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THERMAL EVOLUTION AND PROVENANCE REVEALED THROUGH DETRITAL ZIRCON FISSION TRACK DATING OF THE UPPER CRETACEOUS SHUMAGIN FORMATION, NAGAI ISLAND, ALASKA

MICHAEL JAMES DELUCA, Union College
Research Advisor: J.I. Garver

GEOLOGIC BACKGROUND

The Shumagin Formation is part of the Chugach terrane, and directly inboard of the Chugach terrane the continental framework is made up of the Wrangellia superterrane. The Shumagin Formation is a Maastrichtian turbidite complex that was likely part of an accretionary complex that was intruded by near-trench plutons. These main tectonic elements of the Alaskan margin are reviewed below.

Wrangellia Superterrane. The Paleozoic to Mesozoic Wrangellia superterrane (Insular terrane) consists of intraoceanic volcanic assemblages and basement rocks of the Peninsular, Wrangellia, and Alexander terranes (Plafker et al, 1994). The magmatic-arc assemblages of the Peninsular terrane appear to have been built upon the Wrangellia composite terrane prior to the mid-Cretaceous and include: 1) a portion of the Talkeetna arc of the Peninsular terrane, and 2) a belt of plutonic rocks which includes the Chitina arc in the Wrangellia and Alexander Terranes and 3) the Chisana arc (Plafker et al, 1994).

The Chugach/ Prince William terrane. The Mesozoic Chugach terrane extends from the Sanak Islands to Chatam strait in Southeastern Alaska and extends to the Border Ranges fault, and is 100 km wide and 2200 km long (Weinberger, 2003). The Chugach terrane is confined by two major faults, the Border Ranges fault separates Wrangellia superterrane to the north and the Contact fault separates the Paleogene accreted sequences of the Ghost Rocks and Orca Group to the south (Plafker et al, 1994). To the east, the Chugach terrane is bound by the Fairweather fault system against rocks inferred to be displaced fragments of the Chugach terrane (Plafker et al, 1994). The Chugach terrane consists of sandstone, mudstone, minor volcanic rocks, chert, and metamorphic rocks that were assembled into an accretionary wedge during Cretaceous and early Tertiary subduction along the northwestern margin of North America (Cowan, 2003). The main element of the terrane is the Campanian-Maastrichtian Valdez Group, which is comprised of mélange, turbidites, and minor volcanics. The Prince William terrane consists of Paleocene-Eocene Orca Group, which is comprised of turbidites and volcanic rocks (Carlson, 2011). About 90% of the Chugach and Prince William terranes are a flyschoidal sequence and span over 2000 km and are Campanian to Maastrichtian in age. Along the flysch there are units that are correlative, and include (from west to east): the Shumagin Formation, the Kodiak Formation, the Valdez Group, the Sitka Graywacke, and the Yakutat Group. The only comparable ZFT study to ours in the region was on Kodiak Island (Clendenen, 2003). They dated 9 samples (69 grains) from the Kodiak Formation/ Ghost Rocks and observed reset grain-age populations between ~43-59 Ma, with most at ~50 Ma (Clendenen, 2003). They suggest that these reset samples may have been heated during regional metamorphism or ridge-trench interaction (Clendenen, 2003). They also identified a partially reset population from the seaward belt at ~66 Ma (Clendenen, 2003).

Shumagin Formation. The primary unit of concern in the Chugach terrane in the Shumagin islands is the Maastrichtian Shumagin Formation. The Shumagin Formation was deposited in a submarine fan in a trench setting adjacent to a volcanic arc and occurs on the outer continental margin of the Alaskan

Table 1: Binomial component ages of detrital zircon fission-track data, Shumagin Formation

