GEOCHEMISTRY OF THE KNIGHT ISLAND OPHIOLITE AND CHENEGA ISLAND VOLCANICS, PRINCE WILLIAM SOUND, ALASKA

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INTRODUCTION

The tectonic evolution of southern Alaska is defined by a long history of subduction, accretion, and coastwise transport of terranes along the North American margin (e.g. Plafker et al., 1994). Cowen (1982, 2003) and Haeussler et al. (2003) propose two competing hypotheses for the formation and transport history of the Mesozoic-Tertiary Chugach-Prince William terrane that extends for at least 2000 kilometers along the margin from Sanak Island in the west to Baranof Island in the East (Fig. 1 in Garver and Davidson, this volume). Paleomagnetic and geologic data suggest that the Chugach-Prince William terrane has experienced major coast-parallel northward transport along strike slip faults and thus there are critical questions about the timing and location of terrane accretion (Cowan, 2003; Haeussler et al., 2003; Sisson et al., 2003; Plafker et al., 1994). Near-trench intrusions of the Chugach-Prince William terrane by the Paleogene Sanak-Baranof magmatic belt are strong evidence for ridge subduction and these plutons show a distinct west-east age progression from 61 Ma on Sanak Island to 50 Ma on Baranof Island (Bradley et al., 2003; Haeussler et al., 2003). Cowen (1982, 2003) suggests that ridge subduction (Kula-Farallon) took place near the latitude of Washington State but Haeussler et al. (2003) introduced the Resurrection plate to explain a more northerly option for this plutonic belt.

The Chugach-Prince William terrane is dominated by trench-fill turbidites but it also includes several imbricated ophiolites, notably the Resurrection Penninsula and Knight Island ophiolites. Close correlation in the ages of the ophiolites with the Sanak-Baranof intrusives suggests that the ophiolites are remnants of the Kula-Farallon ridge subduction (Crowe et al., 1992; Lytwyn et al., 1997; Bradley et al., 2003).

The early Tertiary Cresent terrane in Washington State and Metchosin Igneous Complex on southern Vancouver Island consist of basalts interbedded with clastic sediments, dated at 57-51 Ma (Duncan et al., 1982; Babcock et al., 1994; Timpa, 2005). The tectonic setting for the formation of these early Tertiary rocks has been controversial and are interpreted as seamounts, ophiolites, and rift-basin rocks (Glassley, 1974; Babcock et al., 1992; Timpa, 2005; Hirsch and Babcock, 2009). Another terrane of Upper Cretaceous flysch and early Tertiary submarine basalts called the Yakutat block is assumed to have formed south of its present location in the Northern Gulf of Alaska (Burns, 1983). The flysch appears to be correlative to the Chugach terrane and although the early Tertiary basalts are not well exposed, the occurrence of these rocks suggest that they are correlative to the Crescent Terrane of the Pacific Northwest (Bruns, 1983).

Basaltic rocks from the Upper Cretaceous Valdez Group of the Chugach terrane are interpreted to have formed as a primitive island-arc or mid ocean ridge (MOR) setting (Crowe et al., 1992; Lytwyn et al., 1997). Discriminant diagrams using relatively immobile trace elements define the Resurrection Penninsula and Knight Island volcanics of the Orca Group as mid ocean ridge basalts (MORB) and ocean floor tholeiites (Nelson and Nelson, 1992; Plafker et al., 1994). Trace-element abundances from the basalts of these two ophiolites show little enrichment in incompatible elements and show some calc-alkaline signatures, inferred to be the result of sediment contamination of normal mid ocean ridge basalt (Bradley et al., 2003; Lytwyn et al., 1997; Nelson and Nelson, 1992; Crowe et al., 1992). This chemical variation could indicate that the ophiolites formed at a spreading center proximal to a subduction zone but the question remains, are all the volcanic rocks of the Chugach-Prince William terrane from the same source, and if so, what is

