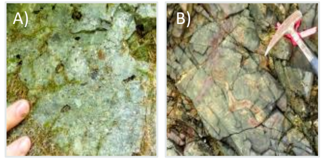

Figure A. Flower Ridge Formation volcanoclastic lapilli tuff.
B. Ainsley Beach, Nanoose pillow basalt. Photos by Sandra Johnstone

Lab Work:

- Each sample was first named and classified based on their physical characteristics, cleaned, split and labeled, divided into a reference sample for storage and an analysis sample
- Analysis samples sent to the Bureau Veritas Group, in Vancouver for ICP-MS geochemical analysis of major oxides and trace elements
- Analytical error for the eleven major oxides ranged from 0-6.25%. For the 33 trace elements the analytical error ranged from 0.83-5% for 28 of them and for five trace elements the error ranged from 5-10%.
- Geochemical data was plotted with previously published data from the research locations for comparison on a series of discrimination diagrams

Study Area

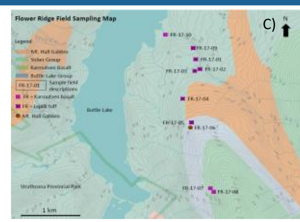

Figure C. Map shows sampling locations at the south end of Buttle Lake, west of Campbell River, BC. Map created using BC MapPlace 2.

Figure D. Map shows Ainsley Beach sampling locations on the southeastern peninsula of Nanoose Bay, BC. Map created using BC MapPlace 2.

Geochemical Results

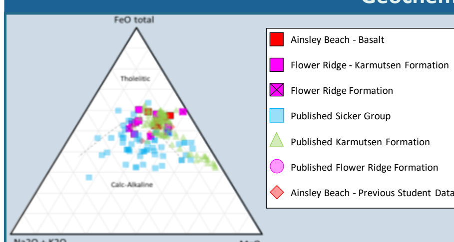

Figure 1. Major oxide AFM diagram showing magma characteristics. FRF samples show a spread range that plots more towards calc-alkaline, similar to SG. Our AB samples plot with the other previous AB rocks along with the published tholeiitic Km. The Km samples found at Flower Ridge somewhat group with the AB rocks.

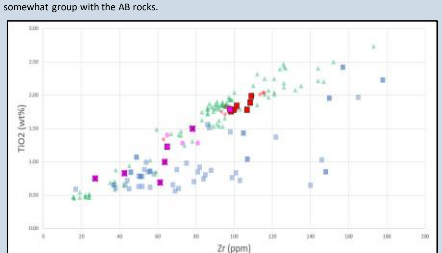

Figure 2. Conserve Trace diagram comparing TiO2 (wt %) and Zr (ppm). Ainsley Beach rock samples plot together with Km[6,7,8] formation ~1.75 wt% TiO2 and ~105 ppm Zr. Flower Ridge distribution correlates with SG; FR lapilli tuff samples are loosely distributed between 0.75-1.5 wt% TiO2 and 30-80 ppm Zr.

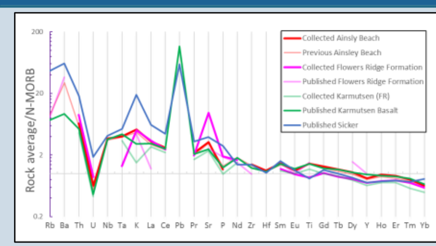

Figure 3. Spider diagram using trace element abundances (ppm) of collected samples normalized to N-MORB Sun and McDonough[9]. Averaged tholeiitic Km[6] and Sicker[4,5]. AB samples show consistent abundances, with K exception plotting variably. FRF show Sr enrichment, and Ti depletion. Conversely, AB shows Ti enrichment with Km.

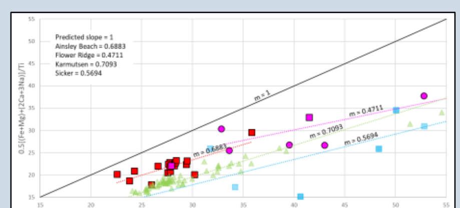

Figure 4. Pearce element ratio[10] (PER) diagram for the mineral assemblage of Olivine+Plagioclase over conserved Ti. Stoichiometric ratios were determined from work done by Stanely and Russel[11]. AB consists of previous student data and data we collected. FRF data consists of Juras' [2] data and data we collected.

Analysis and Discussion

1. FRF plots within SG, predominantly as calc-alkaline. There is minimal overlap of the Km found at Flower Ridge with Ainsley Beach, which shows a primitive magma similar to tholeiitic Km. A single FRF lapilli tuff appears alkaline-depleted and more primitive in comparison to the other FRF samples. This may be supportive of the FRF back-arc hypothesis proposed by Juras[2].

2. The concentration differences between AB and FRF rocks are due to the differential temperatures and pressures found at depth during magma formation. These gradients are what cause increased concentrations of incompatible elements (Zr) to be formed in the more evolved melts. The high concentration of Zr at AB may be from Ti replacement in the basalt. FRF samples have a wider distribution of Zr, as it is hypothesized to be a more evolved arc melt.

