ANALYSIS OF DETRITAL ZIRCON FISSION TRACK AGES OF THE UPPER CRETACEOUS VALDEZ GROUP AND PALEOGENE ORCA GROUP IN WESTERN PRINCE WILLIAM SOUND, ALASKA

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INTRODUCTION

A major component of southern Alaska is a Late Cretaceous-Eocene accretionary complex that extends for 2200 km from Sanak Island in the west to Chatham Strait in the southeast. The complex is comprised primarily of flysch of the Chugach-Prince William (CPW) composite terrane (Plafker et al., 1994). The CPW was diachronously intruded by near-trench plutons of the Sanak-Baranof belt between 61 and 50 Ma, although the location of the intersecting ridge is controversial (cf. Cowan, 2003; Haeussler et al., 2003). Significant margin-parallel transport may have occurred prior to accretion in addition to a second episode of near-trench plutonism in the Late Eocene, which are part of Eshamy Suite of plutons (Johnson, this volume).

Detrital zircon fission track (DZFT) dating is commonly used to elucidate the time-temperature history of rock in accretionary complexes (i.e. Brandon et al., 1998; Clendenen et al., 2003). The location of accretion, the source terranes, and subsequent exhumation and thermal history has broad implications for regional tectonic models and the tectonic history of adjacent terranes. This paper presents and interprets DZFT data to further explore the thermal history of the CPW terrane and builds on previous work completed throughout Prince William Sound (Kveton, 1989; Izykowski, 2011; Milde, 2011).

REGIONAL GEOLOGY

The geology of the southern margin of Alaska is the result of complex processes at the boundary between North America and the Pacific plate (Ridgway and Flesch, 2007; Enkelmann et al., 2010). The margin is comprised of a number of distinct terranes, the largest of which is the Insular superterrane (which includes the Peninsular, Wrangellia and Alexander terranes) that serves as the continental framework against and beneath which the Mesozoic-Cenozoic accretionary complex has accreted (Plafker et al., 1994; Cowan, 2003). Outboard of the Insular superterrane and bounded by the Border Ranges fault is the accreted Chugach-Prince William (CPW) composite terrane, which is dominated by flysch comprised of the Campanian-Maastrichtian Valdez Group and the Paleocene-Eocene Orca Group (Plafker et al., 1994; Fig. 1). The CPW is inferred to represent a thick sequence of turbidites deposited on a submarine fan from a dissected volcano-plutonic complex (Dumoulin, 1987; Sample and Reid 2003). Such a thick sequence and relatively rapid deposition may have been due to either a nearby active volcanic arc or rapid and extensive tectonic exhumation along the North American margin (Sample and Reid, 2003). The Yakutat terrane is presently colliding into part of the Prince William terrane on the southeast margin of Alaska (Enkelmann et al., 2010).

During the Paleocene to Eocene, the CPW was intruded by plutons of the diachronous Sanak-Baranof belt, a belt of near-trench plutons inferred to be the result of ridge subduction (Bradley et al., 2003). Pluton ages get progressively younger from west to east starting at ~61 Ma in the west and ending at ~50 Ma in the east, but in the Prince William Sound area they are ~54 Ma (Bradley et al., 2003; Cowan, 2003; Garver and Davidson, this volume). Following intrusion, the CPW terrane may have been translated ~1100 km north on a series of dextral strike-slip faults to its present position (Cowan, 2003, Gallen, 2008; O’Connell, 2008) before being intruded again by the Eshamy Suite of plutons between 37-40 Ma (Johnson, this volume). Thus in the Prince William Sound area,

