Discriminating Geologic Environments for Nanoose Volcanic Rocks

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Introduction

The purpose of this study is to test a hypothesis proposed by previous student research, which places Nanoose as part of an undocumented back arc basin. Surface samples including 8 mafic volcanic rocks, 1 sedimentary rock and 1 volcaniclastic rock were collected northwest of Nankivell point (see map below) for major oxide and trace element whole rock analysis. We will examine Large Ion Lithophile Elements (LILE) and High Field Strength Elements (HFSE), determined through whole rock analysis, to discriminate arc from back arc environments. During fractional crystallization and partial melting of magma, these two groups have difficulty entering the solid phase so they are concentrated in the liquid phase (Incompatible elements, 2019). The melt is then extracted and a convective flow moves the depleted mantle into the mantle wedge which is depleted in HFSE and enriched in LILE (Murray and Blake, 2005). HFSE depletion in the arc should result in negative Nb anomalies and high Ti/Zr ratios. This could correlate Nanoose with known arcs of Wrangellia: Sicker Group and Flower Ridge Formation.

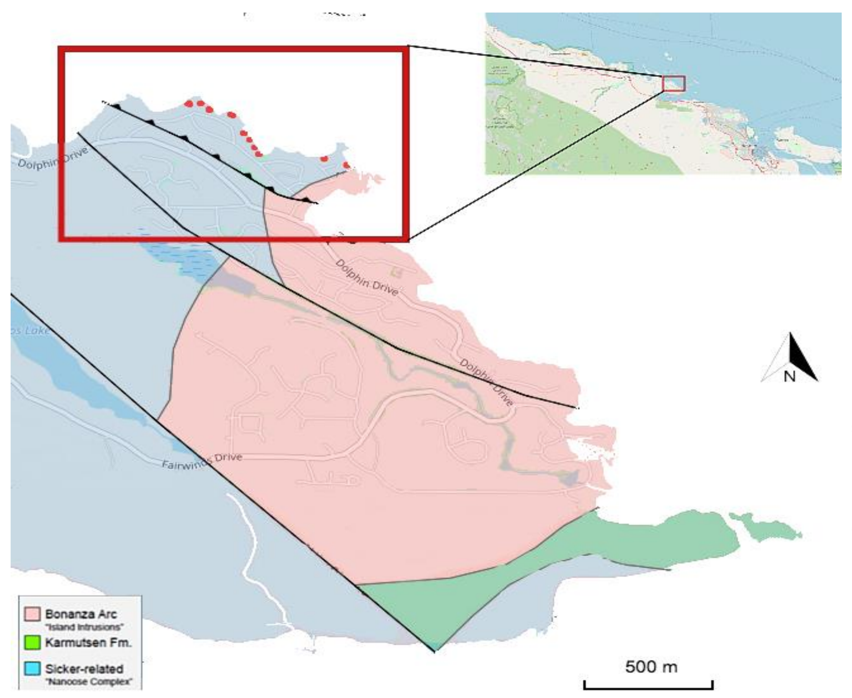
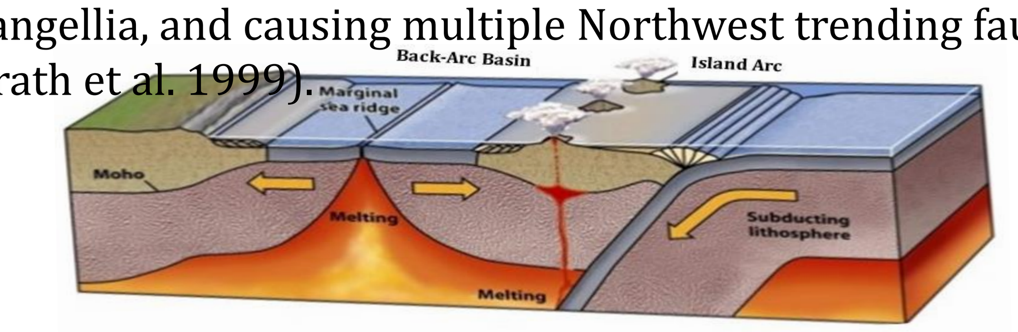


Figure 1: Map of Nanoose Bay including our study area highlighted in red. Bonanza Arc, Karmutsen Formation and Sicker Groups are representatively coloured. Sample locations are denoted as red circles.

(Image source: BCGS MapPlace).

