# A Geochemical Comparison of Basalts of Ainsley Beach, Nanoose Bay, B.C. to a Back-arc Basin

Supervised by Sandra Johnstone, as part of the GEOL 308 course requirement, Fall 2017

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## Introduction

Ainsley Beach on the Nanoose peninsula is currently mapped as Karmutsen Formation basalt[1], established to have formed as an intraplate flood basalt with a potential minor island arc component[3]. However, geochemical interpretation of Ainsley Beach samples by Cristancho et al. (2016) suggested a potentially different tectonic setting for Ainsley Beach rocks: back-arc basin (BAB). Results from Cristancho's study led the further geochemical sampling of Ainsley Beach basalts, in addition to geochemical sampling of an established back-arc basin rock called the Flower Ridge Formation of the Sicker Group.

*The aim of this study was to determine the geologic setting in which the basalts at Ainsley Beach were formed, and more specifically if they formed in a back-arc basin setting. Geochemical comparisons between selected Vancouver Island rock units using archived, and newly collected data sets will be analyzed to determine tectonic setting of rock formation.*

BAB rocks typically have intermediate trace element signatures between mid-ocean ridge basalt (MORB) and island arc basalt (IAB). More specifically, BAB rocks should show a relative enrichment of subduction mobile and large ion lithophile elements (i.e. Ba, La, Sr) compared to Mid-Ocean Ridge Basalts (MORB), and depletion compared to Island Arc Basalts (IAB)[5].

*If Ainsley Beach basalts were formed in a back-arc basin they should be less enriched in subduction mobile and large ion lithophile elements than the IAB Sicker Group, and possibly similar to established BABs, as shown by the selected trace element graphs.*