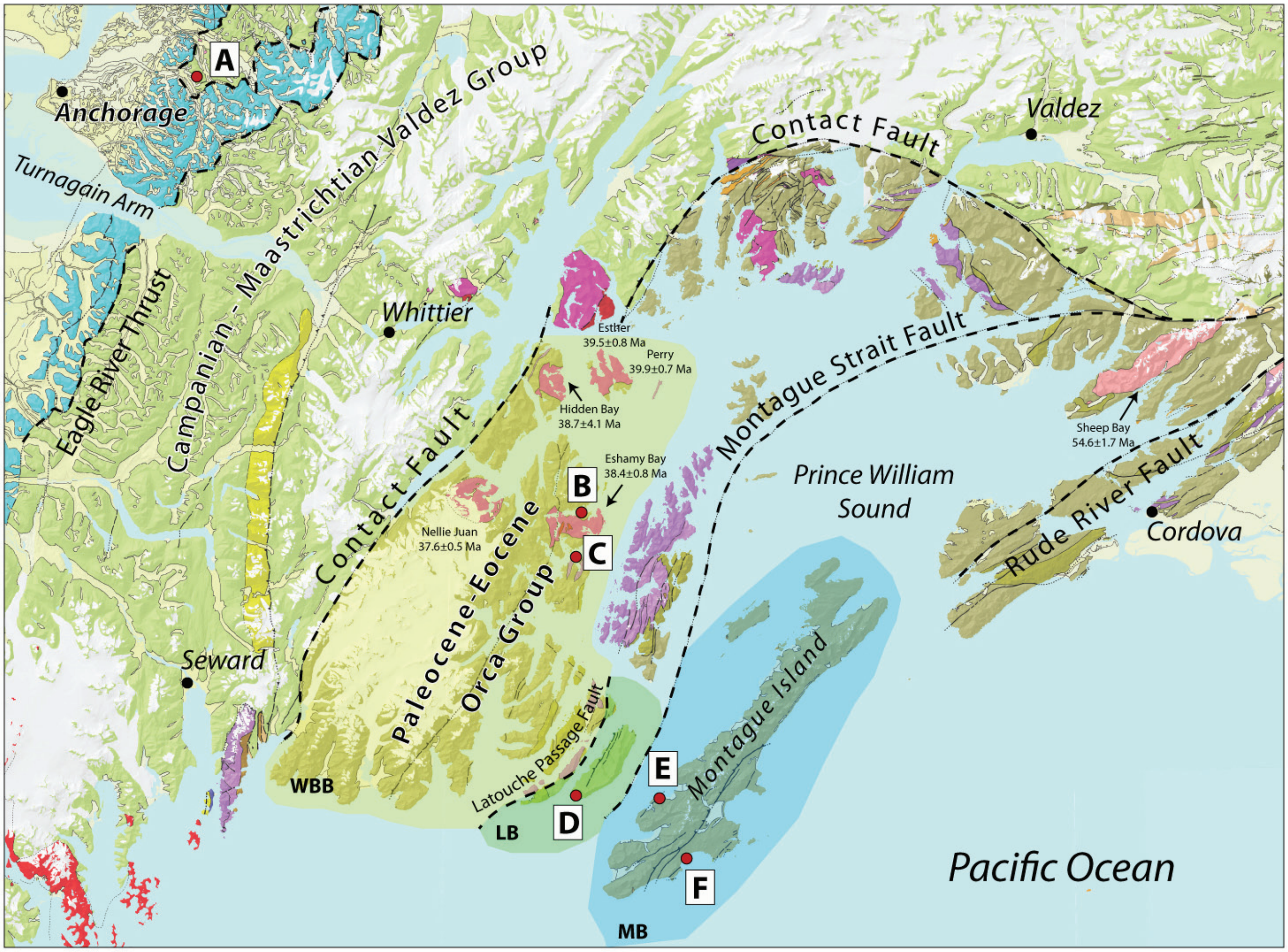

Figure 1. Location map of the Prince William Sound area with terranes, faults and sample site locations. Sample sites are labeled according to their letter. Known ages of plutons throughout Prince William Sound are labeled. WBB=Whale Bay belt (and Bainbridge). LB=Latouche belt. MB=Montague belt. Modified from Wilson and Hults (2008).

the accretionary complex has experienced at least two well-defined intrusive events.

ZIRCON FISSION TRACK DATING

Fission track dating relies on determining the density of fission tracks from the spontaneous fission of ^{238}U. After zircon are mounted and revealed by polishing, tracks are enhanced by chemical etching so they can be viewed under an optical microscope (Wagner and Van den Haute, 1992). Zircon has an effective closure temperature of ~240 ± 30° C (Bernet and Garver, 2005). Above this temperature, tracks quickly anneal and disappear but below it, tracks are retained in the crystal. Reheating of a zircon to moderate temperatures (200-300°C) can cause partial or complete resetting depending primarily on radiation damage, duration of the thermal event, and cooling rate (Bernet and Garver, 2005; Garver et al., 2005; Reiners and Brandon, 2006).