Sample	Etch Time (hr)	n	Age range (Ma)	P1	P2	P3	P4
Shumagin Formation (Reset)							
NI12-06	16.5-22.5	50	26.6-151.0	44.0 ± 1.9 98.0%	154.6 ± 53.4 2.0%		
NI12-10	21	36	35.9-85.0	56.2 ± 2.6 100.0%			
NI12-12	21	50	31.0-131.7	53.8 ± 4.5 79.1%	80.7 ± 25.1 20.9%		
NIAS-114	16.5-27.0	50	25.7-77.1	47.2 ± 2.1 100%			
Combined		119	18.9-123.8	49.8 ± 1.8*	---		
Shumagin Formation (Partially reset)							
NI12-09	21	25	40.6-97.2	50.1 ± 7.4 39.7%	65.9 ± 7.9 60.3%		
NI12-23	16,5-22.5	50	44.3-183.0	58.4 ± 4.6 50.1%	82.8 ± 10.6 36.1%	127.8 ± 22.3 13.8%	
NI12-24	16.5-22.5	50	34.8-121.2	45.4 ± 8.1 9.8%	69.8 ± 5.8 62.7%	101.6 ± 10.8 27.5 %	
Combined		125	34.8-183.2	53.2 ± 5.2 27.8%	71.0 ± 6.8 52.9%	109.3 ± 10.0 19.3%	137.8 ± 21.6* 2.2%
Shumagin Formation (Unreset)							
NI12-08	16.5-22.5	44	45.1-122.4		71.2 ± 6.3 69.1%	92.9 ± 15.1 30.9%	
NI12-18	16.5-22.5	50	40.6-142.3		71.2 ± 3.2 91.2%	121.5 ± 16.85 8.8%	
Combined		94	40.6-142.3		71.7 ± 3.3 84.0%	104.5 ± 13.8 16.0%	

Note: Ages denoted with an astrix (*) are poorly approximated, and here is the χ^2 age of the three fully reset samples. n = number of dated grains; Uncertainties are cited at 68% confidence interval (about ±1 SE; asymmetric errors are averaged). Zircon grains were dated using standard methods for FT dating using an external detector. Zircons were extracted using standard separation procedures. Fission-tracks were counted on an Olympus BX60 microscope fitted with an automated stage and Calcomp digitizing tablet. Total magnification was 1250x (100x objective, 10x oculars, 1.25 tube factor). A Zeta factor of 366.4 ± 9.5 (± 1 se) was as computed from 10 determinations on standard samples (Fish Canyon Tuff, and Peach Springs Tuff). This table shows all binomial peak fitted ages using Binomfit 1.2.63 (Brandon, 1992)

Peninsula (Moore, 1973). The Shumagin Formation is comprised of medium- to thick-bedded turbidites that have a cumulative thickness estimated to be 3 to 4 km thick. The formation is up to 40% volcanically derived framework grains, and it has been metamorphosed to zeolite facies (Moore, 1973), except in areas adjacent to plutons, which are in the hornblende-hornfels and prehnite-pumpellyite facies (Roe et al., 2013). The modern Aleutian arc borders this sedimentary belt to the north and is flanked by the Aleutian trench to the south (Moore, 1973).

Sanak-Baranof Plutonic Belt- The Paleocene to Early Eocene Sanak-Baranof Plutonic Belt consists of plutons of primarily granodiorite, and some granite, tonalite, and gabbro (Bradley, 2003). The CPW terrane was intruded diachronously by the Sanak-Barnof belt, and is inferred to be the result of ridge subduction (Bradley, 2003). Near-trench magmatism of the Sanak-Baranof belt progressed from west to east at ~62-63 Ma to ~50-52 Ma. The Sanak-Baranof belt has been dated as far east as Sanak and the Shumagin Islands, and on Nagai it has U/Pb age of ~63 Ma (Short et. al, 2013).

ZIRCON FISSION-TRACK DATING

Fission track dating of zircon ($ZrSiO_4$) has become one of the most important methods for studying sediment provenance and the exhumation of orogenic belts (Bernet and Garver, 2005). The abundance of zircon in igneous, metamorphic, and sedimentary rocks along with its high resistance to weathering and abrasion make it an excellent candidate for grain-age determinations (Bernet and Garver, 2005). Fission-track dating utilizes the natural and spontaneous fission of ^{238}U, which spontaneously fissions into two daughter nuclides and in leaves a narrow trail of damage along its trajectory, called a fission track (Wagner and van den Haute, 1992). Fission track dating is similar to other isotopic dating methods and is based on the decay of a naturally radioactive parent to a stable daughter atom (Wagner and van den Haute, 1992). The calculation of a fission-track age is based on the number of spontaneous fission tracks and the number of ^{238}U atoms per unit of volume in the sample (Wagner and van den Haute, 1992). Tracks remain permanently in the crystal lattice of zircon as long as temperatures remain relatively low (less