## Background Geology

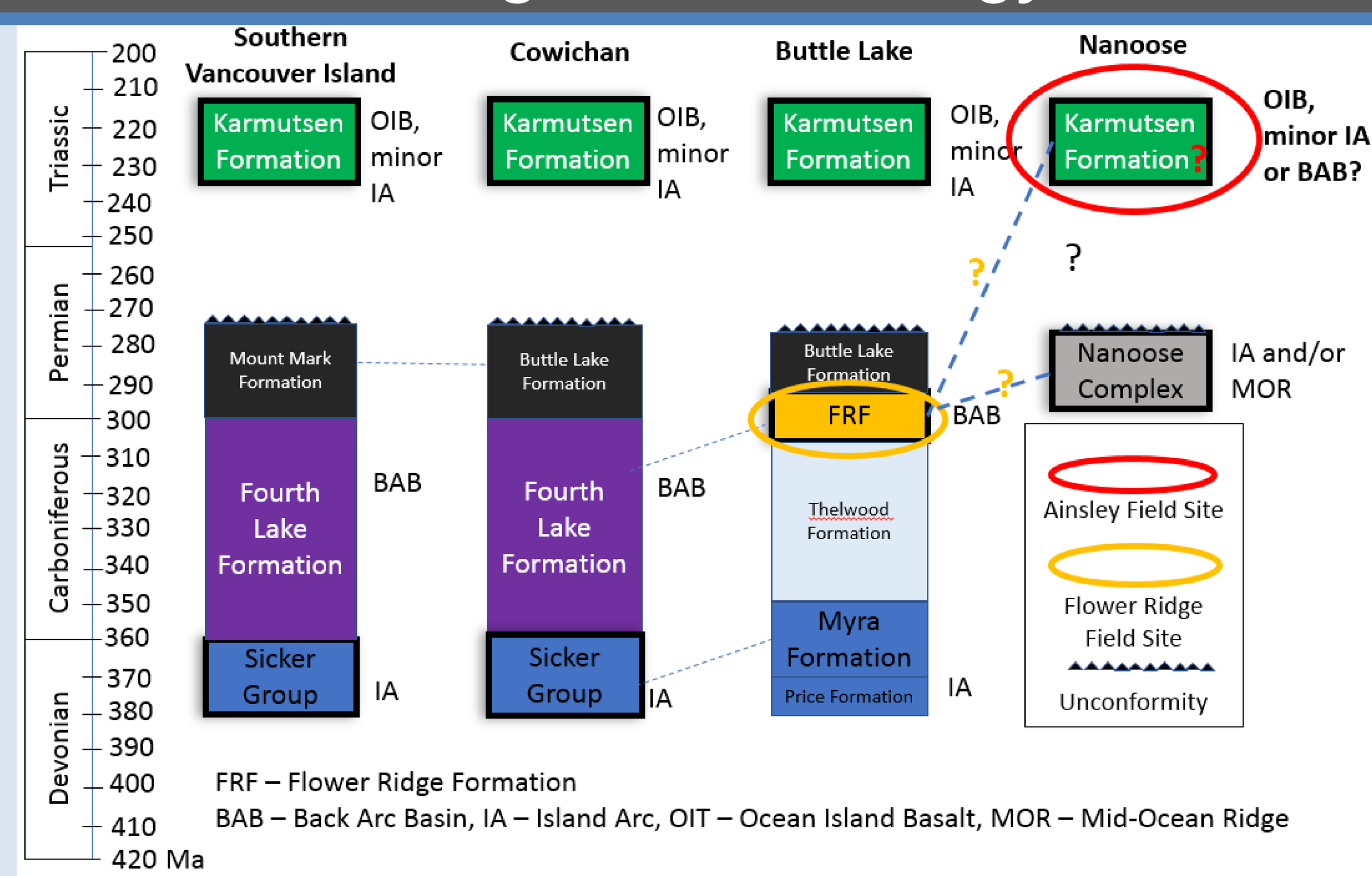



Figure 1: Interpretive chronostratigraphic columns of selected Vancouver Island geology with formation names, correlated units and tectonic settings, modified from Ruks (2015) [10], with additional information [3,4,6,9,10]. Details Mount Mark, Buttle Lake and Thelwood formations were beyond the scope of this project. Lithologic details of the colour-coded units are as follows:

Karmutsen Formation (K) **– flood basalt province: 216 to 232 Ma[3]:**
Mafic volcanics including pillow basalt, pillow breccia, hyaloclastite, and massive basalt[3].

Fourth Lake Formation (FL) **– back-arc basin: ≈ 300 to 359 Ma[9]**
Chert-dominated sedimentary package with minor felsic volcanics[9].

Nanoose Complex (NC) **– ocean island arc and/or mid-ocean ridge: 295 to 355 Ma[10]**
Highly variable lithologies including: pillow basalt, pillow breccia, limestone, chert, argillite, and sandstone[6].

Flower Ridge Formation (FRF) **– back-arc basin: Poorly constrained ≈ 325 to 355 Ma[9]**
Amygdaloidal basaltic lapilli-tuff, tuffaceous siltstone, and tuff[4].

Sicker Group (SG) **– ocean island arc: 362 to <≈388 Ma[9]**
A highly variable unit comprised of mostly volcanics and volcaniclastics such as: massive basalt, basaltic andesite, rhyolite, of tuff, lapilli tuff, agglomerate, volcanic sandstone, and cherty tuff[9].