METHODS

Six medium- to coarse-grained sandstone samples from the Valdez and Orca Groups weighing 4-5 kg each were collected throughout western Prince William Sound for detrital zircon fission track (DZFT) analysis. Samples were collected along a NW-SE trending transect from Eagle River near Anchorage to Montague Island (Fig. 1). Zircons were extracted from the samples according to standard zircon extraction methods (see Bernet and Garver, 2005; and notes to Tab. 1).

RESULTS

Although a total of ten samples were collected for thesis work, this report focuses on only six that are complete at the time of this writing. All samples are overdispersed and also fail χ^2, which is common in detrital samples with heterogeneous zircon populations (Tab. 1). All but two samples have ZFT ages that are younger than deposition, requiring post depositional thermal resetting. However, samples 11HW-18 and 11HW-15, from Montague Island, are not thermally reset, and therefore the ZFT grain ages likely represent cooling ages in the original source terrane. Across the transect from northwest to southeast, both mean ages (Tab. 1) and discreet age populations (Tab. 2) get progressively younger up to the Montague Strait fault, which separates the reset samples to the north from the unreset samples to the south on Montague Island. When data from all samples are pooled, there are two primary cooling ages that are apparent at 35.5 ± 1.7 Ma (33.8% of grains) and 50.1 ± 2.8 Ma (36.6% of grains). There are also two smaller old populations at 83.5 ± 4.6 Ma (18.1%) and 129.4 ± 7.3 Ma (11.5%)(Table 2).

In the reset samples, there is a clear signal of three distinct thermal perturbations that appear to have impacted much of western Prince William Sound. Samples JG10-31 and 11HW-19 record a young thermal event at between 30 and 27 Ma represented by ~20% of the grains in those two samples (Fig. 2C-D). Samples 11HW-11, JG10-31 and 11HW-19 record a major cooling age at between 42 and 37 Ma represented by ~65% of the grains (Fig. 2B-D). The third major cooling age is apparent in samples JG10-21, 11HW-11 and JG10-31 occurred at between 55 and 49 Ma and is represented by ~20% of grains counted (Fig. 2A-C). Older populations also occur (Tab. 2).

Samples from Montague (11HW-15 and 11HW-18) have distinct age populations older than known deposition ages, which is Late Eocene or younger (Hilbert-Wolf, this volume). Averaged ages for the two Montague Island samples reveal a P3 cooling age of 52.3 ± 2.0 Ma (59.8%), a P4 cooling age of 91.2 ± 5.7 Ma (19.5%) and a P5 cooling age of 126.4 ± 7.7 Ma (20.6%) (Fig. 2E-F).

DISCUSSION

The primary goal of this study is to examine the time-temperature history of the Chugach-Prince William terrane and one of the major findings is that there appear to be two sharp thermal discontinuities divided by the Latouche Passage fault and the Montague Strait fault, confirming earlier mapping and thermal data (see Tysdal and Case, 1979; Kveton, 1989; Hilbert-Wolf, this volume). These data allow

Table 1: Zircon fission track data – Western Prince William Sound transect

Sample	ρ_s	N_s	ρ_i	N_i	ρ_d	N_d	n	χ^2	Age*	-1σ	+1σ	Uranium	Track Length (n)
Eagle River - Valdez Group													
JG10-21	9.26 x 10^6	4529	5.89 x 10^6	2879	2.869 x 10^5	1869	40	0.0	62.3	-2.7	+2.8	252±13	09.1 ± 1.83 (146)
Whale Bay belt – Orca Group													
11HW-11	7.86 x 10^6	3725	1.10 x 10^7	5213	3.374 x 10^5	2208	40	0.0	41.7	-1.6	+1.7	400±20	10.1 ± 1.62 (112)
JG10-31	8.87 x 10^6	2478	1.18 x 10^7	3308	2.695 x 10^5	1761	25	0.0	34.9	-1.5	+1.5	539±28	09.9 ± 1.62 (112)
Latouche belt – Orca Group													
11HW-19	6.78 x 10^6	3215	1.01 x 10^7	4782	3.219 x 10^5	2107	40	0.0	35.8	-1.4	+1.5	384±18	8.85 ± 2.13 (151)
Montague Belt – Orca Group													
11HW-18	1.06 x 10^7	6050	8.67 x 10^6	4949	3.246 x 10^5	2125	50	0.0	53.1	-2.1	+2.2	328±15	9.87 ± 1.52 (120)
11HW-15	8.45 x 10^6	4835	7.67 x 10^6	4390	3.340 x 10^5	2187	50	0.0	52.7	-2.1	+2.2	282±14	---------------------