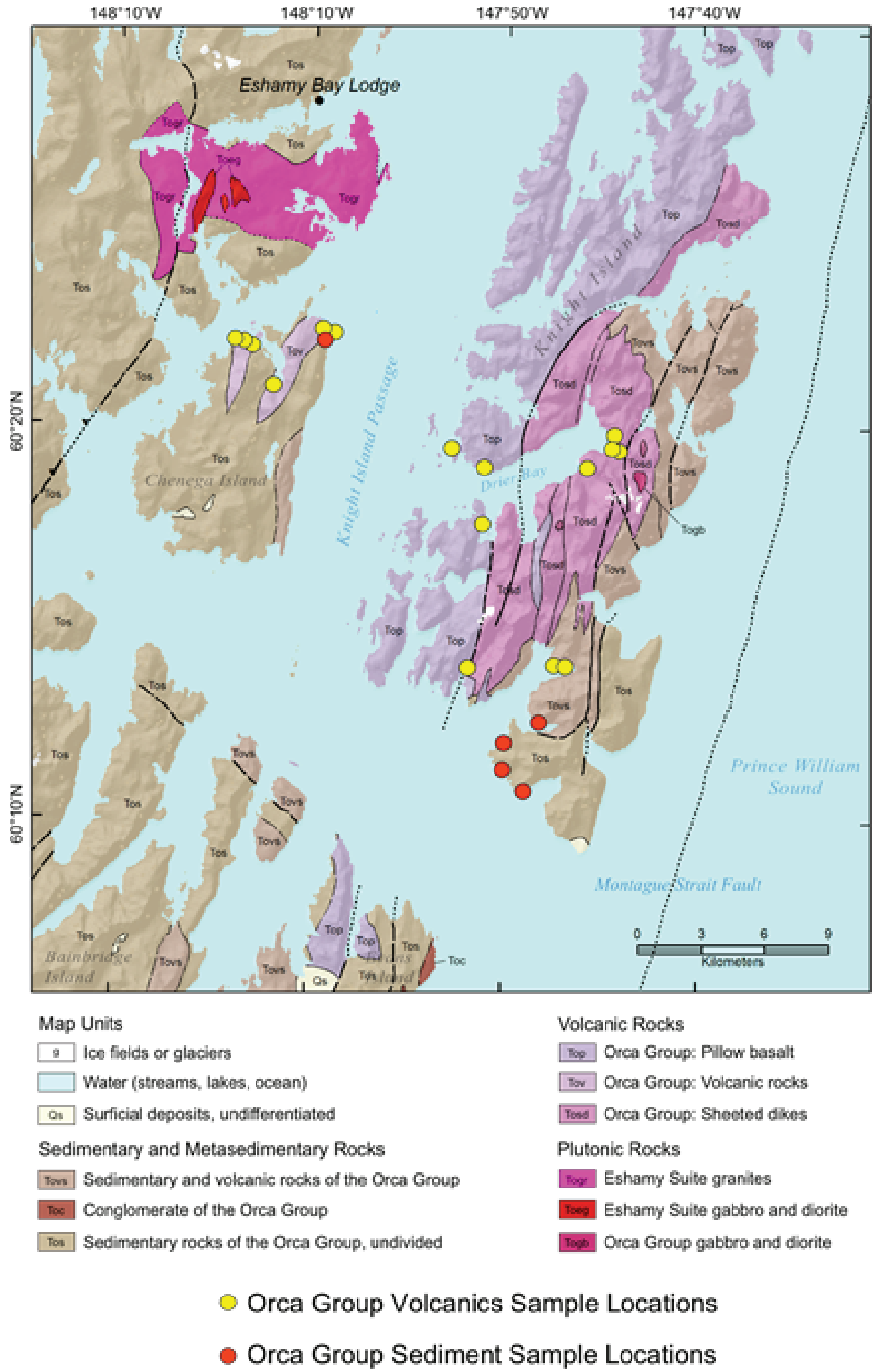

Figure 1. Geologic map of study area for Orca Group volcanics and sediments in Prince William Sound, Alaska

the geochemical nature of that source?