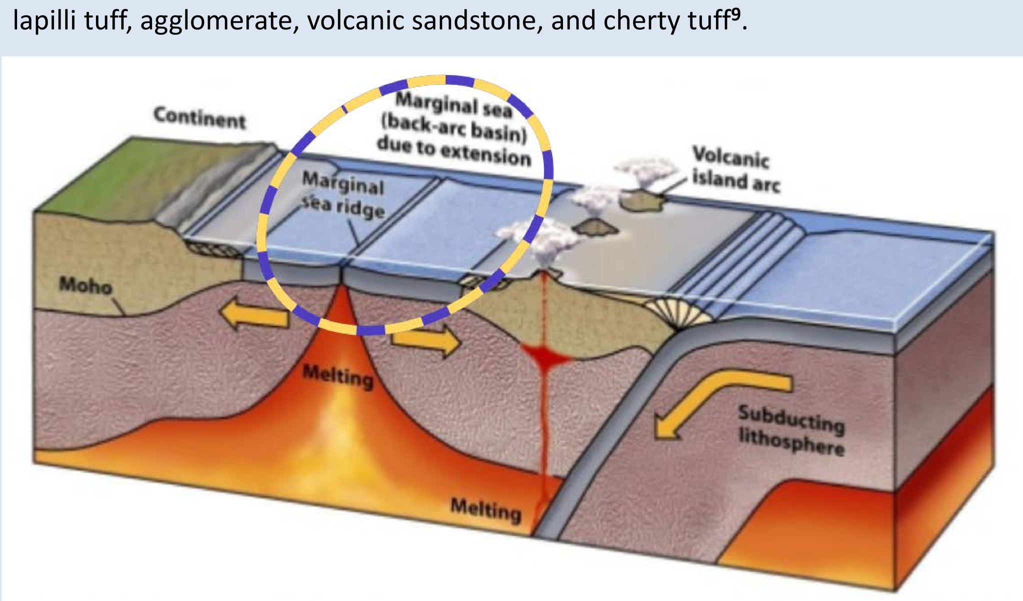



Figure 2: Typical diagram of tectonic processes that have shaped much of Vancouver Island. The yellow and purple circle represents a typical back-arc basin setting correlative with the Flower Ridge Formation and Fourth Lake Formation (modified from [8]).

## Field Work

Ainsley Beach sample collection took place on Sept 22, 2017, yielding six fist-sized basalt samples from outcrops through the study area, pictured in Figure 2(a) and Figure 3(a,b). Flower Ridge sample collection in Strathcona Park took place on Sept 23, 2017 and yielded ten total samples, consisting of basalt, lapilli tuff, and gabbro, pictured in Figure 2(b) and Figure 3(c,d)

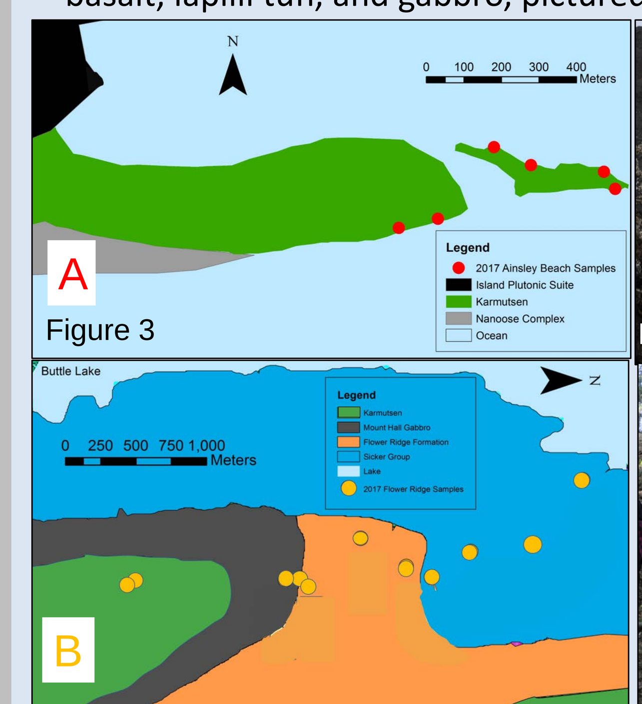
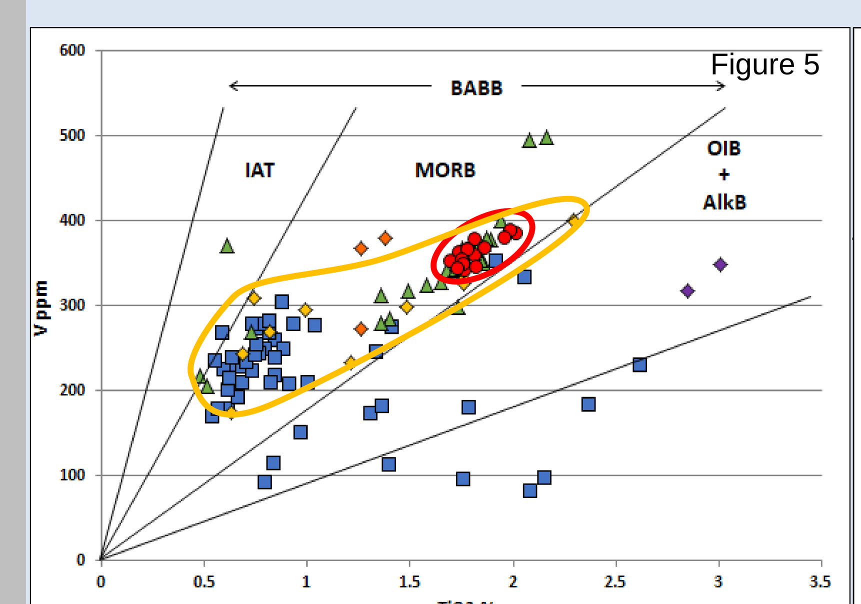


