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TECTONIC EVOLUTION OF THE CHUGACH-PRINCE WILLIAM TERRANE: GEOCHEMISTRY OF THE ORCA GROUP VOLCANIC ROCKS IN EASTERN PRINCE WILLIAM SOUND, ALASKA

ELAINE K. YOUNG, Ohio Wesleyan University
Research Advisor: Karen Fryer

INTRODUCTION

Geologic evidence indicates that slab window subduction may have modified the long-lived accretionary wedge complex of the Chugach-Prince William terrane (CPW), producing marine basalts interbedded and structurally interleaved with the Paleocene flysch of the CPW (Bradley et al., 2003, Marshak and Karig, 1977, Haeussler et al., 2003, Kusky et al., 2003). Similar features are found in Washington and British Columbia (Breitsprecher et al., 2003), causing a debate in the literature regarding the significance of a trench-ridge-trench (TRT) triple junction in both locations. Two competing hypotheses address the potential relationship between Alaska and the Pacific Northwest. The translation hypothesis (Cowan, 2003) proposes that the Baranof Schist of the CPW in Alaska and the Leech River Schist on Vancouver Island were contiguous when they formed and the CPW subsequently underwent 1100 km of northward translation between 61 and 50 Ma. The in situ hypothesis (Haeussler, 2003) proposes the presence of a now subducted oceanic plate, the Resurrection Plate, whose boundaries would have caused two TRT triple junctions to subduct, one in south central Alaska and one near Vancouver Island. The in situ hypothesis explains the similarities between the geologic history of the CPW and the Pacific Northwest of Vancouver Island and Washington as resulting from identical simultaneous conditions rather than the same TRT triple junction. Paleomagnetic data from the Ghost Rocks Formation, especially from Alitak Bay on the southern coast of Kodiak Island, suggest that the Alaska rocks were about 2750 km south of their present location about 60-62 Ma (Plumley et al., 1983). As part of the Chugach terrane, the Ghost Rocks paleomagnetic data support the translation hypothesis for the history of the southern Alaska margin. In this study, the geochemical composition of the Orca Group volcanic rocks is used to evaluate their relationship to Chenega Island, the Knight Island and Resurrection ophiolites, the Yakutat basement, and Siletzia in the Pacific Northwest (PNW). Maximum depositional ages of the interbedded sedimentary sequences (Grimm, this volume) indicate that the Orca Group volcanic rocks formed between 57- 51 Ma. The relationship of the volcanic rocks from eastern Prince William Sound (PWS) to the Knight Island and Resurrection ophiolites, Chenega Island volcanic rocks, Yakutat basement terrane, and Crescent Formation in the Pacific Northwest can increase our understanding of the tectonic history for the CPW.

BACKGROUND

Together the Chugach, Saint Elias, Ghost Rocks, and Prince William terranes form one of the largest accretionary complexes in the world (Plafker et al., 1994). The Chugach and Prince William terranes are an accretionary wedge complex primarily composed of interbedded sandstone and shale that form the Valdez and Orca Groups (Bradley et al., 2003). The Orca Group is a Paleocene to early Eocene sedimentary and volcanic sequence located along the continental margin of southern Alaska, with particularly extensive exposures in Prince William Sound PWS. The mappable units are thin and thick-bedded turbidites (Helwig and Emmet, 1981) conformable with altered basalts (pillowed and nonpillowed flows, pillow brecciated tuff, and intrusives), lenticular bioclastic limestone, red and green argillite, chert, and conglomerate (Winkler, 1976). The Knight Island ophiolite, the Resurrection ophiolite, and the Chenega Island rocks, located within the Orca Group, are of particular importance to this study because their volcanic sequences have geochemical compositions indicative of mid-ocean ridge basalt (MORB) mixing with near-trench accretionary complexes and turbidites (Bradley et al., 2003).

The Yakutat microplate is located east of PWS and is responsible for the uplift in the Chugach and St. Elias Mountains. The Yakutat terrane, an allochthonous piece of continental crust (Plafker et al., 1994), was brought into the subduction zone of the Kula-Farallon ridge. The original location of the Yakutat is important for understanding the evolution and location of the TRT triple junction. The basalts of Yakutat correlate with basalts in the Pacific Northwest (Davis and Plafker, 1986; Worthington et al., 2012), indicating the microplate is a piece of crust that was sliced off and subsequently translated northward.