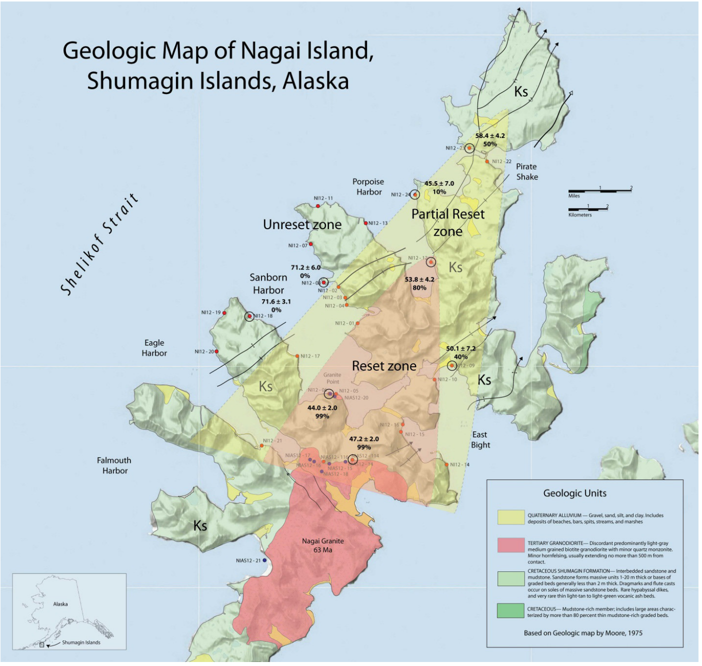

Figure 1. Area of study on Nagai Island, Alaska and sample sites with mean FT ages and percentage of grains reset. The red Reset area encompasses an area of entirely reset grain populations, and the yellow area encompasses an area with partially reset grain populations. The Nagai pluton is shown in red. Samples NI12-18 and NI12-08 (to west) contain unreset grain populations.

than 200 °C – Bernet and Garver, 2005; Garver et al., 2005). Therefore, indicated grain-ages represent how much time has passed since last exposure to the closure temperature. Note that in a typical crustal column with a geothermal gradient of 25°C/km, this closure temperature corresponds to a depth of about 10 kilometers.

METHODS

A total of 33 samples were collected from the Maastrichtian Shumagin Formation on Nagai Island, of which nine were carried through for full ZFT dating. Samples collected in the field consisted of 2 to 5 kg of coarse- or medium-grained sandstones. Samples for ZFT dating were collected in localities in a rough transect across the Shumagin Formation on Nagai Island. This cross section hopefully provides the stratigraphic range necessary to study provenance and thermal evolution of the Shumagin Formation in this part of the Shumagin Islands.

Zircon Extraction. Samples were processed according to the standard extraction procedures in the Union College Fission Track Laboratory Manual (see also Bernet and Garver, 2005). Extraction and preparation for detrital zircon fission track analysis begins with initial crushing using a Chipmunk jaw crusher and a Bico Braun® Pulverizer. Mineral separation is accomplished using a Rodgers table and geoliquid® tetrabromoethane, both of which separate minerals by their specific gravity. Samples were then put through the Frantz magnetic separator several times to remove magnetic minerals. Separation was complete after the final separate was passed through methylene iodide, of which the dense fraction from this separation was then used for analysis.

Sample Preparation. After extraction, zircon grains were mounted in Teflon® squares at 330 °C on a hot plate using the glass-sandwich method (Bernet and Garver, 2005). Mounts were also made using this technique for the Fish Canyon Tuff, and Peach Springs Tuff age standards. Mounts were then cut using 800 grit sandpaper and polished on a Buehler variable speed grinder using two diamond suspension solutions to reveal grain surfaces, and finally with Micropolish II aluminum oxide slurry. Polishing was considered to be complete after mounts were examined at 400x magnification and had few if any scratches.