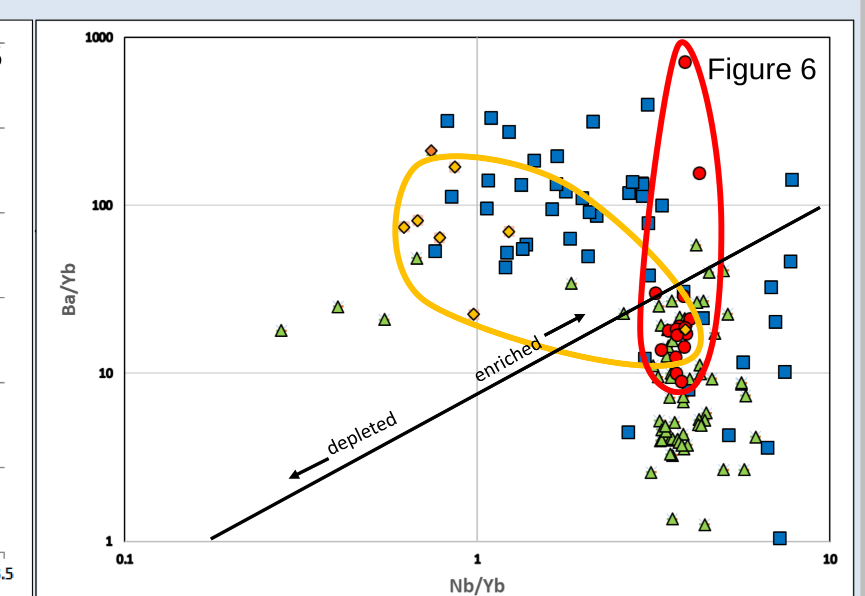

Figure 3: Sample site locations on top of BC Geological Survey maps[2] at a) Ainsley Beach in Nanoose and b) Flower Ridge Trail in Strathcona Park


Figure 4: Sample site photographs with a) Ainsley Beach outcrop, b) Ainsley Beach basalt sample , c) Flower Ridge outcrop, d) Flower Ridge lapilli tuff sample

## Analytical Methods & Geochemistry

Samples were prepped in VIU Geology Lab and sent to Bureau Veritas for major, minor and trace element analysis by Inductively Coupled plasma Mass Spectrometry(ICP-MS). From these values, two established trace element plots[5] and a spider diagram[5] were plotted to test predictions. In addition to the collected Ainsley Beach basalt, and Flower Ridge basalt and lapilli tuff data, archived data [3,4,6,9,10] for units in the Background Geology section, were also plotted.