The Crescent Formation is early to middle Eocene oceanic basalt with massive flows, pillow basalts, basalt and mudflow breccia, and small amounts of intrusive rock; upper Eocene to Miocene and minor Pliocene marine sedimentary rocks overly the Crescent basalts (Tabor and Cady, 1978). Geographically, the ages of the igneous rocks in the Crescent and Siletz terranes tend to increase away from the center of the region, which is explained by the presence of a subducted spreading center (McCrory and Wilson, 2013). The volcanic rocks range from basaltic andesite to rhyolite but are dominantly dacite. The mafic rocks are mostly metaluminous (Madsen et al., 2006). Compositions of intermediate to felsic igneous rocks in the forearc region (Breitsprecher et al., 2003) are consistent with MORB mixing with anhydrous asthenosphere and sediments, although there is some geochemical evidence for a mantle plume providing source magma a bit further south (Denny, 2012). The older basalts are interbedded with continentally derived sedimentary sequences ranging from conglomerates to turbidites (McCrory and Wilson, 2013), which supports the close proximity of the magmatic activity to the forearc. Wells et al. (2014) cite the Yellowstone hotspot as a source of supplemental magmatism beyond a spreading center in the Pacific Northwest. This idea is still debated, and does not seem to influence the hypotheses regarding the relationship between Alaska and the Pacific Northwest.

METHODS

I prepared 14 samples for XRF and ICP-MS geochemical analyses for major, trace, and rare earth elements (REE). The samples were collected from three areas within the Orca Group in eastern Prince PWS: three from northern Hawkins Island; seven from Canoe Passage, Mummy Island, and northeastern Hinchinbrook; and four from Port Etches and English Bay (Fig. 1). I crushed the samples to chips using a hardened steel mortar and pestle, ultrasonically cleaned each sample with deionized water for cycles of 25 minutes, then picked the samples selecting only unaltered and unweathered chips. The picked samples were sent to the GeoAnalytical Laboratory at Washington State University, where XRF and ICP-MS analyses were performed. I made 11 thin sections in the Petrography Laboratory at Ohio Wesleyan University and 10 thin sections were made by Texas Petrographic Services, Inc. The 21 samples are basalt, gabbro, volcaniclastic, and basalt-limestone contacts. Identified as basalt in the field, sample CV14-15A was excluded from geochemical discussions after it was identified in thin section as a volcaniclastic.

RESULTS

Petrographically, samples range from unaltered basalts to basalts that have experienced greenschist facies metamorphism. Unaltered samples have an intergranular texture with elongate pyroxene and elongate plagioclase grains that are frequently skeletal indicating rapid growth; dominant silicate minerals are pyroxene, olivine, and plagioclase feldspar. Chlorite, calcite, and prenite are abundant in altered samples. Opaque minerals range from 3% to 15% in thin section.