Regional Geology

An active convergent margin located on the west coast of the North American Cordillera has created a zone of complex geology. Around 380 Ma ago, Wrangellia terrane started forming as an Ocean Island Arc (OIA) environment through multiple volcanic events from which we mainly focus on the Sicker Group with the Flower Ridge Formation (FRF) of the Devonian period, Nanoose Complex of the Paleozoic, and the Karmutsen Formation of the Vancouver Group which belongs to the Triassic period (Ruks 2015). This terrane was accreted to the North American continent and subjected to high tectonic activity, giving uplift to the Nanoose Bay area, exposing the rocks of Wrangellia, and causing multiple Northwest trending faults (Yorath et al. 1999).



Rock Unit	Age
Sicker Group → **Flower Ridge Formation**	Devonian (360-380 Ma) (350 Ma)
Nanoose Complex	Paleozoic (295-355 Ma)
Vancouver Group → **Karmutsen Formation**	Triassic (230 Ma)

Table 1: Geochronology of Relevant Rock Units and the Tectonic Setting of the area. Data from Ruks (2015) and Yorath et al. (1999), photo from Marshak (2015).

Methodology

Ten rock samples were prepared at the Bureau Veritas mineral laboratory in Vancouver, B.C. The samples were crushed, split and pulverized to 200 mesh. The powdered samples were then, using HCL, dilute to standardized concentration and prepared for ICP-MS analysis. The concentration of REEs were detected in parts per million accuracy that deflected from the argon plasma field within the ICP-MS instrument. Some calibration maybe involved in identifying some of the trace element that has similar atomic mass to argon; however, ICP-MS was able to establish a wide spectrum of REEs (22 in total) that are needed for further geochemical analysis.

In addition to the ICP-MS method, ICP-OES provides measurements for major oxides concentrations. The additional optical chamber in ICP-OES allowed the instrument to identify larger particles/element based on wavelength.

The detected REEs and major oxide are used to plot trace and Rare Earth Elements as both methods allow for a low ppm detection limit, ensuring reliable results. The Nanoose Basalts analysis was then compared to Normal Mid Ocean Ridge (N-MORB) and chondritic in order to determine REEs behavior in difference tectonic settings. The major oxide data was then used in the discrimination diagram in order to identify whether the rock samples are formed in the back arc basin or subduction zone. The comparison was plotted on several graphs in

Trace Element Data Analysis

Table 1: Rock Names based on BGS naming scheme.

Normalized Multielement Plot for Nanoose Basalts, Sedimentary Rocks, Sicker Group, and Flower Ridge Formation

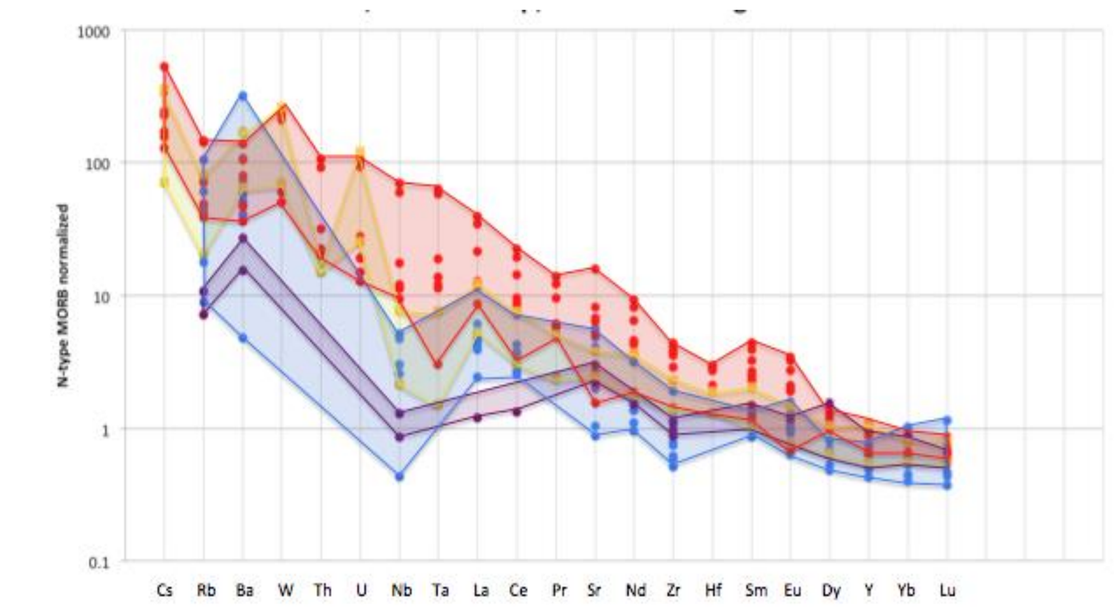


Figure 1: Multi-element plot for Nanoose basalts and sedimentary rocks (collected February 2020), Sicker Group (Yorath et.al. 1999), Flower Ridge Formation (Juras 1987) normalized to N-type MORB. This plot displays the field of variability within samples for trace element concentrations when compared to N-type MORB environments (Sun and McDonough 1989). General trend of decreasing trace element concentration moving right from Cs to Lu with expectation to both Sicker Group and Flower Ridge Formation highest trace element at Ba. There is a noticeable dip in the trend at Nb for all three groups and at Ta for the Nanoose rocks.