Note: In this table, Age* is the χ^2 age – which is the minimum population - if the χ^2 value is below five, note that - this age overestimates the minimum age compared to the young population determined by binomial peak fitting (see Table 2). ρ_s is the density (cm^2) of spontaneous tracks and N_s is the number of spontaneous tracks counted; ρ_i is the density (cm^2) of induced tracks and N_i is the number of induced tracks counted; ρ_d is the density (cm^2) of tracks on the fluence monitor (CN5) and N_d is the number of tracks on the monitor; n is the number of grains counted; χ^2 is the Chi-squared probability (%). Zircon fission track ages (± 1σ) were determined using the Zeta method, and calculated using the computer program and equations in Brandon (1992). A Zeta factor of 360.22 ± 9.50 (± 1 se) is based on 8 determinations on standard samples from the Fish Canyon Tuff, Buluk Tuff, and Peach Springs Tuff. Glass monitors (CN5) placed at the top and bottom of the irradiation package were used to determine the fluence gradient. All samples were counted at 1250x using a dry 100x objective (10x oculars and 1.25x tube factor) on an Olympus BX60 microscope fitted with an automated stage and a Calcomp digitizing tablet. Track lengths are give in microns with standard deviation (and number measured in parentheses), the standard error for these samples is between 0.15 to 0.17.

