ORIGIN OF THE LATE EOCENE ESHAMY SUITE GRANITOIDS IN WESTERN PRINCE WILLIAM SOUND, ALASKA

EMILY JOHNSON, Whitman College
Research Advisor: Kirsten Nicolaysen

INTRODUCTION

The Eshamy suite plutons (ESP) are in the midst of the Sanak-Baranof (SB) belt, a series of near-trench, Paleocene to Eocene granitic intrusions into the Chugach-Prince William (CPW) terrane flysch along the southern margin of Alaska (Fig.1, Garver and Davidson, this volume and references therein). Intruded from 62-48 Ma, west-to-east migration of a subducting north-south-striking mid-ocean ridge is the widely accepted model for the emplacement of the SB plutons (Bradley et al., 2003; Cole et al., 2006; Cowan, 2003; Haeussler et al., 2003; Madsen et al., 2006). However, Cowan (2003) suggested that the same pattern of intrusion of the SB plutons can be explained by the coast-parallel migration of the CPW terrane over a stable trench-ridge-trench (TRT) intersection at the latitude of Washington State (48-49°N). Regardless of the tectonic geometry of the TRT interactions, these authors propose that as the ridge subducted, the adjacent oceanic plates diverged creating a slab window that exposed the continental margin to hot sub-oceanic asthenosphere and its associated basaltic melts. Near the trench, advective heat would drive melting of water-rich, poorly-consolidated sedimentary rocks. Intrusions formed through this process would be a mixture of mid-ocean ridge basalt (MORB) and accretionary prism sediments (Bradley et al., 2003; Kusky et al., 2003 and citations therein).

Problematically, ESP granitic plutons are both younger than and in the midst of the Sanak-Baranof belt; (Fig. 1) so their presence confounds expectations of the timing of magmatism based on this tectonic model (Nelson et al., 1985). Alternative tectonic models propose that Eocene plate reorganization returned ridge subduction to the Prince William Sound area resulting in these late Eocene plutons and the Caribou Creek volcanic field further inland (Cole et al., 2006; Cole and Stewart, 2009; Kusky et al., 2003; Madsen et al., 2006). As yet, the geochronology and geochemistry of the ESP has been rather cursorily investigated, providing an opportunity to test predictions related to the plate reorganization models.

In June of 2011, my collaborators and I described and sampled coastal outcrops of the Eshamy Bay and Nellie Juan plutons, their abundant xenoliths, and Orca Group sediments as a prelude to performing U-Pb zircon dating and bulk rock geochemical analyses. Following verification that these two ESP are younger than the Sanak-Baranof plutons, we analyzed the geochemistry with the expectation that a slab window geochemical signature would combine MORB-like and accretionary prism sedimentary (Orca Group) contributions. Our preliminary results confirm the younger Eshamy suite ages but the trace element geochemistry suggests that a strong accretionary sediment signature eclipses signs of any material contribution of MORB-like magmas. Finally, we demonstrate that the Eshamy Bay and Nellie Juan plutons are compositionally similar to the rhyolites of the synchronous Caribous Creek volcanics that occur across strike and about 200 km inland in the Matanuska and Talkeetna areas.

FIELD AND PETROGRAPHIC DESCRIPTIONS

The Eshamy Bay pluton is an extremely heterogeneous granitoid whereas the Nellie Juan pluton is more homogeneous. Granitic outcrops of the Eshamy Bay pluton are medium-grained leucocratic rocks containing biotite, hornblende, and Fe-Ti oxides. They range in composition from alkali-feldspar granite to granite to two-mica, quartz-rich granitoid, and show non-existent to well-defined foliation. Xenoliths are abundant in the Eshamy pluton and range in texture from fine- to coarse-grained and in composition from gabbro to diorite. The nature of the contact between the xenoliths and granitoid vary from sharp to diffuse boundaries and some cases are cuspate-lobate in texture. Many xenoliths have mafic cores with diffuse more felsic margins. The Nellie Juan pluton is a non-foliated, medium-grained leucocratic rock ranging from granite to alkali-feldspar granite. Nellie Juan xenoliths tend to have sharp boundaries. Hilbert-Wolf and Carlson (this volume) describe the source and thermal history of the lithic sandstones and shales of the Orca Group that represent the accretionary wedge.