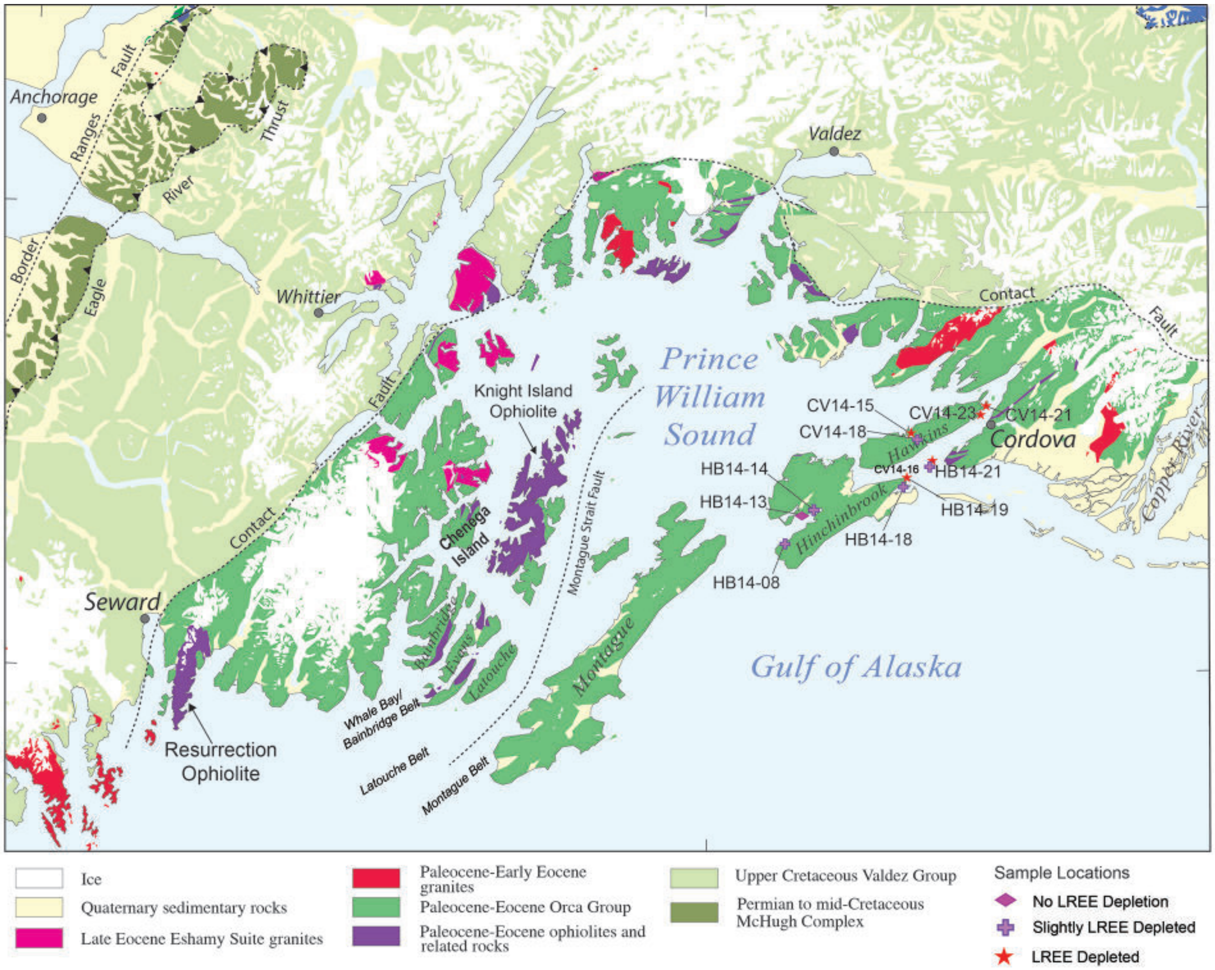

Figure 1. Geologic map of the Chugach-Prince William Terrane and sample locations in Prince William Sound, Alaska modified from Bradley and Miller (2006) and Kveton (1989). Note that location HB14-21 has both slightly LREE depleted and LREE depleted samples.

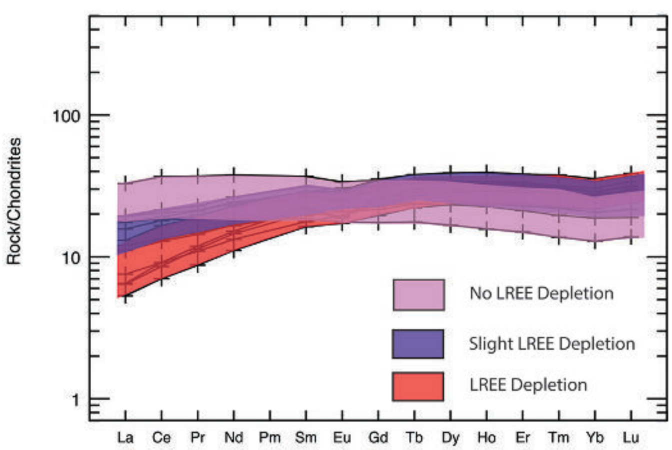

Figure 2. Rare earth element abundances of eastern Prince William Sound basalts normalized to chondrites after Sun and McDonough (1989). The samples fall into three groups: light rare earth element (LREE) depleted, slight LREE depletion, and no depletion.

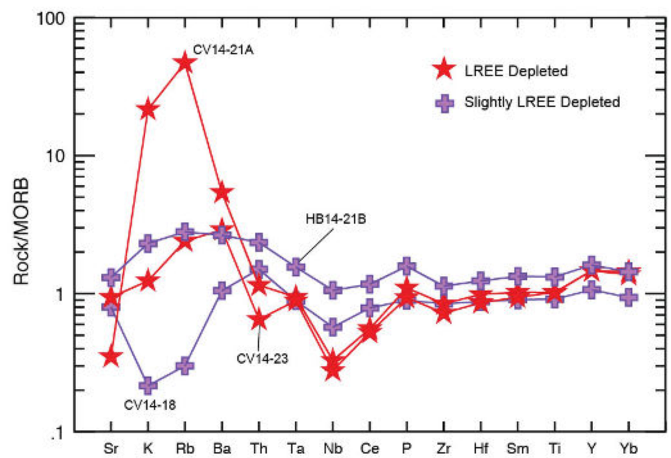

Figure 3. Trace Element abundances of eastern Prince William Sound basalts normalized to mid-ocean ridge after Pearce (1983). Shown here are four samples that represent the types of variation in large ion lithophile elements within the basalts from this study. The variation in trace elements, especially among the large ion lithophiles does not follow the same groupings as the rare earth element abundances.