The goal of this study is to investigate the geochemistry of the volcanic rocks from Knight Island and Chenega Island in Prince William Sound, Alaska to explain their relationship, source, tectonic setting, and thus, history. Geochemical data from the Orca Group volcanics are compared to submarine basalts of the Pacific Northwest in order to test models of significant coastwise terrane transport suggested by (Cowan, 1982, 2003).

GEOLOGIC SETTING

The Orca Group, an accreted Paleocene to Upper Eocene deep-sea-fan complex (see Hilbert-Wolf, this volume) contains ophiolites and other volcanic units and together the sediment and volcanics define the Prince William terrane (Plafker et al., 1994; Winkler, 1976). The Orca Group is complexly folded, faulted, and metamorphosed, ranging primarily from prehnite-pumpellyite facies to low greenschist facies, but the outermost rocks on Montague are zeolite facies (Tysdal et al., 1977; Plafker et al., 1994).

Volcanic rocks comprise ~15% of the Orca Group and consist of ophiolite sequences located on Resurrection Peninsula, Knight Island, and Glacier Island (Nelson and Nelson, 1992; Crowe et al., 1992). The Knight Island ophiolite is a fault-bounded complex within isoclinally folded flysch of the Orca Group. Knight Island has not been dated but plagiogranite from the Resurrection Penninsula ophiolite has been dated at 57 Ma and is thus inferred to be the age of the Knight Island ophiolite (Nelson and Nelson, 1992). Oceanic crustal rocks of Knight Island include a sequence of pillow and massive basalt (5,000 m thick) and sheeted dikes, affected by greenschist-facies metamorphism, and limited ultramafic rocks (Tysdal et al., 1977; Nelson and Nelson, 1992; Crowe et al., 1992).

Volcanic rocks of the Orca Group not associated with the Knight Island ophiolite include sections of pillow basalt, massive flows, and flow breccia, with minor flysch (Crowe et al., 1992; Plafker et al., 1994). These volcanics are thought to be broadly compatible with the ophiolites of the Orca Group and this study investigates the two volcanic suites, specifically how they can be modeled by varying degrees of fractional crystallization and sediment mixing and their relation to the Resurrection Penninsula ophiolite and basalts of the Crescent terrane.

ANALYTICAL METHODS

Twenty-nine samples of volcanic rocks from the Orca Group were collected for geochemical analysis. Seven samples were collected from Chenega Island, all basalts, including five pillows and two massive flows (Fig. 1). Twenty-two samples were collected from Knight Island at a number of localities (Fig. 1). Eighteen of the Knight Island volcanic samples were labeled in the field as basalts; five pillows, two flows, and ten dikes. Three gabbros were sampled from Knight Island and one quartz diorite was collected. Additionally, nine samples of Orca Group sediments were collected from five localities (Fig. 1). Sample preparation and whole-rock geochemical analyses took place at Macalester College in Saint Paul, MN. All 29 volcanic samples and nine sediment samples were made into beads and pellets for analysis of major and minor elements, respectively. Geochemical analysis was performed using the Phillips PW2400 X-ray Fluorescence Spectrometer at Macalester College.

PETROGRAPHY

In thin section, Knight Island volcanics are mostly intergranular with less-abundant porphyritic textures. Phenocrysts of plagioclase are subhedral to euhedral and typically strongly zoned whereas clinopyroxene phenocrysts are subhedral and crystallized after the plagioclase. The phenocrysts reside in a cloudy matrix of clinopyroxene, chlorite, and opaque minerals. Samples of volcanic rocks from Chenega Island are thoroughly altered at low-grade conditions (greenschist) as evidenced by abundant chlorite and actinolite as interstitial minerals. No fresh glass is visible in these samples.

GEOCHEMICAL RESULTS

Petrographic observations indicate the Orca Group volcanics of Prince William Sound have undergone low-grade metamorphism but retain primary igneous textures. Thermal studies indicate that in this area the rocks cooled form peak metamorphic conditions at about 38-40 Ma (Carlson, this volume). Certain incompatible trace elements are thus used in the successive plots because they are known to be relatively immobile during hydrothermal alteration and low-grade metamorphic conditions.