Normalized Rare Earth Element Plot for Nanoose Basalts, Nanoose Sedimentary Rocks, Sicker Group, and Flower Ridge Formation

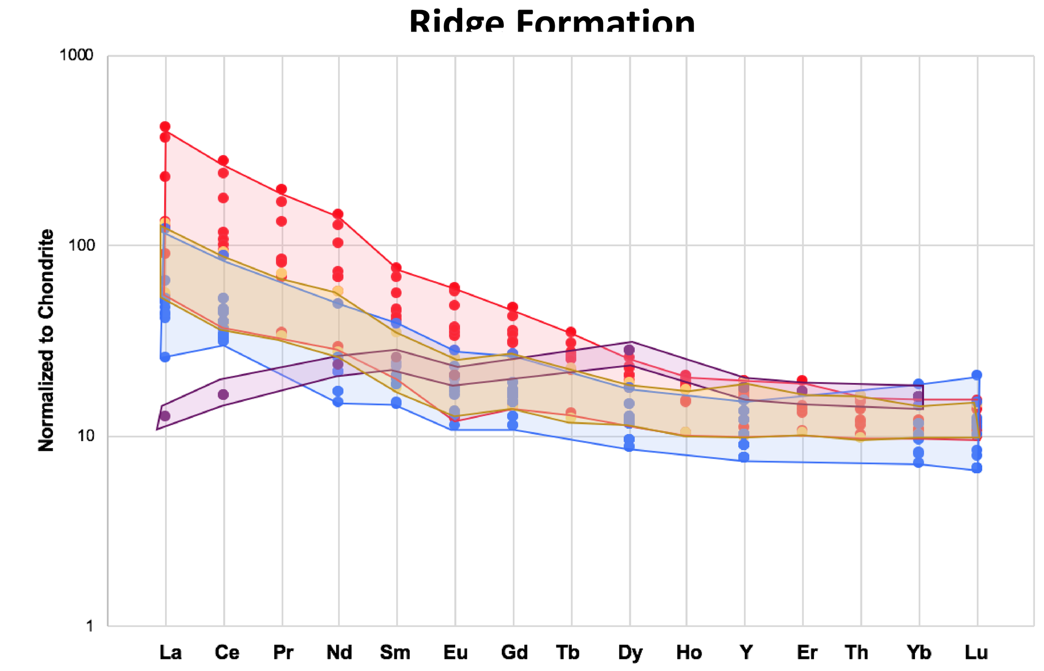


Figure 2:Rare earth element plot for Nanoose basalts and Nanoose Sedimentary Rocks (collected February 2020), Sicker Group (Yorath et.al. 1999), Flower Ridge Formation (Juras 1987) normalized to Chondrite . This plot displays the field of variability within samples for rare earth element concentrations when compared to Chondrite environments (Sun and McDonough 1989). General trend of decreasing rare earth element concentration moving right from La to Lu with expectation to Flower Ridge Formation which shows an increase in from La to Dy followed by a decrease to Lu.