When plotted on a total alkali versus silica diagram by LeBas et al. (1986), 11 samples are basalts and two samples are trachy-basalts. CIPW norms place the two coarse-grained samples in the olivine gabbro and the nepheline-bearing olivine gabbro fields. The 13 samples from this study fall into three groups based on chondrite-normalized REE abundances: light REE (LREE) depleted, slightly LREE depleted, and no depletion (Fig. 2). All samples are enriched relative to both MORB and chondrite. These melts probably originated in the mantle at depths shallower than the garnet peridotite, suggesting a normal mid-ocean ridge basalt (N-MORB) type source. There is a slight negative europium anomaly in six samples indicating early crystallization of plagioclase; however the depletion is so slight that no definitive interpretation of the anomaly can be made. Sample HB14-13A represents the most primitive sample based on having the highest Mg#, Ni and Cr abundances, and CaO weight percent (Rhodes and Dungan, 1979); HB14-18 is the most altered sample. When trace elements are normalized to MORB (Pearce, 1983), some samples show large ion lithophile element (LILE) enrichment and others are depleted; this variation does not correspond to the groups based on REE patterns. In samples CV14-21A, CV14-21B, and CV14-13A, the K and Rb are highly enriched while in other samples, K and Rb are either slightly enriched, not enriched, or depleted (Fig. 3). A negative Nb anomaly is present in most samples, indicating a subduction related component interacted with the melt. All samples have abundances of Ni and Cr that are ≤136 ppm and ≤366 ppm respectively. Samples were also plotted on a Ti/V diagram (Shervais, 1982) to differentiate the sources: six samples plot in the overlap between MORB and back arc basin (BAB), three plot in the MORB only field, and four are more similar to island arc tholeiites (Fig. 4a).

DISCUSSION

MORB-normalized trace element abundances show N-MORB like patterns for high field strength elements (HFSE) with more variability in the abundances of LILEs suggesting alteration due to sediment mixing, fractional crystallization, and/or hydrothermal alteration (Fig.3). The variation in LILEs is most likely a result of sediment mixing in samples CV14-21A, CV14-21B, and CV14-13B because the K and Rb are highly enriched and the Sr is not enriched. The negative Nb anomaly present in most samples is also indicative of sediment addition, especially in samples that also have K and Rb enrichment. In samples with low K and Rb and enriched Ba and Sr, the Nb depletion is more likely a result of a subduction related component (Sun and McDunough, 1989). The absence of veins, amygdules, vugs, and minerals associated with hydrothermal alteration in most thin sections suggest that few samples have variation in LILEs due to only hydrothermal alteration. Hydrothermal alteration can cause Na, K, Ca, Sr, Ba, and Rb to become mobile, making it a possible source of LILE patterns in all samples; however thin section analysis suggests that LILE patterns in HB14-13A and HB14-13B result from hydrothermal alteration, while incorporation of sediments and related fluids into the melt causes the LILE pattern in the rest of the eastern PWS samples.

Relationship to other Orca Group Basalts:

All samples from eastern PWS have abundances of Ni and Cr that indicate a less primitive source with a longer history of fractionation (Rhodes and Dungan, 1979) than samples from Chenega and Knight Islands (Miner, 2012). Five of the samples in eastern PWS resemble basalts on Chenega Island, and seven are similar to basalts from the Knight Island ophiolite in western PWS, and two are outliers (Miner, 2012) (Fig. 4b). The similarities between Knight Island and Chenega Island and the eastern PWS samples follow the same grouping as the REE patterns. Using the Zr/Nb ratios to determine the similarity of eastern PWS samples' sources to the sources of Miner's samples: HB14-13A and HB14-13B seem to have a distinct source while the rest are similar to the Chenega and Knight Islands samples (Fig. 4c). The Resurrection ophiolite has slightly more enriched LREE pattern relative to the eastern PWS samples, which suggests a source more similar to enriched mid-ocean ridge basalt (E-MORB) than N-MORB. The samples from eastern PWS that have similar REE patterns to the Resurrection ophiolite (Kusky et al., 2004) are CV14-21A, CV14-21B, and CV14-13B. The eastern PWS samples are less primitive than the Resurrection ophiolite; however, Lytwyn et al. (1997)