Major element classification of the Orca Group volcanic rocks is made using the Jensen cation plot (1976) (Fig. 2). Almost all samples from this study fall within the basalt fields (Fig. 2); all but two of the volcanics from Chenega Island are tholeiitic high-Fe basalts, whereas the Knight Island volcanic rocks are tholeiitic, or transitional to calc-alkaline, high-Mg basalts (Fig. 2). One sample plots as an andesite, and a sample of a coarse-grained intrusive rock collected in Mummy Bay (south end of Knight Island) is classified as a dacite by this diagram (Jensen, 1976).

Incompatible trace element abundances for the least altered Orca Group volcanic samples (Fig. 3) have normalized values near those of N-MORB values (near 1) for the immobile elements Nb to Yb, but have somewhat enriched values for the more incompatible elements Sr, K, Rb, Ba, and Th. Volcanic rocks from Knight Island and Chenega Island have similar trace element patterns, but the Chenega Island volcanics are more enriched in K, Rb, Ba, and Y, and relatively depleted in Nb. Compared with the volcanic rocks, Orca sediments show a stronger enrichment in the LILE and exhibit a slight enrichment in Nb to Hf, and slight depletion in Sm, Ti, Y, and Yb (Fig. 3).

On the discrimination diagram shown in Figure 4, Knight Island volcanics plot mostly in the fields of volcanic arc basalt and either modern within plate basalt or N-MORB while the Chenega Island volcanics plot only in the Yttrium-rich edge of the N-MORB and volcanic arc basalt field. No overlap is observed between the two volcanic suites on diagrams using these elements (Fig. 4).

DISCUSSION

Geochemical results from this study suggest that volcanic rocks of Knight Island and Chenega Island are distinct volcanic suites. For major elements, Chenega Island volcanics contain more Fe than Knight Island, suggesting lower degrees of fractional melting in the production of the Chenega volcanics (Fig. 2). The variation in Sr, K, Rb, Ba, and Th between the volcanics of Chenega Island and Knight Island suggest derivation from different sources, possibly by partial melting, sediment contamination, or other mantle processes.

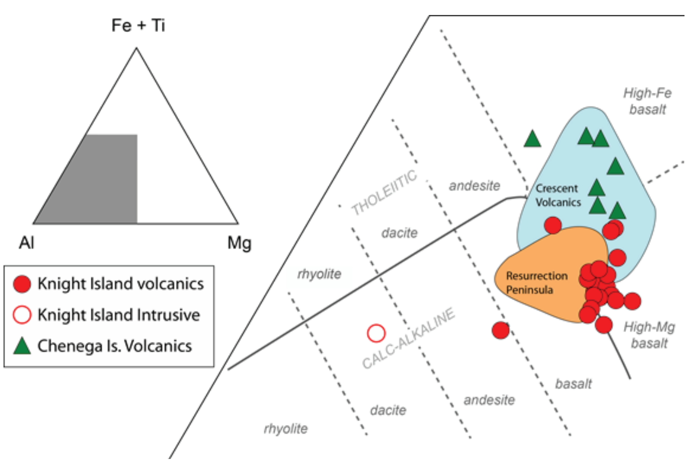

Figure 2. Ternary classification diagram of whole rock geochemical analysis from volcanics of the Orca Group. End members are cation concentrations of Fe+Ti, Al, and Mg. Shaded fields represent volcanics of the Crescent terrane (Glassley, 1974) and Resurrection Peninsula basalts (Lytwyn et al., 1997)