Ti/Zr Comparison of Nanoose Basalts, Sicker Group, and Flower Ridge Formation

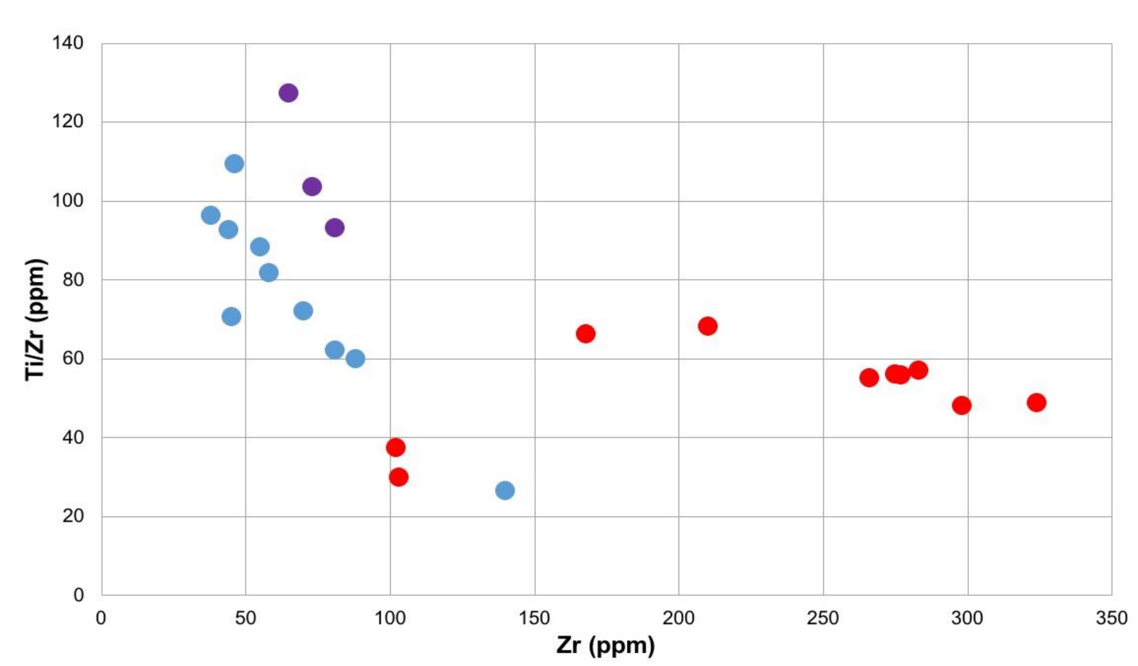
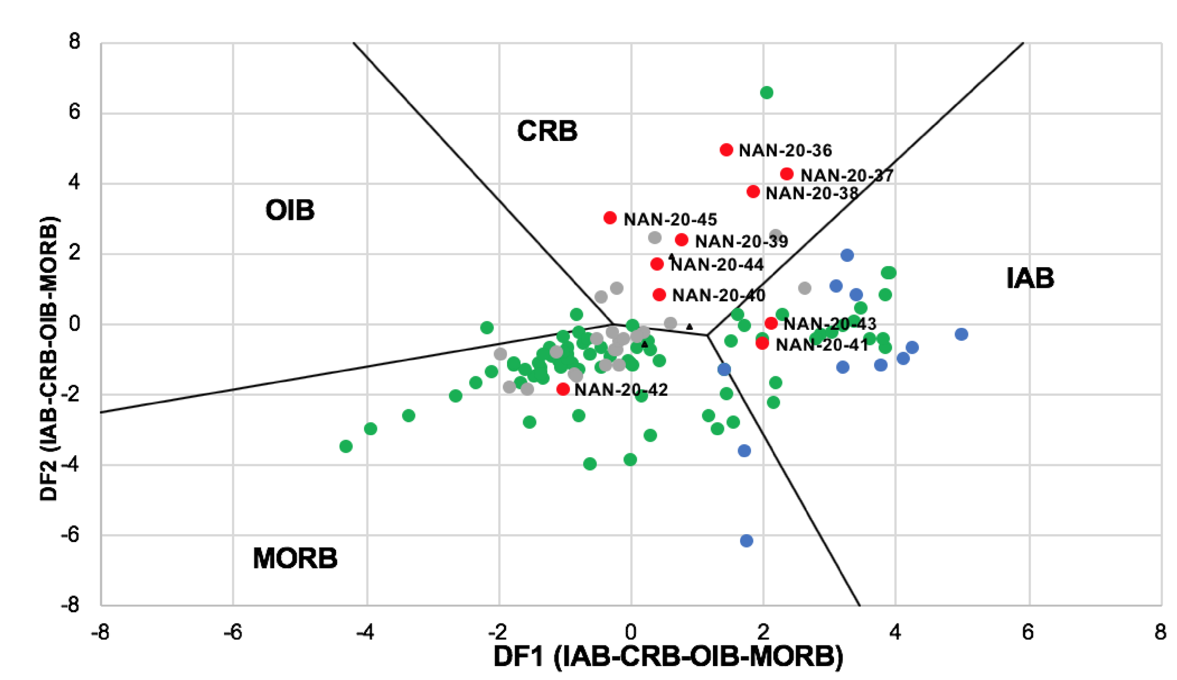


Figure 3: Ti/Zr ratio comparison diagram for Nanoose basalts (collected February 2020), Sicker Group (Yorath et.al. 1999), Flower Ridge Formation (Juras 1987). Flower Ridge Formation contain the highest Ti/Zr ratio and Nanoose Basalts containing the lowest. Whereas Nanoose Basalts contain the highest Zr values with a range from 100-300ppm and Sicker Group containing the lowest with range from 40-140ppm.