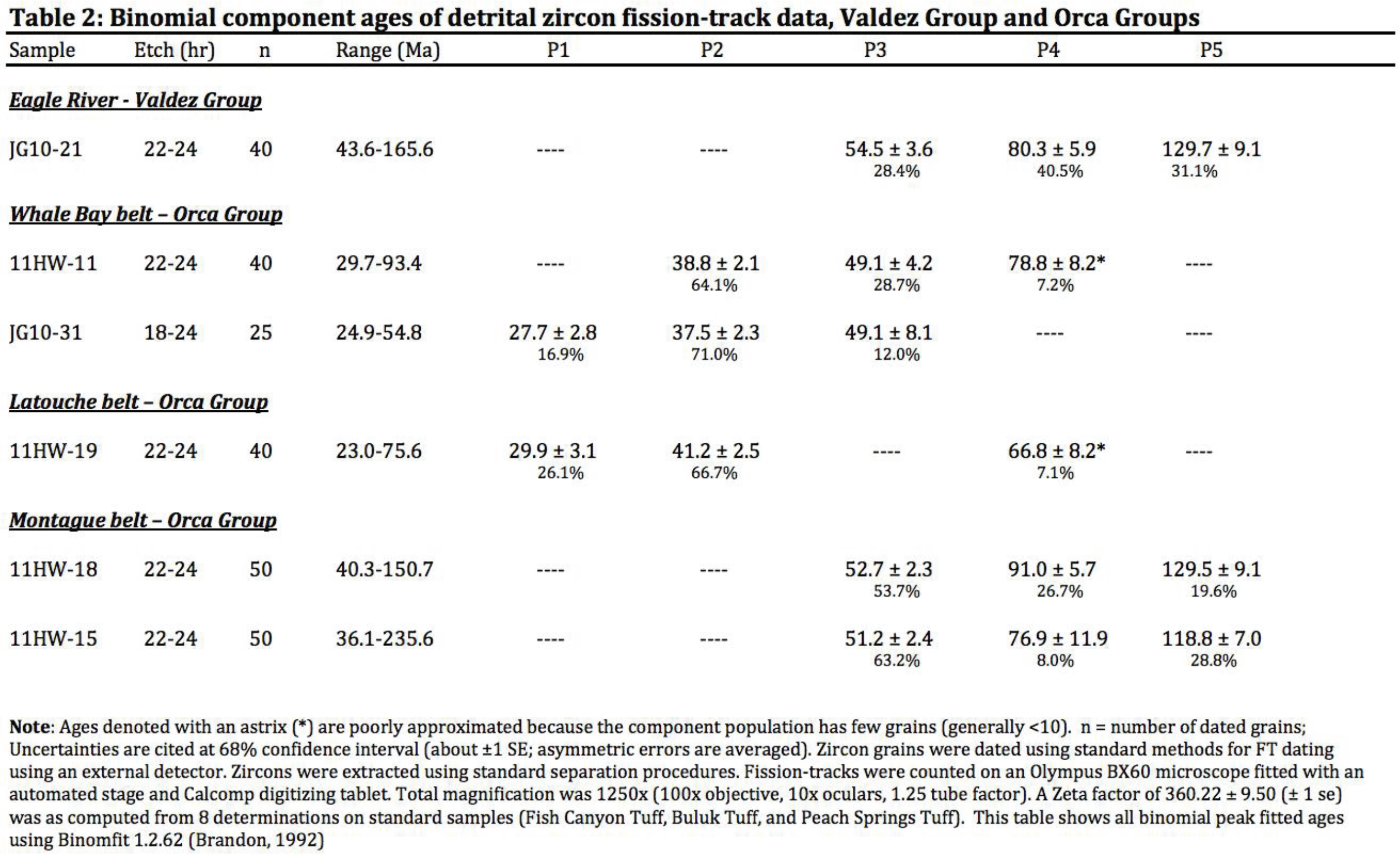

Table 2: Binomial component ages of detrital zircon fission-track data, Valdez Group and Orca Groups

Sample	Etch (hr)	n	Range (Ma)	P1	P2	P3	P4	P5
Eagle River - Valdez Group								
JG10-21	22-24	40	43.6-165.6	----	----	54.5 ± 3.6 28.4%	80.3 ± 5.9 40.5%	129.7 ± 9.1 31.1%
Whale Bay belt – Orca Group								
11HW-11	22-24	40	29.7-93.4	----	38.8 ± 2.1 64.1%	49.1 ± 4.2 28.7%	78.8 ± 8.2* 7.2%	----
JG10-31	18-24	25	24.9-54.8	27.7 ± 2.8 16.9%	37.5 ± 2.3 71.0%	49.1 ± 8.1 12.0%	----	----
Latouche belt – Orca Group								
11HW-19	22-24	40	23.0-75.6	29.9 ± 3.1 26.1%	41.2 ± 2.5 66.7%	----	66.8 ± 8.2* 7.1%	----
Montague belt – Orca Group								
11HW-18	22-24	50	40.3-150.7	----	----	52.7 ± 2.3 53.7%	91.0 ± 5.7 26.7%	129.5 ± 9.1 19.6%
11HW-15	22-24	50	36.1-235.6	----	----	51.2 ± 2.4 63.2%	76.9 ± 11.9 8.0%	118.8 ± 7.0 28.8%

Note: Ages denoted with an astrix (*) are poorly approximated because the component population has few grains (generally <10). 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 360.22 ± 9.50 (± 1 se) was as computed from 8 determinations on standard samples (Fish Canyon Tuff, Buluk Tuff, and Peach Springs Tuff). This table shows all binomial peak fitted ages using Binomfit 1.2.62 (Brandon, 1992)

a division of Prince William Sound into the Whale Bay/Bainbridge belt (Paleocene), the Latouche belt (Middle Eocene) and the Montague belt (Upper Eocene) (Fig. 1). Both the Whale Bay/Bainbridge and Latouche belts have experienced heating (>200°C) but maximum depositional age changes from <57Ma in the Whale Bay belt to <38Ma for the Latouche belt. The Montague belt has experienced little to no heating since deposition, which occurred at <35Ma, leaving fission tracks in zircon unreset.

Thus rocks of the Valdez and Orca Group contain a rich thermochronologic history that records three distinct cooling ages that are likely related to regional-scale heating events or exhumation. These thermal events are: 1) ~50 Ma driven by plutonism of the SBB belt; 2) ~38 Ma driven by plutonism of the 37-40 Ma Eshamy suite; 3) 25-30 Ma cooling that may be related to exhumation and collision of the Yakutat microplate. Extensive regional heating is supported by high vitrinite reflectance values of 2.9-4.05 for most of the Orca Group west of the Montague Strait fault, suggesting maximum temperatures of 200-300°C (Kveton, 1989).