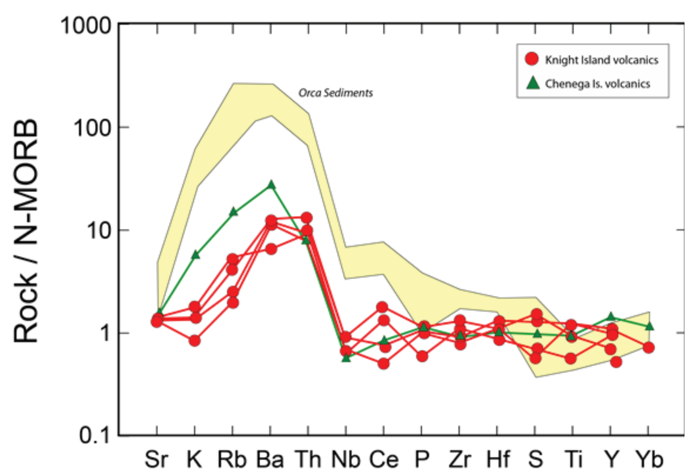

Figure 3. Spider diagram of trace element abundances of Orca Group volcanics and sediments normalized to N-MORB (Sun and McDonough, 1989). Analyses of Knight Island volcanics (circles) and Chenega Island volcanics (triangles) indicate slight enrichment of LILE relative to N-MORB, suggesting they did not form in a mid ocean ridge setting.

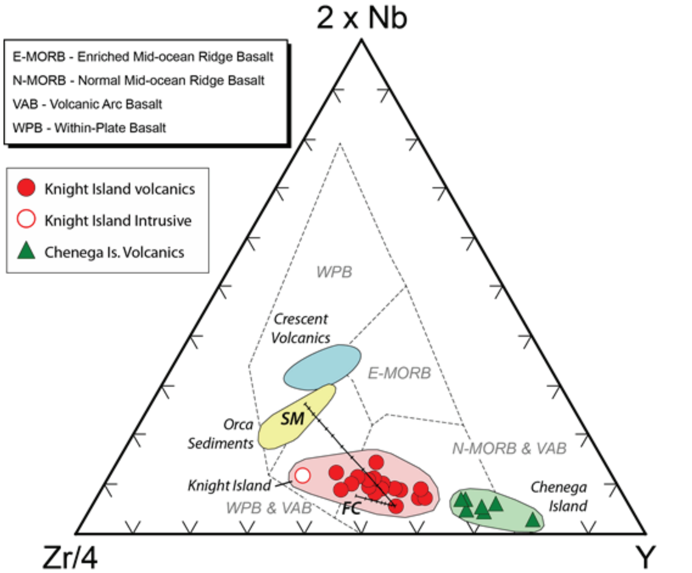

*Figure 4. Discriminant diagram using 2*Nb, Zr/4, and Y. Longer dashed line (SM) represents a sediment mixing line at ten percent increments between basalt and sediment. Shorter dashed line (FC) represents fractional crystallization model at ten percent increments from F = 1.0 to F = 0.2*

Orca Group volcanics appear to follow a trend consistent fractional crystallization (Figures 4 and 5). While these are clearly geochemically distinct suites, it appears that the volcanics from Chenega and Knight Islands could be derived from the same depleted source, produced by varying degrees of fractional melting (Figs. 4 and 5). Overall, the trace element abundances of both groups are similar to volcanic rocks erupted in supra-subduction zone settings. The low Nb and high LILE values of the Orca Group volcanics indicate their likely derivation from a depleted mantle source that has been modified by supra-subduction zone processes (Fig. 4).

Knight Island volcanics overlap with volcanics of the Resurrection Peninsula, verifying the correlation between these two ophiolite sequences (Fig. 2; Lytwyn et al., 1997; Nelson and Nelson, 1992). Resurrection Peninsula lavas and dikes exhibit relative enrichments in these same incompatible elements, Th, K, Rb, and Ba, further suggesting the correlation between the Orca Group ophiolites (Crowe et al., 1992; Nelson and Nelson, 1992).

Certain tectonic settings are implied by the results of this study though future research is needed to completely explain the tectonic environment of the Chugach-Prince William terrane. Trace element abundances compared to N-MORB suggest that the Orca Group volcanics formed in an environment markedly enriched in incompatible elements in relation to N-MORB (Fig. 3).