After polishing, Teflon mounts were etched in a NaOH-KOH solution heated to the eutectic (228°C) for 16-24 hours. The flattened and cleaned mounts were then fitted with a hand-cut mica flake and placed in an irradiation tube with glass standards at the front, middle, and top of the sample stack. The tube of samples was sent to Oregon State University where it was irradiated in the Oregon State Nuclear Reactor, receiving a nominal fluence of $2x10^{15}$ n/cm^2 (Irradiation U52Z, August 2012). After irradiation, Teflon mounts and associated mica sheets were cut and detached so the have the exact some dimensions. Mica sheets were etched in 48° HF solution for 15 minutes. Teflon mounts with zircon and corresponding mica sheets were mounted as mirror images on a glass slide with epoxy and a glass cover slip beneath the mica sheet to accommodate the difference in height between the Teflon mount and the thinner mica flake.

Counting Fission Tracks. The natural spontaneous fission tracks on the zircon grains and the induced tracks on the mica were counted at 1250x using

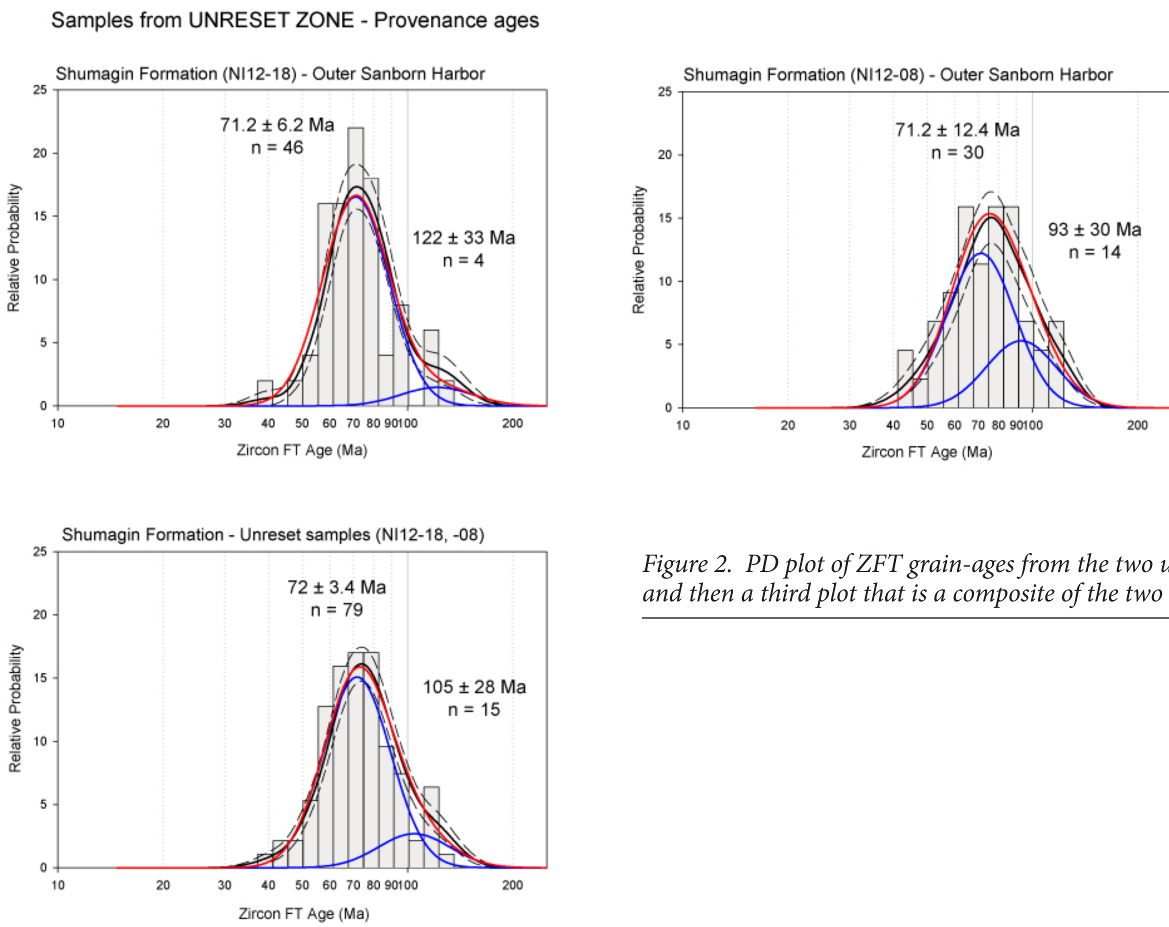

Figure 2. PD plot of ZFT grain-ages from the two unreset samples, and then a third plot that is a composite of the two samples.