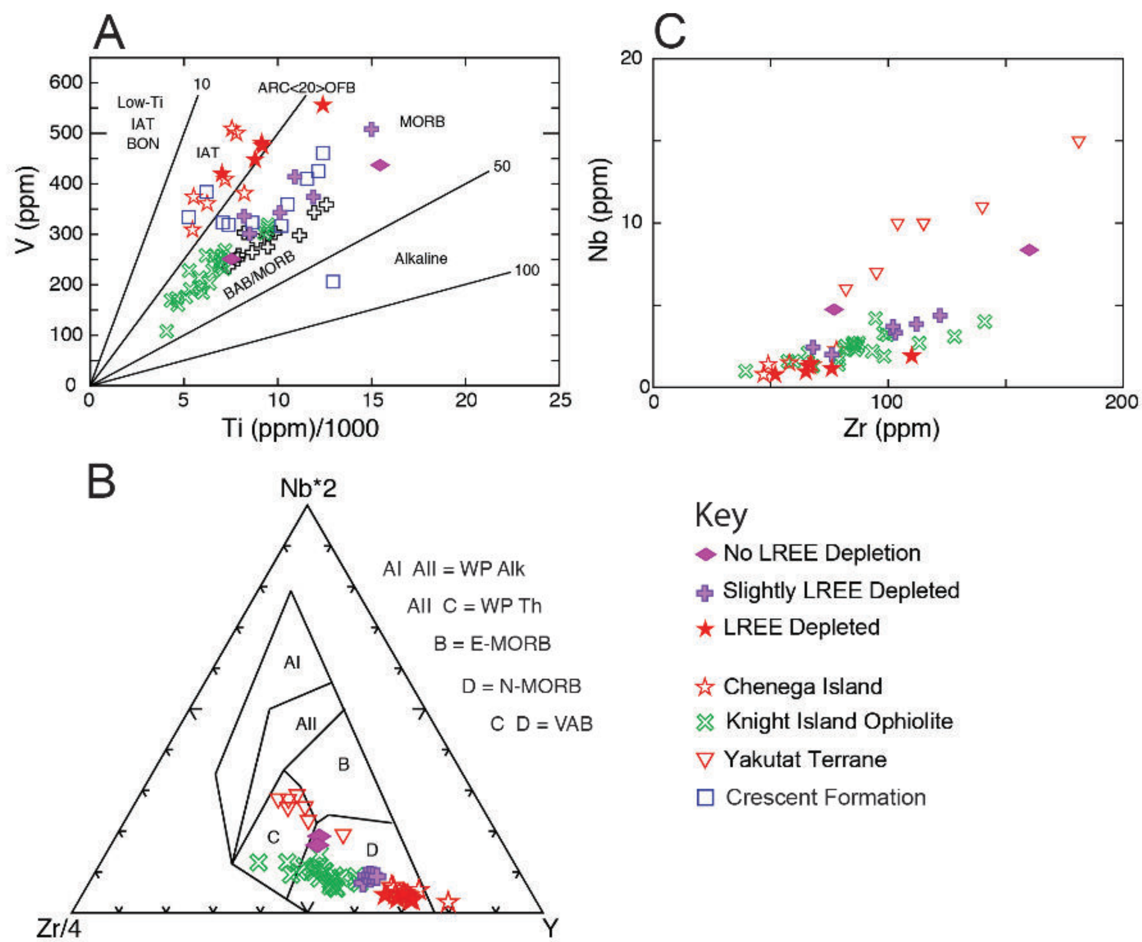

*Figure 4. Basalts from eastern Prince William Sound (PWS), Chenega Island, the Knight Island ophiolite (Miner, 2012), the Resurrection ophiolite (Lytwyn et al., 1997), the Yakutat terrane (Davis and Plafker 1986),and the Crescent Formation (Denny, 2012) plotted on three basalt discrimination diagrams. Filled in symbols are from eastern Prince William Sound. A) A Ti/1000 vs. V basalt discrimination diagram after Shervais (1982) differentiates the source for basalts from PWS and the Crescent formation. B) A ternary diagram Nb*2-Zr/4-Y (Meschede, 1986) illustrates the similarities between source material for the PWS and Yakutat basalts. The light rare earth element (LREE) depleted samples from eastern PWS are similar to Chenega Island basalts while the slightly LREE depleted samples are more similar to Knight Island. C) Zr/Nb ratios are used to demonstrate similarities in source material. The slope of each locality is unique, indicating separate sources, however the difference in ratios between locations is similar enough to indicate related sources.*
MORB = mid-ocean ridge basalt, N-MORB = normal-MORB, E-MORB = enriched-MORB, BAB = back arc basin.