Most Knight Island samples compositionally plot in a range that can be accounted for by fractional crystallization of a MORB parent (Figs. 4 and 5). Previous researchers have proposed that the volcanic rocks of Knight Island, Resurrection Peninsula, and Chenega Island are related by variable partial melting of a MORB type mantle combined with variable interaction with sediment (Lytwyn et al., 1997). Lytwyn et al. (1997) and Nelson and Nelson (1992) proposed that the flysch contaminated basaltic lavas as they migrated upward along a partially subducted ridge before eruption. To test these models, sediment mixing and fractional crystallization models were created to consider how such processes contributed to the production of the varying geochemical compositions of the Chenega Island and Knight Island volcanics (Lytwyn et al., 1997; Barker et al., 1992). End members of the sediment mixing model are the most primitive volcanic sample and an average of the Orca sediments (Figs. 4 and 5). The fractional crystallization model uses Lytwyn's (1997) proportions of crystallizing phases of olivine, clinopyroxene, plagioclase, spinel, and magnetite, providing a fractional crystallization path that fits the trend of the volcanics in this study (Figs. 4 and 5). On Knight Island, Orca flysch is interbedded with pillow lavas (Fig. 3 in Hilbert-Wolf, this volume), signifying that the sediments likely covered the subducting ridge. Thus, the sediment-mixing model in Figures 4 and 5 cannot account for the full range of basaltic compositions in this study.

The geochemical results of this study could lead to correlation between the volcanics of the Prince William and the Crescent terranes. Major element data (Fig. 2) shows that the Crescent terrane basalts overlap with the compositions of Orca Group volcanics, indicative of their potential derivation from the same source. A field representing the Crescent volcanics in Figure 4 denotes a within-plate basalt tectonic setting,

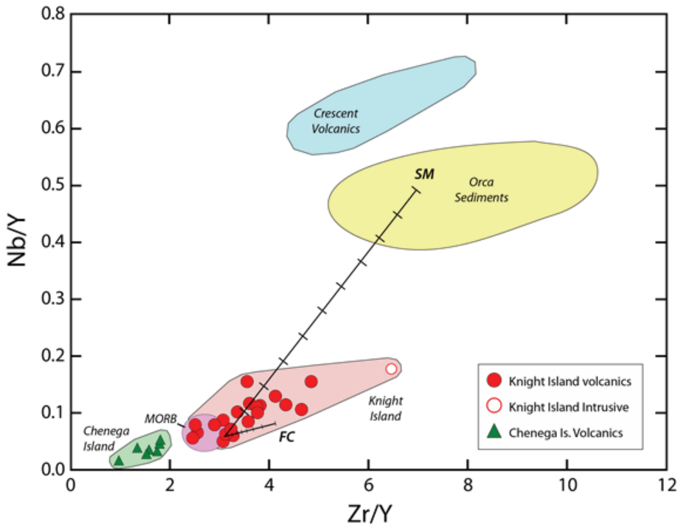

Figure 5. Binary diagram of Nb/Y versus Zr/Y. Knight Island (circles) and Chenega Island (triangles) follow similar fractionation trends. Symbols and modals are same in Figure 4.

consistent with the suggestion of a rift environment proximal to the continental margin (Timpa, 2005; Smith et al., 2009).

CONCLUSION

Early Tertiary subduction of a mid ocean spreading ridge beneath the accretionary complex of the Chugach-Prince William terrane provides a framework for the tectonic history of the area (Lytwyn et al., 1997; Bradley et al., 2003). The compositions of Orca Group volcanics on Knight and Chenega Islands are similar to each other, and to those of the Resurrection Peninsula (Lytwyn et al, 1997; Nelson and Nelson 1992). The range of basalt compositions within the Orca volcanics cannot be sucessfully modeled by mixing Orca Group flysch with parental basaltic melts; a fractional crystallization model better accounts for the trend observed in the Knight Island and Chenega Island volcanics. Basalts from the Crescent terrane of show markedly similar compositions to the Orca Group volcanics when utilizing major elements Fe + Ti, Al, and Mg, supporting Cowan's hypothesis of terrane translation though further investigations are recommended (Cowan, 2003). Further, geochemical analysis should be performed on other Orca Group volcanics that are not part of the ophiolites.

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