an Olympus® BMAX-60 microscope using both transmitted and reflected light. The equipment used to orient, navigate, and mark grains include: FTstage v2.0 software, a Kinetik® automated stage, and a CalComp® digitizing tablet. Grains were marked for age determination and were assessed for countability based on the following: etch figures oriented parallel to c-axis, free of inclusions, little zonation, an even uranium distribution, sufficient countable area, and optical clarity (Bernet and Garver, 2005). Tracks on individual grains were counted using a 10 x 10 grid placed in the microscope ocular. Induced tracks on the associated mica print were then counted to determine uranium concentrations. To calculate the zeta calibration factor, spontaneous and induced tracks were counted in at least 10 grains for each of about 12 standards of known age. Track densities were then used to calculate zeta factors in the Zetamean program, which produced a zeta factor for each standard. Individual component populations were determined using Binomfit (from M.T. Brandon, Yale Univeristy).

RESULTS

A total of nine samples were analyzed by ZFT dating. Binomfit was used for all samples that fail χ^2, and for samples that passed χ^2, the pooled ages are used. NI-06, NI-10, and NIAS-114 all passed χ^2, and the reported age is the pooled age. NI-09 also passed χ^2, and was the only exception because only 25 grains were counted and was peak fitted using Binomfit. NI-08, NI-12, NI-18, NI-23, and NI-24 all failed χ^2 and were peak fit.

These samples can be divided into those that are reset, partially reset, and unreset. Considering the depositional age of 73-77 Ma (Campanian-Maastrichtian - see Roe et al, 2013), samples that have grain-age populations that are younger than the time of deposition must indicate annealing and thermal resetting after deposition. There appear to be three distinct ZFT signatures in all samples. NI-08 and NI-18 are not thermally reset and likely represent the cooling age distribution of the rocks in the original source terrane (Fig. 2). Data from these Unreset