ANALYTICAL METHODS

U-Pb Geochronology

We separated zircons from five ESP (Eshamy Bay, Nellie Juan, Hidden Bay, Esther Island, Perry Island) and from a nearby SB pluton at Sheep Bay. Fourteen to 26 zircons per sample were analyzed with Laser-Ablation Multicollector ICP Mass Spectrometry at the Arizona Laserchron Center at University of Arizona (see https://sites.google.com/a/laserchron.org/laserchron/home/ for analytical protocols).

Geochemistry

Five granitoid and eleven xenolith samples from the Eshamy Bay pluton, two granitoid and six xenoliths samples from the Nellie Juan pluton, and ten Orca group sands and shales were analyzed for major and trace elements using X-Ray Fluorescence at Macalester College.

RESULTS

U-Pb Geochronology

Consistent with ages previously analyzed for the SB belt in this location, Sheep Bay pluton has a crystallization age of 54.5 ±1.8 Ma (Table 1). As predicted from K-Ar and Ar-Ar dating of Nelson et al. (1985), the Prince William Sound plutons are younger (37.6 ±0.5 Ma to 39.9 ±0.7 Ma; Table 1, Fig.2). Geographically, the ages of the Eshamy suite young from east to west.

Geochemistry

The Eshamy Bay pluton consists of low-K, peraluminous granitoids (n=5, wt.% SiO_2 = 70.4 -76.9, wt.% MgO = 0.03 -0.60, wt.% Al_2O_3 = 12.1-13.3, Fig. 3a, b). The Eshamy Bay samples are enriched in Ba, Rb, K, Ce, La, Th and Nb and depleted in Ti, P, and Sr compared to Pacific normal mid-ocean ridge basalt (NMORB). All Eshamy Bay xenoliths are low-K and peraluminous; one is gabbroic in texture and composition (wt. % SiO2 = 48.6; wt. % MgO = 10.4; wt.% Al2O3=17.2) and the other ten are more silicic and very heterogeneous (wt.% SiO_2 = 55.2 -74.3, wt.% MgO = 0.2 -6.2, wt.% Al_2O_3 = 12.8 -15.5, Fig. 3a, b). The xenoliths have the same trace element trends as the granitoids.

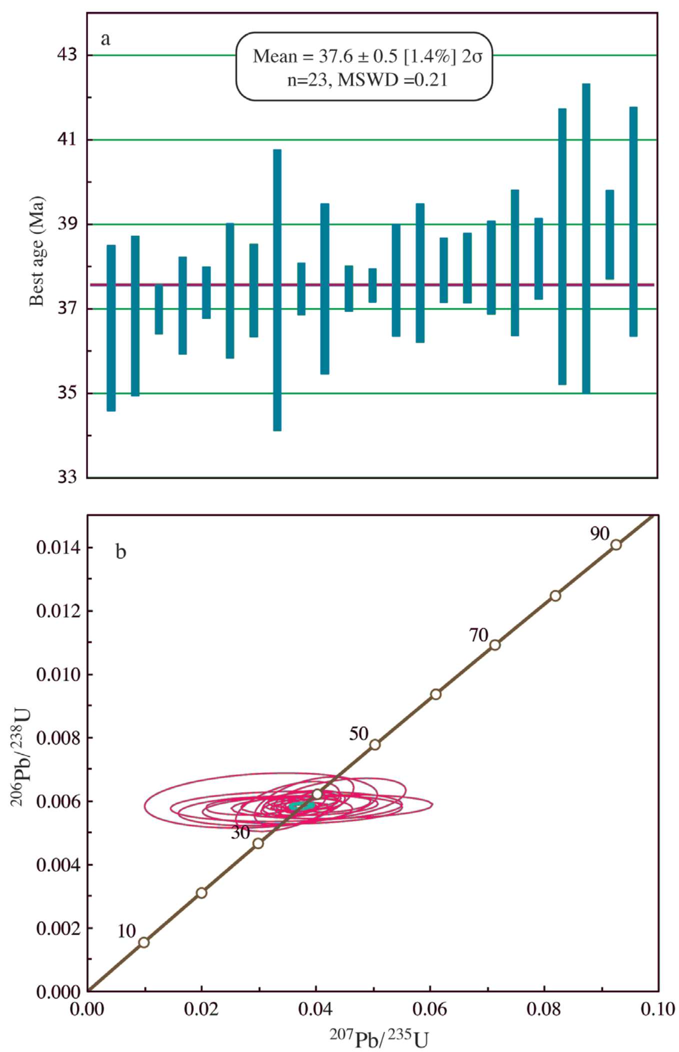

Figure 2a. The mean of 23 single zircon analyses returned an age of 37.6 Ma for the Nellie Juan pluton. 2b. Two-sigma error elipses cluster concordantly with the mean value in the blue ellipse.