Whale Bay/Bainbridge belt

Samples from the Valdez Group (Eagle River) and Orca Group in western PWS have significant grain-age populations between 54 and 49 Ma, similar to previous results (Kveton, 1989; Milde, 2011; Izykowski, 2011). This age range is probably a result of the same regional heating event that occurred at 52-48 Ma as recognized in reset ages regionally (Plafker et al., 1994). This thermal activity is almost certainly related to the Sanak-Baranof belt plutonism that affected 2100 km of the Alaskan margin between 61-50 Ma, but these plutons are about 54 Ma in Prince William Sound (Plafker et al., 1994; Bradley et al., 2003; Garver and Davidson, this volume).

Younger resetting was likely driven by intrusion of the Eshamy Suite of plutons (all newly dated between 37 and 40 Ma; Johnson, this volume). All three samples of the Orca Group immediately north of the Montague Strait fault have their largest fraction of reset grain ages between 42 and 37 Ma. This population of grain ages is not present in the more inboard

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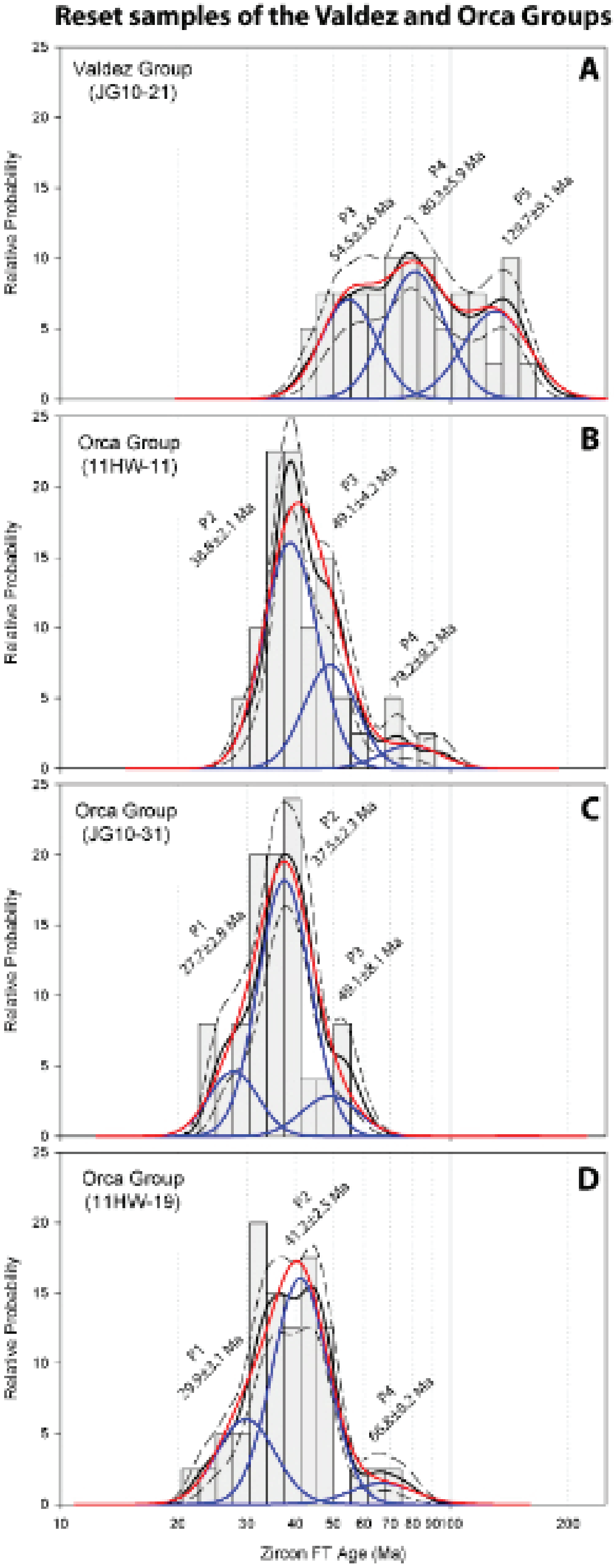