attribute most of the variation in their Resurrection ophiolite samples to sediment contamination from Orca flysch rather than hydrothermal alteration, but the eastern PWS samples experienced both. All of the locations considered in this study, Chenega Island, Knight Island and Resurrection ophiolites, and eastern PWS, seem to have multiple parental magmas that underwent different degrees of fractionation, hydrothermal alteration, and incorporation of Orca sedimentary material.

Relationship to Yakutat Basement

Petrographic descriptions of altered basalts from the Yakutat by Davis and Plafker (1986) match the petrography of altered Orca basalts. Two groups exist within the Yakutat basalts: LREE enriched and LREE depleted (Davis and Plafker, 1986); when normalized to chondrites, the Yakutat samples that are LREE depleted have a similar pattern to eastern PWS LREE depleted samples. The Zr/Nb ratios for the Yakutat (Davis and Plafker, 1986) are slightly different than ratios for eastern PWS samples (Fig. 4c). While sediment interactions can change the Zr/Nb ratio, the variability in Nb depletions among eastern PWS samples suggests that the difference in Zr/Nb ratio between the Yakutat and Orca basalts is a result of the two locations having a distinct yet related source.

Comparing the Orca Group to the Crescent Formation

Siletzia, a large igneous province composed of the Crescent and Siletzia terranes, formed during Paleocene-Eocene time and is thought to be the result of a mantle plume from the Yellowstone hot spot interacting with a subducting ridge in the Pacific Northwest (Wells et al., 2014), although there are other hypotheses (Duncan 1982; Brietsprecher et al., 2003). At the same time, the basement of the Yakutat terrane formed on the opposite side of the ridge through a similar process (Worthington et al., 2012). Siletzia basalts can be considered the forearc and magmatic arc basalts of the TRT triple junction while the basalts in the Orca Group and the Sanak-Baranof plutonic belt are the near-trench anomalous magmatism associated with ridge subduction (Tysdal et al., 1977). The slightly LREE depleted N-MORB-like samples from eastern PWS are similar to basalts from the Lower Crescent Formation on the Olympic Peninsula in Washington State (Denny, 2012), plotting in the MORB/BAB field on a Ti/V diagram (Fig. 4a). The geochemistry of the two regions suggests similar, but different sources. The variation in sources could result from the location of the rocks relative to the spreading center and the magmatic arc within the TRT triple junction. Assuming the Crescent Formation volcanic rocks are further inboard of the trench than the Orca Group, then the more evolved and felsic compositions of the Crescent samples indicates increased interaction with the overlying plate.

CONCLUSIONS

The geochemistry, particularly the presence of at least one group of basalts from each location that are depleted in LREE, is consistent across locations. The mobilization of K, Ba, Sr, and Rb indicates sediment mixing and hydrothermal alteration, which is indicative of a subducting ridge formation environment. The variations in source from N-MORB to more E-MORB between Alaska and the Pacific Northwest are consistent with the variation observed at a subducting ridge and likely correlate with proximity to ridge, slab window, trench, and magmatic arc. The source materials for these rocks at each locality are distinct but related. The timing of the basalts from all locations is roughly coeval, and given the correlative relationships between the basalts and surrounding sedimentary sequences, including turbidites, limestones, volcaniclastics, and conglomerates, the argument that these samples formed in the same setting is strong. Because the northward translation of the Yakutat terrane has been established, and the basalts of the Orca Group have similar sources to both the Yakutat and the Crescent Formation basalts, the translation hypothesis for the evolution of the Chugach-Prince William terrane is likely. The geochemistry, provenance, and detrital zircon ages link the CPW in Alaska to the Pacific Northwest (Pettiette et al., 2013). Paleomagnetic data reinforce this connection by placing the Alaska rocks at about 48°N during the Paleocene (Plumley et al., 1983). Together, these components provide compelling evidence for extensive northward translation of the CPW following ridge subduction in the Pacific Northwest.

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