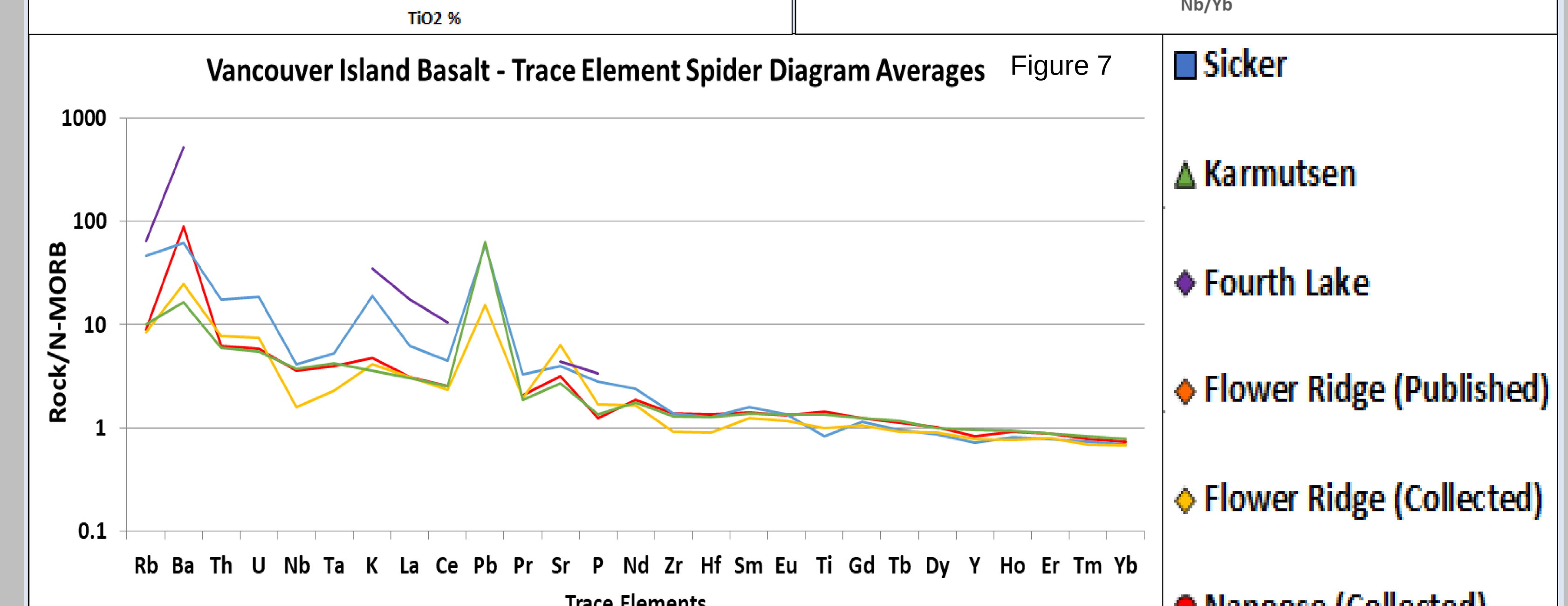




Figure 5: Ainsley Beach data is strongly clustered, proximal to Karmutsen data in the MORB range near the OIB range boundary. Sicker plots mostly in the MORB range near the IAT boundary, with a large spread of outliers. The Flower Ridge Formation is spread through the intermediate of Sicker and Karmutsen/Ainsley Beach values in the MORB range. If Ainsley Beach rocks were BABBs, an intermediate spread would be expected, similar to the Flower Ridge Formation data. However this is not observed, therefore not conclusively showing Ainsley Beach Rocks to be BABBs.

Fig 6: High Ba/ Nb ratios indicate an arc-like signature. BAB rocks typically plot either as an arc or within the MORB array. Note: Sicker Group has a mostly arc-like signature. Karmusten Formation were expected to plot dominantly within the MORB array. However, they have variable Ba concentrations, showing a weak bimodal distribution. Ainsley beach have enriched Ba/Nb ratios relative to MORB. Flower Ridge plots from in between the MORB array and the arc-like signature and somewhat into the arc-like field [3,4,6,9,1]

Fig 7: Spider diagram showing high Ba, Rb, Sr and Pb (low temperature mobile elements) characterize shallow subduction. Note all formations show this signature and the shallow subduction signature of the Ainsley Beach rocks similar to Fourth Lake Fm., may therefore suggest it is part of a BAB system[5].

## Conclusions & Recommendations

**If the mafic volcanic rocks at Ainsley Beach are formed in a back-arc basin setting we should see:**

| Predictions | Rationale | Yes/No/ Inconclusive |
|---|---|---|
| Geochemical data showing considerable variation from MORB and IAB but an overall intermediate composition | The considerable variation of BABBs is because they are often contaminated by partial melting of the surrounding country rock or from the subducting slab[5] (See Figure 5 and 7). | Inconclusive |
| Ainsley Beach enrichment of Ba, La, Th and Sr relative to MORB | The enhanced concentration of LIL elements is because of the subduction component common to back-arc basins[5] (See Figure 6). | Inconclusive |
| Enrichment of subduction-mobile elements and depletion of subduction-immobile incompatible elements | There's a subduction component within BABs therefore it's expected that subduction-mobile elements are enhanced relative to N-MORB whereas subduction-immobile elements will be similar to N-MORB[5] (See Figure 6). | Inconclusive |

**Recommendations:**

- Detailed lithological and structural mapping of Ainsley Beach to determine stratigraphic sequencing and unconformities.
- Thin section petrography of Ainsley Beach samples to determine modal mineralogy and degree of alteration
- Repeated or additional Ainsley Beach samples with Pb included in geochemical suite as it is useful for tectonic discrimination diagrams
- Age dating of Ainsley Beach unaltered basalt, potentially using $^{40}Ar/^{39}Ar$ [7] or $^{206}Pb/^{238}U$ [3] age dating methods to find out the age of the Ainsley Beach rocks.
- Further investigation into the formation and geochemical signature of the Karmutsen formation. Specifically, in regards to sample site locations and geochemically different sample sites on the island to determine a geographic distribution of the two (or more?) distinct lithogeochemical Karmutsen Formation units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