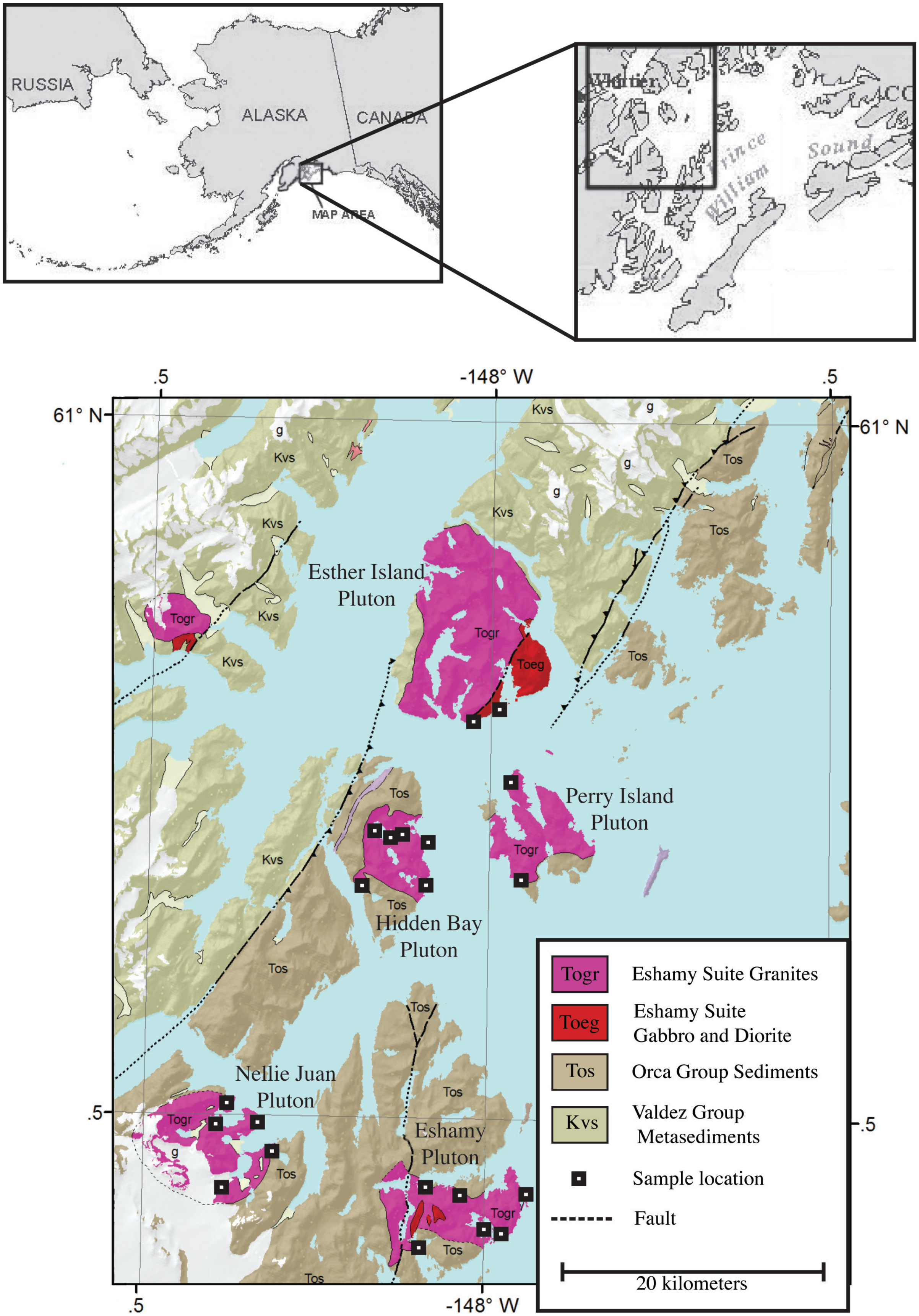

Figure 1: Geologic map showing the Eshamy suite plutons and sample locations in Prince William Sound, Alaska. Modified from Wilson et al. (2008).