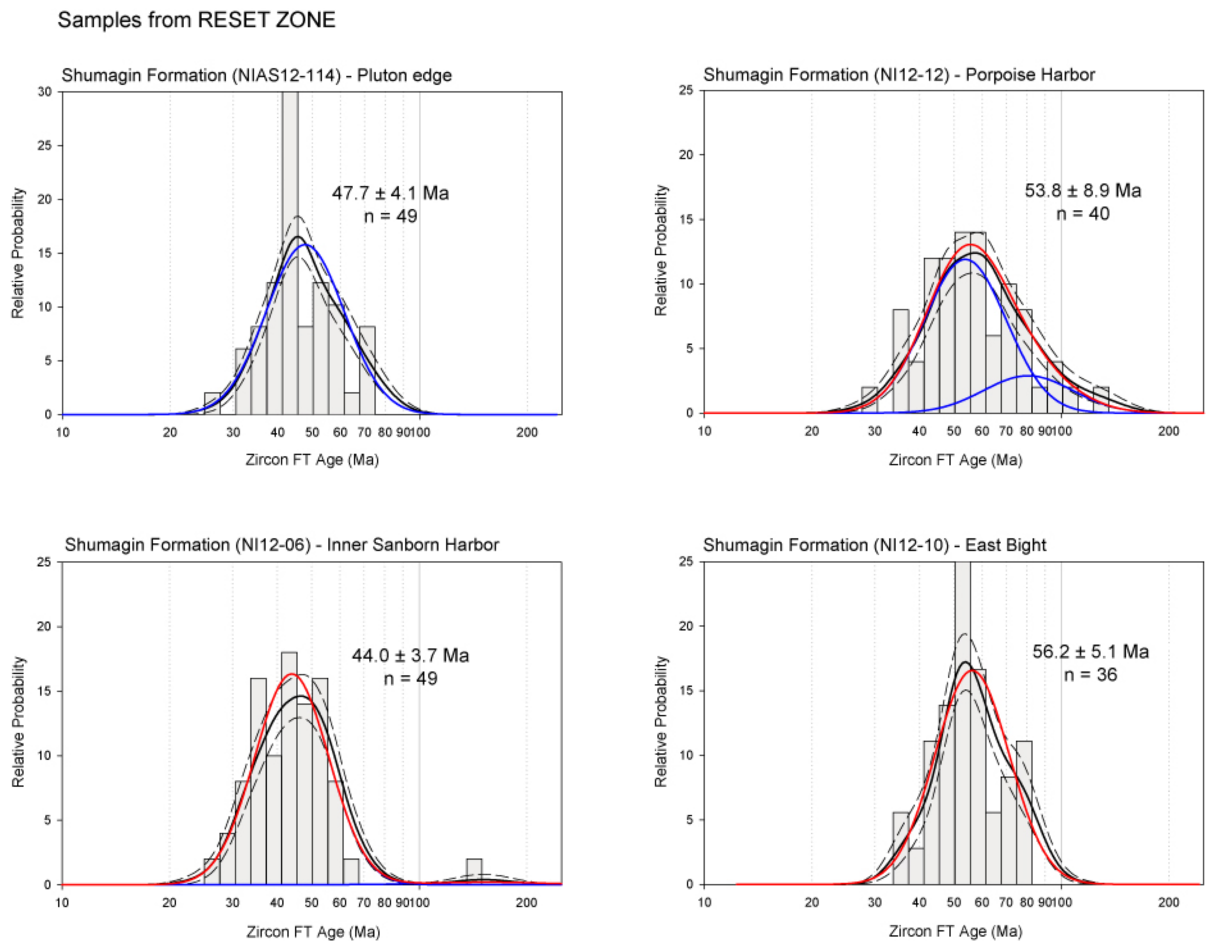

Figure 3. PD plot of ZFT RESET grain-ages from Nagai Island. Shown on the plot is the young component age population.

samples (NI-08, NI-18) were pooled and reveal two distinct cooling ages at 72 and 105 Ma. These two unreset samples contain a young age around 71-72 Ma, and these are statistically indistinguishable from the deposition age, and therefore considered to be unreset. Samples NI-06, NI-10, NI-12, and NIAS-114 all record ages younger than formation ages and are likely reset (Fig. 3). The Reset population ranges from 44-53 Ma and this is from samples directly adjacent to the plutons and others where ~80-100% grains are reset. NI-23, NI-24, and NI-09 contain partially reset grain age populations because they contain a young component and one or more that is older. The partially reset population shows wide scatter and a range of grain ages younger than deposition, but the main group is from 45-58 Ma (10-50% grains reset) but these samples also have older grain age populations. Samples NI12-12 and NI12-23 were double-dated using ZFT and U/Pb dating, and ages reveal two distinct suites. The younger suite contains U/Pb ages between 70-100 Ma and ZFT ages between

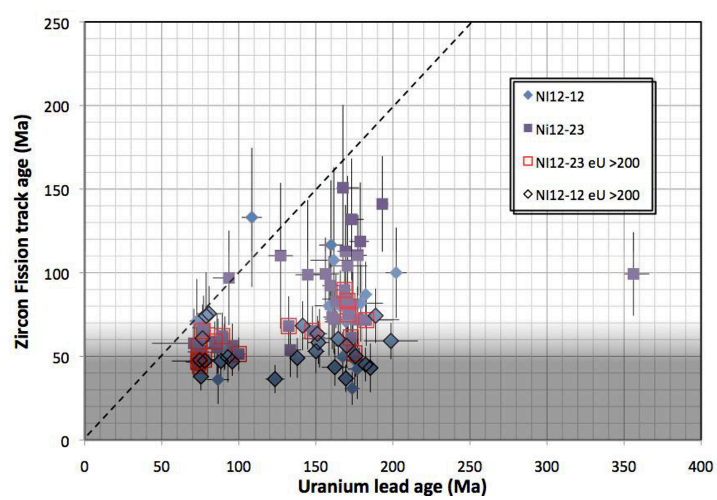

Figure 4: Double dated samples.