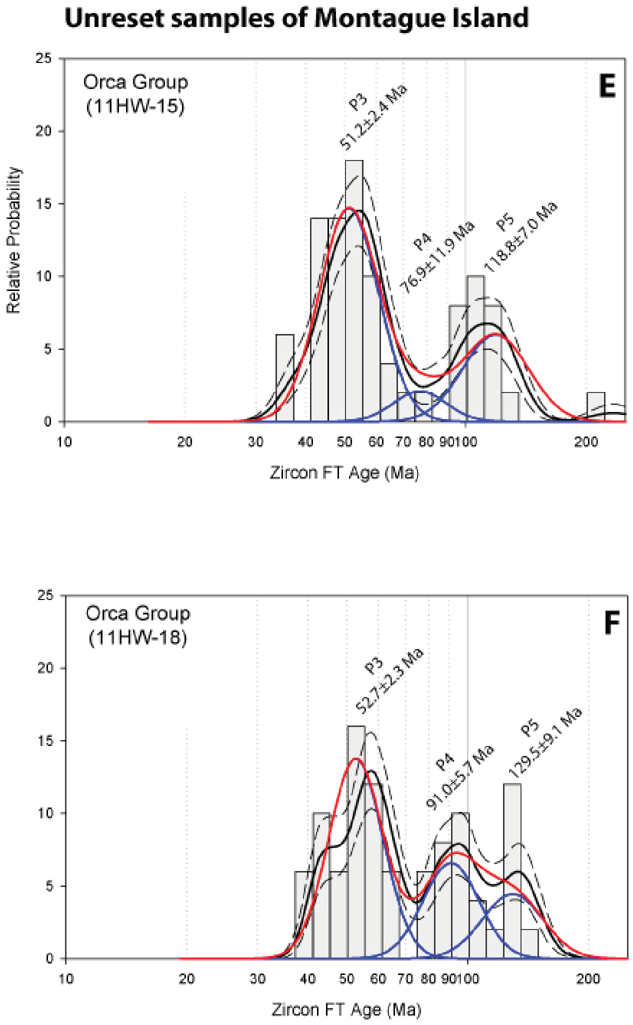

Figure 2A-F. Population density plots for fission track ages of Valdez and Orca Group samples in order from northwest to southeast. All coherent age populations are labeled.

Valdez Group (Eagle River), but it is very significant in the Valdez Group along the Richardson Highway to the northeast (see Milde, 2011), suggesting heating was not as widespread or as great in magnitude as the early Eocene plutonism.

Latouche belt

Rock from the Latouche belt has experienced two significant thermal events at ~41Ma and ~25-30 Ma, likely due to Eshamy plutonism followed by Yakutat-related uplift and exhumation (Table 2). However, an abrupt younging in depositional age south of the Latouche Passage fault suggests a very different history for this belt (see Hilbert-Wolf, this volume). For the Eshamy plutonism to impact the Latouche belt and cause the observed resetting, the Latouche belt must have been deposited and then immediately intruded. It is well within error for these two events to have occurred synchronously. However, if the young cooling age is related to uplift and exhumation, the Latouche belt must have been buried to sufficient depth such that exhumation would cause the presence of a secondary thermal event.

Therefore, we propose that rock of the Latouche belt was deposited and then immediately intruded by the Eshamy suite of plutons at ~38 Ma before cooling and being carried down into the subduction zone. Although the faults in this area tend to be strike-slip in nature, dip-slip movement has been recognized, potentially accommodating this subduction (Bol and Roeske, 1993). Prior to the onset of the Yakutat collision, the Latouche belt must have reached temperatures barely hot enough to begin annealing some fission tracks (~180-200°C – see Garver et al., 2005). Uplift and associated exhumation caused by the beginning of the Yakutat collision at ~25-30Ma brought the Latouche belt back through zircon's closure temperature, explaining the observed young cooling age.

The rocks with the youngest reset ages (27-31 Ma) occur far to the south near the Montague Strait Fault where a small but significant number of grain ages fall between 27 to 31 Ma (Oligocene). Similar cooling ages have been recognized previously in both eastern and western Prince William Sound (see Kveton, 1989; Izykowski et al., 2011; and Izykowski, 2011). In western PWS, Kveton (1989) observed a grain-age population of ~25 Ma in one sample from the Bainbridge mélange belt (near sample 11HW-19) as well as many individual grain ages near ~30 Ma. In eastern PWS, Izykowski (2011) recognized a significant grain-age population between 23 to 33 Ma in most of his samples from the Orca Group, which is more or less along strike from the samples in this study.