The Nellie Juan pluton consists of medium-high K, peraluminous granitoids (n=2, wt.% SiO_2 = 75.5 -80.2, wt.% MgO = 0.05 -0.25, wt.% Al_2O_3 = 10.2 -12.1, Fig. 3a, b). The samples are enriched in Ba, Rb, K, Ce, Nd, Sm, Yb, Y, La and Th, and depleted in Ti, P and Sr compared to Pacific NMORB. The Nellie Juan xenoliths are low-K, peraluminous and less heterogeneous than Eshamy xenoliths (n=6, wt.% SiO_2 = 63.4 -71.6, wt.% MgO = 0.14 -2.19, wt.% Al_2O_3 = 12.8 -15.7, Fig. 3a, b), and are enriched in Ba, Rb, K, Ce, Nd, Yb, Y, La and Th, and depleted in Ti, P and Sr compared to Pacific NMORB.

The Orca Group sands and shales are similar to the xenoliths in major element composition though less heterogeneous than the xenolith suites, however the shales are slightly more aluminous and potassic as expected. The Orca sediments are also enriched in Ba, Rb, K, Ce, Sr, Th, Nb, Ta, La and Nd, and depleted in Sm, Hf, Ti and Y relative to NMORB.

DISCUSSION

In the Eshamy Bay pluton, the xenoliths are more mafic than the granitoids, and some major elements of both trend toward the composition of Pacific NMORB. These trends are particularly clear in TiO_2 (Fig. 3b), MgO, FeO, and Al_2O_3 vs SiO_2. There is no consistent correlation in trace element chemistry between the Eshamy Bay samples and NMORB composition. The Nellie Juan xenoliths follow similar trends towards the NMORB in major element chemistry, but are not as mafic and do not extend to NMORB composition. The trace element chemistry shows no correlation with NMORB, and spider element patterns for the granites cannot be generated by simple fractional crystallization of NMORB, suggesting again that the trace element signature of NMORB is obscured by other compositional sources.

The Orca Group sediments fall on the trend between the Eshamy Bay and Nellie Juan granitoids and NMORB in some major elements. In trace element chemistry, the Eshamy Bay xenoliths tend to clump around the Orca Group shales, while the Nellie Juan xenoliths consistently fall between the Nellie Juan granitoid and Orca Group shales (Fig. 3c; Fig. 4a).