Discrimination Function Plot for Nanoose Basalts, Sicker Group, Karmutsen, and Ruks



Sicker Group (Yorath Et. Al. 1999), Karmutsen (Dostal Et. Al. 2011), and Ruks (Ruks 2015). Plotted with natural log of concentration ratios to provide a more statistically-collect results. Majority of Nanoose Basalts collected plot within the CRB whereas the previous plot within MORB. Sicker Group plot in IAB with minor in MORB. Karmutsen plot in MORB and IAB. Ruks plot in both MORB and CRB.

Legend

Nanoose Basalts · Nanoose Sedimentary Rocks · Sicker Group · Flower Ridge Formation · Previous Nanoose Basalts · Karmutsen

Discussion

Nb anomalies plotted on the multi-element diagram show values much greater for our Nanoose basalts than for both the Sicker Group and Flower Ridge Formation. Arcs associated with back-arc basins are generally depleted in HFSE, including Nb, because these highly incompatible elements are preferentially partitioned into the liquid phase and erupted in the back-arc region. The depleted mantle is then cycled through convective currents into the mantle wedge below the arc, and subsequently erupted magma has a relatively lower amount of Nb, as it has already been removed (Murray and Blake, 2005). This evidence supports the hypothesis that the Nanoose rocks are part of a back-arc basin environment. There is one Nanoose sample that shows a fairly low Nb anomaly, but this sample is a sedimentary rock, and so is not representative of volcanic processes occurring at the time.

The plot of Ti/Zr supports this hypothesis as well. Zr is less compatible than Ti, meaning it is depleted more by the time the magma reaches the arc (Murray and Blake, 2005). This means that arcs associated with back-arc basins generally have high Ti/Zr ratios, and their associated back-arc basins have lower Ti/Zr ratios. This is exactly what our graph shows, as all except two of the Nanoose samples have a lower ratio than both the Sicker Group and Flower Ridge Formation samples. Those two that do not follow the trend are both sedimentary rocks, and so this discrepancy can be overlooked.

The REE plot supports this hypothesis further by showing a slight depletion in Eu in the Nanoose samples. Eu is commonly substituted in for Ca during crystal fractionation and formation of plagioclase in basalts (Winter, 2012). The initial mantle composition is therefore depleted in Eu, by eruption of basalts in the back-arc basin, by the time it reaches the mantle wedge below the arc.

One factor to consider is the differentiation between a rifted back-arc basin and a spreading back-arc basin. These can be distinguished from arc environments by comparing the ratios of Th/Nb. Th concentrations are fairly consistent throughout the three environments, which is why it is chosen to be compared against the highly variable Nb for this purpose (Murray and Blake, 2005). Rifted back-arc basins have a higher subduction component, and so span the gap between arc environments and spreading back-arc basins. While this data was plotted as part of this project, it was deemed to be beyond the scope of our specific hypothesis. In summary, the Nanoose basalts seen to have been part of a rifted back-arc basin, based off the ratios that were plotted. The probable hypothesis of Nanoose recording a rifted back-arc basin is the reason why we have chosen to use Continental Rift Basalt (CRB) as a proxy for a back-arc basin. The rifted back-arc basin would show a signature similar to CRB, as there is a large component of continental assimilation during the early stages of rifting.

Conclusions and Recommendations

Our analysis of Nanoose Bay was to test whether the volcanic rocks were formed from part of an undocumented back-arc basin associated with either the Sicker Group or Flower Ridge Formation. Our results show that this is a possibility, however, it will remain inconclusive without geochronological evidence.

Predictions:	Results:
• Strong depletion in HFSE in Sicker Group and FRF compared to Nanoose rocks.	✔ : Ti/Zr ratio lower in Nanoose rocks than Sicker Group and FRF.
• Negative Nb anomalies in Sicker Group and FRF, and higher Nb values in Nanoose rocks.	✔ : Much higher Nb values in Nanoose rocks, with the lowest anomaly being a sedimentary rock.
• Discrimination diagrams plotting Nanoose rocks in the CRB domain (proxy for possible rifted back-arc basin).	✕/✔ : Seven of our samples plotted in the CRB domain, but the other three showed MORB and IAB signatures.

Recommendations for Future Work:

•Geochronological dating of volcanics in Nanoose (if possible) to associate them with a specific time period.

•Analysis of how the mafic volcanic geochemical signatures vary moving along a transect from Dolphin Beach to Nankivell Point (as the other groups have done).

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