40-65 Ma, with many ZFT ages between 90-100 Ma. The older suite contains U/Pb ages between 130-290 Ma and ZFT ages between 40-150 Ma, with many ZFT ages between 40-60 Ma and 70-90 Ma.

DISCUSSION

Samples from the Shumagin Formation indicate three distinct grain-age populations and are most likely associated with proximal thermal heating from plutonism (Figures 2,3). Three populations are derived from the data: unreset (Fig. 2), reset (Fig. 3), and partially reset zone (not shown in this paper). These three zones extend outward from the pluton in an elongate (NE-SW) orientation. The elongate reset pattern may indicate a complex thermal history of Nagai Island, and it is possible that there are other plutons at depth that played an integral role in resetting ZFT ages. The Shumagin Formation, and the associated CPW terrane, were diachronously intruded and heated by the Sanak-Baranof plutonism that progressed from west to east between ~63 Ma and ~50 Ma , respectively (Bradley, 2003), and we have dated a granitic intrusion on Nagai Island to 63 Ma (Roe, 2013). The subsequent cooling pattern is revealed by reset DZFT ages in many samples from Nagai Island (Fig. 3). Similar FT data has been observed in the Kodiak Formation/ Ghost Rocks, which are a piece of the CPW terrane very similar to The Shumagin Formation (Clendenen, 2003). They observed FT ages representative of a reset zone (~50Ma) and a partially reset zone (~66 Ma), which are very similar to our findings (Clendenen, 2003). Although they only dated 69 grains, it appears that it does reinforce our findings.

Two samples were double-dated using U/Pb and ZFT techniques (Fig. 4). U/Pb ages indicate the original crystallization age of a zircon, and the ZFT age gives the time of cooling. If a sample has not been subsequently heated after deposition, the U/Pb and ZFT ages should be indicate the duration of time between formation and cooling. In the case of a volcanic grain, both U/Pb and ZFT should be the same. In the case of granites, the difference is the time required to cool the pluton or exhume the rock toward the surface. In the case here, samples were deposited and then subsequently heated to temperatures approaching the closure temperature of zircon (as low as 200°C). In this case <u>some</u> of the ZFT ages will represent that thermal event, whereas other more retentive grains may get partially reset or may remain unreset.

Our results from the two double-dated samples have several implications. It appears that grains with high uranium concentration (or here high eU, which accounts for Th) are more likely to be reset than those with low uranium concentrations. Overall the U/Pb ages show that grains are indicative of two distinct suites of rock in the source area. The younger suite indicates a U/Pb age of between 70-100 Ma with FT ages between 30-70. We suggest that these rocks are from the volcanic arc, and FT ages reveal no significant heating after initial cooling.

The second suite consists of U/Pb ages between ~130 and 190 Ma, with FT ages between ~30-120 Ma. We suggest that these grains are derived from a metaplutonic basement complex, and show a wide range of cooling histories. However, many of the grains with low uranium concentration appear to be more resistant to thermal FT resetting, and therefore may not accurately represent the cooling history (Figure 4, data points bordered in red). FT ages of high eU range from ~50-90 Ma, which we infer to be the reset cooling ages of these samples.

Two sandstone samples appear to be unreset and thus provide original provenance information. Unreset grains have not been annealed by subsequent heating events, and thus ZFT dating reveals the time at which zircon grains cooled from their original source. It has been suggested from geochronological and paleomagnetic data that the CPW terrane, which includes The Shumagin Formation, has been translated to its current position along the southern margin of Alaska and subsequently intruded by plutonism associated with ridge subduction and the associated slab-window (Cowan, 2003). Therefore the unreset DZFT samples indicate the nature of the source terrane, and possibly the original position of the Shumagin Formation. Note that the two primary grain-age populations are at 72 and 105 Ma. The first population is nearly identical in both units and this undoubtedly represents volcanic grains – an interpretation supported by the double dating. The older population is wide, and when the two samples are combined yields a cooling age of 105

Ma. Therefore, these ZFT ages represent original provenance ages and record cooling of the source rock, not the subsequent subduction and plutonic events. There are a number of faults in the PWS that have kinematics that indicate right-lateral strike-slip faulting (Bol and Roeske, 1993). Considering that the Shumagin Formation may have been translated a significant distance northward on the Pacific plate margin prior to accretion and intrusion in its present location, it is plausible that the source was the Coast Mountains orogen in British Columbia.