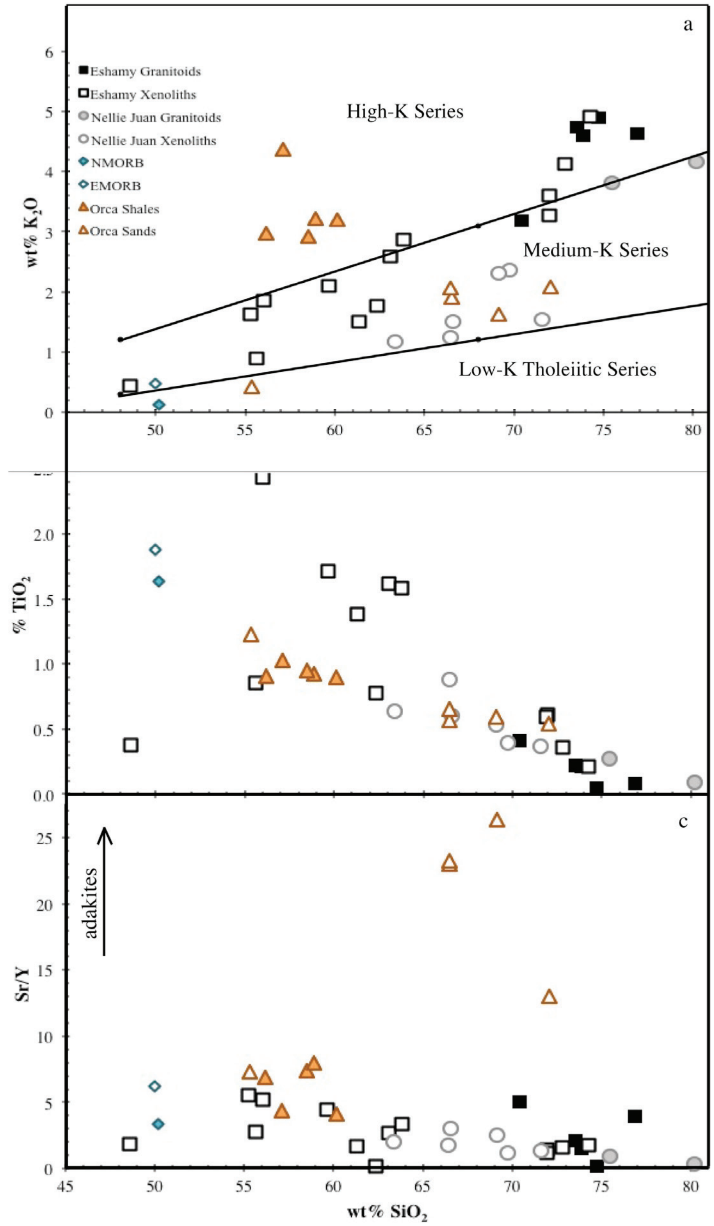

Figure 3a. K_2O vs. SiO_2 subalkalic rock classification diagram. With the exception of the most mafic xenolith from the Eshamy pluton and the granies from the Nellie Juan pluton, the samples fall in the low-K tholeiite series. 3b. TiO_2 vs. SiO_2. Note the trend from the Orca Group shales toward the plutons and up towards the xenoliths (restites). We interpret this as due to fractionation of observed titanite and other Ti-bearing phases in enclaves with smaller abundances of these Ti-bearing phases in the granitoids and some siliceous xenoliths. Also note the dissimilarity to both NMORB and enriched MORB. The Eshamy Bay samples show much more variation than the Nellie Juan samples. 3c. Sr/Y vs. SiO_2. High Sr/Y is one of the primary signatures of adakite lavas (Yogodzinski et al., 2001; Cole et al., 2003) but Eshamy and Nellie Juan granitoids do not have an adakite signature. Intriguingly some Orca Group lithic sandstones trend in the direction of adakite compositions.

Sample	Location	Latitude	Longitude	n	U (ppm)	U/Th	Age (Ma)	2σ (Ma)
10EB-05	Eshamy Bay	N 60.462	W 148.009	24	2944	2.4	38.4	0.8
11CD-21	Nellie Juan	N 60.45493	W 148.38866	23	849	2.5	37.6	0.5
11CD-27	Perry Island	N 60.74121	W 147.98184	23	321	2.2	39.9	0.7
11CD-29	Esther Island	N 60.78421	W 148.04295	20	286	3.3	39.5	0.8
JG10-35	Hidden Bay	N 60.6999	W 148.154	11	489	4.0	38.7	4.1
TI10-02	Sheep Bay	N 60.6908	W 145.969	18	751	3.8	54.5	1.8
n = number of individual zircon grains analyzed								

Table 1. U-Pb zircon dates of plutons in Prince William Sound.

This suggests that the granitoids and some xenoliths look like partial melts of sediments as they extend beyond the area of simple mixing between the bulk sediment composition and NMORB. The partial melting trend away from the Orca Group shales towards the granitoids could be enhanced by fractional crystallization. The xenoliths that do not fall between the composition of the granitoids and Orca Group sediments could represent restites of sediment partial melting.

Approximately 200 km to the north of the ESP, the Caribou Creek Volcanic Field (CCVF) consists of extrusive volcanic rocks ranging from basalt to rhyolite, some of adakitic composition (Cole et al., 2006). Using $^{40}Ar/^{39}Ar$ dating, Cole (2006) found the ages of two adakites from the CCVF are 59.0 ± 0.4 Ma and 39.9 ± 0.7 Ma (Cole et al., 2006). Adakites are rocks that formed by partial melting of the subducting oceanic slab, which could occur during ridge subduction and at the edge of slab windows due to the high heat flow (Cole et al., 2006; Kay, 1978; Yogodzinski et al., 2001). In light of the adakites and the presence of a strong NMORB signature in the CCVF basalts, the CCVF is attributed to a slab window and local crustal extension (Cole et al., 2006). The Eshamy granitoids, although geographically close and overlap in timing with the CCVF, do not exhibit adakitic trace element composition (Fig. 4a). However, the PWS granitoids do show a correlation in LILE and HFSE with the CCVF rhyolites, and one rhyolite mirrors the Eshamy granitoids in trace element composition (Fig. 4b).