In a study of the nearby Chugach Metamorphic Complex (CMC) to the east, Gasser et al. (2011) determined that the gneiss zone (metamorphosed CPW flysch) has ZFT cooling ages of 26 to 31 Ma. Likewise the main young ZFT cooling age in six of nine samples from the Chugach and erosional detritus in the Yakataga Formation on the Yakutat block fall between 25 and 33 Ma (Enkelmann et al., 2008).

Starting at ~30 Ma, the leading edge of the Yakutat block began subducting beneath North America, causing the Alaskan margin to experience uplift and exhumation (Enkelmann et al., 2008; Enkelmann et al., 2010). Assuming the young grain-age population recognized throughout Prince William Sound represents a distinct cooling event, it may be a result of uplift and erosional exhumation caused by the early stages of the Yakutat collision.

Montague belt

The two samples from Montague Island have experienced very different thermal histories than their counterparts to the north based on DZFT evidence. The youngest coherent grain-age population is ~52 Ma, similar to the timing of the Sanak-Baranof plutonism that is attributed to the Paleocene cooling ages in the rest of the Valdez and Orca Groups. However, we do not believe they are related in this case. All the grains analyzed for DZFT on Montague were double dated using U/Pb dating by Hilbert-Wolf (this volume). The youngest robust depositional age obtained is ~35 Ma (Hilbert-Wolf, this volume). The lack of a Late Eocene cooling age in Montague samples suggests that these rocks were not in close enough proximity to the Eshamy suite of plutonism for resetting to occur (they had not yet been deposited). Furthermore, mean track lengths of nearly 10 µm and vitrinite reflec-

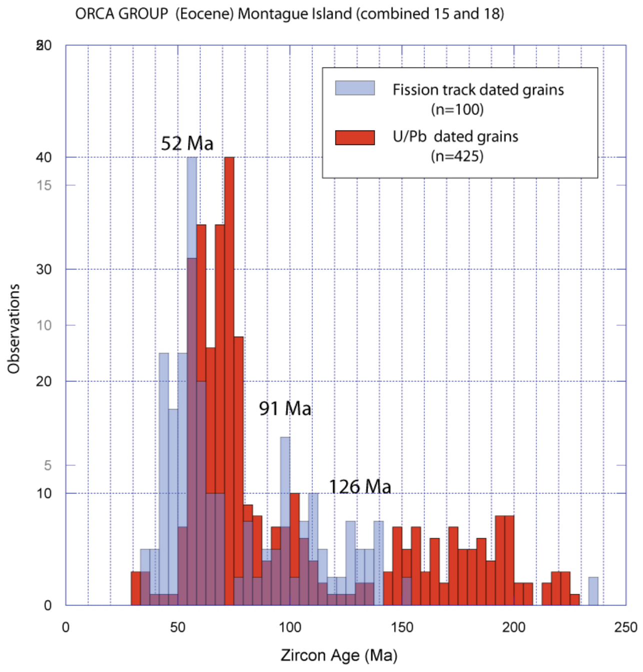

Figure 3. Population density plot of all fission track cooling ages (blue) and U/Pb crystallization ages (red) from Montague Island. Coherent cooling age populations are labeled and appear to lag ~20 Myr behind associated crystallization ages.

tance values of only 0.8-1.1 confirm these rocks have experienced minimal heating and no resetting since deposition (Helwig and Emmet, 1981).

Considering that rocks of Montague Island appear to have been unaffected by the regional heating that occurred at ~38 Ma, it may be that the strata on Montague had not yet been accreted to the Alaska margin by that time. Bol and Roeske (1993) identified numerous right-lateral strike-slip faults that cut CPW rocks in Prince William Sound. In addition, they observed that synchronous dextral-slip faulting and thrusting is likely to have occurred during accretion (Bol and Roeske, 1993). Therefore, the farthest outboard Orca Group rocks of Montague Island may have been translated by dextral strike-slip faulting and accreted onto the main CPW terrane post-38 Ma.

These two samples from Montague were double-dated, so we have crystallization ages and cooling ages on the same grains. When considering potential source terranes for the outboard CPW, U/Pb crystallization ages obtained from double dating appear to consistently lag ~20 Myr behind their counterpart ZFT cooling ages (Fig. 3). U/Pb ages are closely compatible with crystallization ages from the Kootznahoo Formation and other elements of the northern Coast Plutonic Complex (CPC) along the western Canadian margin making it a potential cource terrane (Ancuta, 2010; Evenson, 2010).

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