It has been suggested that the Shumagin Formation was subducted to depth (Moore, 1975) and FT dates should be indicative of the thermal history throughout subduction and subsequent exhumation. In our samples, we identify four reset samples (NI-06, NI-10, NI-12, and NIAS-114), three partially reset samples (NI-23, NI-24, and NI-09), and two unreset samples (NI-08 and NI-18). Two key observations guide thought about burial path for these rocks: 1) Most resetting appears to be spatially related to the pluton; 2) the post-intrusive cooling is 10-15 Myr younger than intrusion; 3) thermal resetting did not affect all samples, thus the rocks were probably not brought to depths with temperatures > 250 or 300°C. Thus we can conclude that burial was to depths at or near the lower bound of the zircon partial annealing zone, and after intrusion of the plutons the rocks remains at depth until the Eocene (c. 50 Ma) when they then passed upward to lower temperatures. Slow cooling would explain the wide range of grain ages.

REFERENCES CITED

Bernet, M., and Garver, J.I., 2005, Fission-track analysis of detrital zircon: Reviews in Mineralogy and Geochemistry, v. 58, p. 205-238.

Bradley, D., Kusky, T., Haeussler, P., Goldfarb, R., Miller, M., Dumoulin, J., Nelson, S.W., and Karl, S., 2003, Geologic signature of early Tertiary ridge subduction in Alaska, in Sisson, VB. Roeske, S.M., and Pavlis, T.L., (eds.), Geology of a transpressional orogen developed during ridge-trench interaction along the North PacIfic margm: Boulder, Colorado, Geological Society of America Special Paper 371, p. 19-49.

Carlson, B.M., 2012, Analysis of detrital zircon fission track ages of the Upper Cretaceous Valdez Group and Paleogene Orca Group in Western Prince William Sound, Alaska. Unpublished undergraduate thesis, Union College, Schenectady, NY. 116, pp.

Clendenen, W.S., Fisher, D., Byrne, T., 2003, Cooling and exhumation history of the Kodiak accretionary prism, southwest Alaska: Geological Society of America, Special paper 371.

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, p. 463-475

Garver, J.I., Reiners, P.W., Walker, L.J., Ramage, J.M., and Perry, S. E., 2005, Implications for timing of Andean uplift from thermal resetting of radiation-damaged zircon in the Cordillera Huayhuash, Northern Peru: Journal of Geology, v. 113, p. 117-138.

Moore, J.C, 1975, Cretaceous Continental Margin Sedimentation, Southwestern Alaska: Board of Studies in Earth Sciences, University of California, Santa Cruz, California pp?

Plafker, G., Moore, J. C., and Winkler, G. R., 1994, Geology of the southern Alaska margin, in Plafker, G., and Berg, H. C., (eds.), The Geology of Alaska: Boulder, Colorado, Geological Society of America, The Geology of North America, v. G-l.

Roe, C.F., Davidson, C.M., Garver, J.I., DeLuca, M.J., and Short, A.K., 2013. Provenance and thermal history of the Upper Cretaceous Shumagin Formation, Nagai Island, southern Alaska, 2013 Cordilleran tectonics workshop, Kingston Ontario, Abstracts with Program, p. 51-52.

Short, A.K., 2013. Age and Petrogenesis of the Shumagin Batholith in Western Chugach-Prince William Terrane, Alaska, p. 1-8

Wagner, G., Van den Haute, P., 1992, Fission-track dating: Solid Earth Sciences Library, Kluwer Academic Publishers, Amsterdam

Weinberger, J., Sisson, V. B., 2003, Pressure and temperature conditions of brittle-ductile vein emplacement in the greenschist facies, Chugach metamorphic complex, Alaska; Evidence from fluid inclusions, The Geological Society of America, Special Paper 371