The connection between high-silica rhyolites and granitoids is not well understood. Studies in the Sierra Nevada, CA, suggest that rhyolites are not geochemically complementary to their residual pluton- in fact, that the trace element patterns are significantly different between the two rocks (Glazner et al., 2008). A possible explanation for the similarity between the ESP and the CCVF rhyolites is the difference between residual and non-residual plutons. The ESP is not directly associated with any rhyolites and thus did not become depleted or enriched in trace elements due to partial melting processes. Therefore the similarity in trace element trends in the CCVF and ESP could represent a possible stage of CCVF rhyolite development.

The compositional similarities between the CCVF rhyolites and the Eshamy Bay and Nellie Juan plutons suggest that the granitoids, although heterogeneous and from a deeper crustal level, represent a snapshot of the processes that led to the CCVF rhyolites. Sediment melting of the Orca Group is likely an important process in the formation of these granitoids. It is likely that MORB also has a contributing role in the formation of the PWS granitoids, mainly in heat contribution but also compositionally (e.g. the gabbroic Eshamy Bay xenolith, and basalt-cored xenoliths). The model of mid-ocean-ridge subduction suggested by Cole et al. (2006) fits the data we collected with the exception of the lack of adakite composition in the Eshamy granitoids.

CONCLUSIONS

The five sampled granitoid intrusions of the Eshamy suite in Prince William Sound were emplaced between 37.6 ± 0.5 and 39.9 ± 0.7 Ma, indicating that they were intruding much later than SB belt intrusions and at the same time as the later volcanic activity to the north in the CCVF. Geochemically, our samples

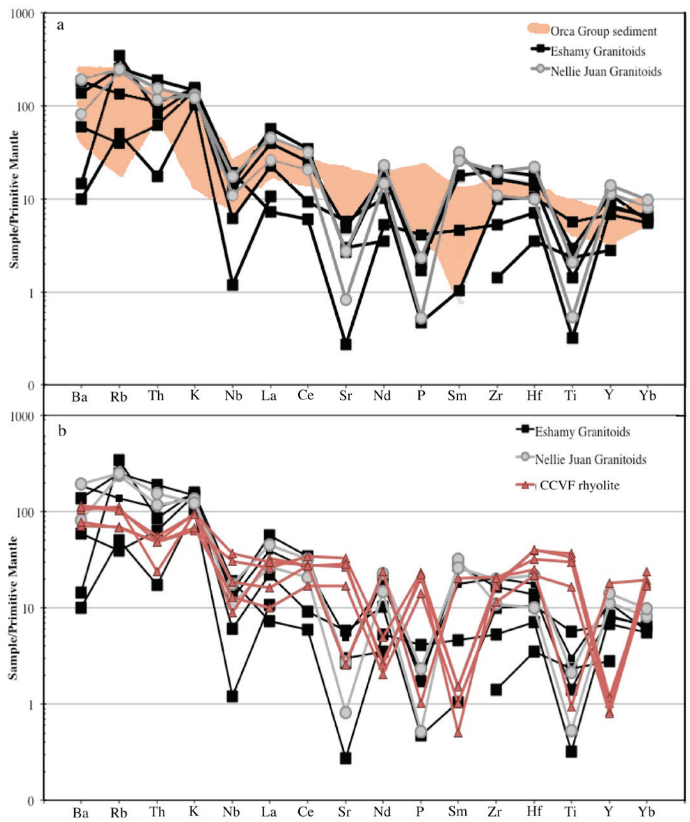

Figure 4a. Spider diagram showing the Eshamy and Nellie Juan granitoids overlap the compositional range of the Orca group sediments, normalized to primitive mantle values (Palme and O'Neill, 2004). Note wide variation in the Eshamy granitoids compared to the Nellie Juan granitoid, and the general overlap between the sediments and ESP. 4b. Spider diagram showing the Eshamy and Nellie Juan granitoids and the CCVF rhyolites. The similarity between the trends in HFSE and LILE we interpret as similar melt-forming processes. Also note the one rhyolite sample that very closely mirrors the ESP trace element trend.