3. Relative Sr enrichment of FRF suggests incompatible behavior of Sr in a higher-pressured system compared to AB, which in turn influences the mineralogy. Compatibility is dependent on pressure of system, therefore low pressure causes Sr to behave compatibility, reducing melt concentration[12] perhaps by substituting in for Ca in plagioclase. Differentiation in Ti concentration reflect FRF's proposed arc environment, where Ti is depleted due to possible fractionation of titanomagnetite or magnetite[13] whereas AB enrichment may reflect the presences of these minerals.

4. None of the data plot on the predicted slope, therefore we can not definitively say that the chemical composition of the rocks is consistent with the fractionation of Ol+Plag. However, different slopes can suggest that Ol+Plag is not fractionizing or that it is fractionizing along with other minerals[11]. If the slopes are similar such as AB and Km, 0.6883 and 0.7093 respectively, they could possibly have similar magma sources, but different processes have acted on them causing the variability in the rocks. The same can be said for FRF and SG (m = 0.4711 and 0.5694).

Conclusions and Recommendations

Ainsley Beach and the Flower Ridge Formation are concluded to be **separate units**, differentiated by the resulting geochemistry interpretations from processes which they form.

Prediction	✓ / X	Rationale
1	X	Ainsley Beach appears more primitive with tholeiitic Karmutsen Formation, while the Flower Ridge Formation plots more evolved with Sicker Group
2	X	Ainsley Beach and Flower Ridge Formation were not formed by the same temperature and pressure conditions
3	X	Ainsley Beach formed under lower pressure than Flower Ridge Formation.
4	X	Ainsley Beach and Karmutsen are from the same source, while Flower Ridge Formation is from Sicker Group

Recommendations

- Further sampling of the Flower Ridge Formation and Ainsley Beach
- Geochronology using absolute ages derived from Rb-Sr and Sm-Nd radiogenic isotopic analysis
- Thin section analysis of modal mineralogy, specifically mafic mineral examination and differences between units

References

1. Cristancho A, Orrick T, Godard D, Deland J, Gates S, Nordstrom G. 2016. A geochemical study of basalts at Nanoose Bay, Vancouver Island, British Columbia. Technical poser presented at VIU Create Conference 2016 for GEOL 308.
2. Juras S.J. 1987. Geology of the polymetallic volcanogenic Buttle Lake Camp, with emphasis on the Price Hillside, Central Vancouver Island, British Columbia, Canada. PhD thesis, University of British Columbia, Vancouver B.C.
3. Massey, N. 1992. Geology and Mineral Resources of the Cowichan Lake Sheet, Vancouver Island 92C/16. Province of British Columbia, Mineral Resources Division. Victoria: Canadian Cataloguing
4. Yorath, C.J., Sutherland, A., and Massey, N.W.D. 1999. Lithoprobe, Southern Vancouver Island, British Columbia: Geology, Geological Survey of Canada Bulletin 498
5. Ruks T. 2015. Stratigraphic and paleotectonic Studies of Paleozoic Wrangellia and its contained volcanogenic massive sulfide occurrences, Vancouver Island, British Columbia, Canada. PhD thesis, University of British Columbia, Vancouver B.C.
6. Greene A.R., Scoates J.S., Weis D., Nixon G.T., and Kieffer B. 2009. Melting History and Magmatic Evolution of Basalts and Picrites from The Accreted Wrangellia Oceanic Plateau, Vancouver Island, Canada; J. Petrol. 50: 467
7. Lassiter J. C., Depaolo D.J., Mahoney J.J. 1995 Geochemistry of the Wrangellia flood basalt province: Implications for the role of continental and oceanic lithosphere in flood basalt genesis; J. Petrol. 36 [1995] 983-1009
8. Barker F, Sutherland Brown A, Budahn JR, Plafker G. 1989. Back-arc with frontal-arc component origin of Triassic Karmutsen basalt, British Columbia, Canada. Chem. Geol. 75: 81-102
9. Sun, S.S. and McDonough, W.F. 1989. Chemical and isotopic systematics of oceanic basalts: implications for mantle composition and processes, in: Saunders, A.D., and Norry, M.J. (eds), Magmatism in the Ocean Basins, Geological Society Special Publication No. 42, pp. 313-345
10. Pearce T.H. 1968. *A contribution to the theory of variation diagrams: Contributions to Mineralogy and Petrology*, v. 19, p. 142-157
11. Stanley C.R., Russel J.K. (1989) *Petrologic hypothesis testing with Pearce element ratio diagrams: derivation of diagram axes*. Contributions to Mineralogy and Petrology 103: 78-89. Springer-Verlag
12. Winter, J.D. 2010. An introduction to igneous and metamorphic petrology, Prentice Hall, Upper Saddle River, NJ.
13. Mullen ED. 1983. MnO/TiO2/P2O5: a minor element discriminant for basaltic rocks of oceanic environments and its implications for petrogenesis. Earth and Planetary Science Letters. 62: 53-62

Acknowledgements: Strathcona Provincial Park, BC Parks; Previous and Current VIU Students; VIU for hosting VIU Create 2018