show no clear MORB signature and do not have an adakitic composition suggestive of chemical contributions from the melting subducted slab or the mantle. However, the Eshamy suite granitoids and xenoliths show similar LILE and HFSE trace element compositions to the rhyolites of the CCVF (Cole et al., 2006). This suggests that the Eshamy suite granitoids provide a snapshot of the crustal processes that created the CCVF rhyolites, namely mixing of a minor amount of basalt with a substantial amount of sediment melt as represented by Orca Group compositions. Some xenoliths in these plutons could possibly represent restites of the partially melted Orca group sediments, but a few (gabbroic xenolith in EB and basalt-cored xenoliths in EB) may represent MORB components. The model that suggests a slab window as the driving process for the formation of the Eshamy suite intrusions is plausible.

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REFERENCES

Bradley, D., Kusky, T. M., Haeussler, P. J., Goldfarb, R., Miller, M. L., Dumoulin, J., Nelson, S. W., and Karl, S., 2003, Geologic signature of early Tertiary ridge subduction in Alaska: Geological Society of America Special Paper, v. 371, p. 19-49.

Cole, R. B., Nelson, S. W., Layer, P. W., and Oswald, P. J., 2006, Eocene volcanism above a depleted mantle slab window in southern Alaska: Geological Society of America Bulletin, v. 118, no. 1-2, p. 140-158.

Cole, R. B., and Stewart, B. W., 2009, Continental margin volcanism at sites of spreading ridge subduction: Examples from southern Alaska and western California: Tectonophysics, v. 464, no. 1-4, p. 118-136.

Cowan, D. S., 2003, Revisiting the Baranof–Leech River hypothesis for early Tertiary coastwise transport of the Chugach–Prince William terrane: Earth and Planetary Science Letters, v. 213, no. 3-4, p. 463-475.

Glazner, A. F., Coleman, D. S., and Bartley, J. M., 2008, The tenuous connection between high-silica rhyolites and granodiorite plutons: Geology, v. 36, no. 2, p. 183-186.

Haeussler, P. J., Bradley, D. C., Wells, R. E., and Miller, M. L., 2003, Life and death of the Resurrection plate: Evidence for its existence and subduction in the northeastern Pacific in Paleocene-Eocene time: Geological Society of America Bulletin, v. 15, no. 7, p. 867-880.

Kay, R. W., 1978, Aleutian magnesian andesites: melts from subducted Pacific Ocean crust: Journal of Volcanology and Geothermal Research, v. 4, p. 117-132.

Kusky, T. M., Bradley, D., Donley, D. T., Rowley, D., and Haeussler, P. J., 2003, Controls on intrusion of near-trench magmas of the Sanak-Baranof belt, Alaska, during Paleogene ridge subduction, and consequences for forearc evolution: Geological Society of America, v. Special Paper 371, p. 269-292.

Madsen, J. K., Thorkelson, D. J., Friedman, R. M., and Marshall, D. D., 2006, Cenozoic to Recent plate configurations in the Pacific Basin: Ridge subduction and slab window magmatism in western North America: Geosphere, v. 2, no. 1, p. 11.

Nelson, S. W., Dumoulin, J., and Miller, M. L., 1985, Geologic Map of the Chugach National Forest, Alaska: U.S. Geological Survey Miscellaneous Field Studies Map MF-1645B, p. 14.

Palme, H. and O'Neill, H. St. C. (2004). Cosmochemical Estimates of Mantle Composition, in: Treatise on Geoechemistry, Holland, H. D. and Turrekian, K. K. (Editors), Elsevier, Amsterdam, The Netherlands. 2: 1-38.

Yogodzinski, G. M., Lees, J. M., Churikova, T. G., Dorendorf, F., Wöerner, G., and Volynets, O. N., 2001, Geochemical evidence for the melting of subducting oceanic lithosphere at plate edges: Nature, v. 409, p. 500-504.

Wilson, F.H., Hults, C.P., Labay, K.A., and Shew, N., 2008, Preliminary integrated geologic map databases for the United States: Digital data for the reconnaissance geologic map for Prince William Sound and the Kenai Peninsula, Alaska: U.S. Geological Survey Open-File Report 2008-1002, 66 p., 1 sheet, scale 1:350,000: pubs.usgs.gov/of/2008/1002.