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FISSION TRACK AGES OF DETRITAL ZIRCON FROM THE PALEOGENE KOOTZNAHOO FORMATION, SE ALASKA

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INTRODUCTION

The Kootznahoo Formation is a Paleogene nonmarine clastic sedimentary unit exposed in the Admiralty trough in southeast Alaska. Strata are comprised of poorly sorted arkosic and lithic sandstone, conglomerate and lesser shale and coal deposited in fluvial and paludal environments (Dickinson and Vuletich, 1990). The formation sits unconformably on rocks of the Alexander-Wrangellia Composite terrane. The Kootznahoo Formation may have been deposited in a continuous basin referred to as the Admiralty Trough, which is an elongate depression 320 km long and 50 km wide ranging from northern Admiralty Island to the southeastern side of Prince of Wales Island (Dickinson and Vuletich, 1990).

The Kootznahoo Formation is well exposed in several areas in southeast Alaska, two of which are the focus of this study at the Little Pybus Bay area on Admiralty Island and the Keku Straight area on Kupreanof Island (Fig. 2, Davidson et al., this volume). Unlike many of the rocks in southeastern Alaska, the Kootznahoo Formation has not been metamorphosed or deeply buried and these strata rest unconformably on basement rocks (Muffler, 1967). Thus, the Kootznahoo Formation provides an excellent opportunity to examine sediment provenance and the exhumation history of adajacent terranes, particularly the Chugach terrane to the west and the Coast Mountains batholith complex (Gehrels et al., 2009) to the east.

Numerous studies have been conduced in southern Alaska that have used detrital zircon fission track (DZFT) provenance analysis to reveal details of convergence and exhumation related to the collision of the Yakutat terrane with the continental margin which is largely composed of the Chugach-Prince William terrane (e.g. Enkelmann et al., 2008; Perry et al., 2009; Merkert, 2009; Garver et al., 2010). No comparable studies have been conducted in the Admiralty Trough area of Southeast. An understanding of the sediment provenance of the Kootznahoo Formation should provide insight into the nature of adjacent terranes, and help our understanding of the translation history of outboard terranes.

This study is part of a larger project that focused on different aspects of the Kootzanohoo Formation, and several of these studies are primarily focused on understanding provenance using detrital zircon (see Davidson et al., this volume). For this study, sediments of the Kootznahoo Formation were evaluated using detrital zircon fission track (DZFT) analysis. The ages of detrital zircon were compared to known and inferred cooling ages of zircon in adjacent source areas. Zircon fission tracks record when zircon cooled below a closure temperature of ~240° C ± 50° C and is widely used to examine the thermal history of flanking terranes and thermal resetting of sediments within a basin (Bernet and Garver, 2005). In this study, ten arkosic and lithic sandstones were dated using DZFT. Aliquots of zircon from five of these samples were also dated using U/Pb dating using Laser Ablation at the University of Arizona (see Evenson, this volume; Henderson, this volume). This report presents and interprets DZFT data in the context of stratigraphic correlation between sections, basin evolution, sediment provenance and exhumation and translation of flanking terranes.

REGIONAL GEOLOGIC SETTING

Southern Alaska is comprised of numerous allochthonous terranes that were accreted to North America in the Mesozoic and Cenozoic. Major terranes include the Wrangellia composite terrane (Wrangellia, Alexander, Peninsular, Gravina-Nutzotin terranes), the outboard Chugach-Price William composite terrane and the Yakutat terrane, which is currently colliding into the southern margin of Alaska (Monger et al., 1982; Cowan et al., 1997; Cowan, 2003, Perry et al., 2009). These terranes were accreted to the pre-existing continental framework that is largely made up of the Intermontane supperterrane (Plafker et al., 1989, Monger et al., 1982). The Coast Mountains batholith complex consists of a distinctive and important metamorphic and plutonic thermotectonic belt that extends along the margin from southeast Alaska along western British Columbia (Monger et al., 1982; Gehrels et al., 2009).

The accretion of Wrangellia was followed by the subsequent translation and accretion of the 2000 km long, 60-100 km wide Chugach-Prince William composite (CPW) terrane, which includes the Chugach and Prince William terranes. At its southern margin, the Chugach terrane is in fault contact with the Prince William terrane along the Contact fault (Plafker et al., 1989). Both terranes represent deposition in a similar accretionary complex environment formed from the off scraping of sediments as the Pacific oceanic lithosphere subducted under the Wrangellia composite terrane.

A key point in provenance studies in this area is that clastic sediments of the CPW may have been largely derived from material eroded from the Coast Mountain batholith in British Colombia and southeastern Alaska (Sample et al., 1983; Kveton, 1989; Haeussler et al., 2004). Aside from the distinct lithologies and history as an accretionary complex, the CPW terrane is marked by the distinctive time-transgressive Sanak-Baranof intrusive belt (Cowan, 2003).

The entire CPW was translated northward along dextral strike-slip faults that likely involved the Border Ranges fault system that accommodated 1100 km of dextral strike-slip motion occurring largely between 50 and 40 Ma (Cowan, 2003). K-Ar ages on whole-rock, biotite, and hornblende from Baranof Island yielded dates ranging from ~35 to 46 Ma (Zumsteg et al., 2003), which largely represents cooling that must have followed and accompanied translation (Garver et al., 2010).

The currently colliding Yakutat terrane is inferred to have basement that might include rocks of the CPW terrane (Cowan 2003; Perry et al., 2009). Cover strata on the Yakutat terrane include the Kultieth and Poul Creek Formations that are interpreted to be derived from the Coast Mountains batholith (Perry et al., 2009). In this scenario, these cover strata were derived from a northern source that lacks syndepositional volcanics, though a far-traveled hypothesis for the basement rocks cannot be ruled out (Perry et al., 2009).

The Coast Mountains batholith complex is a belt of metamorphic and plutonic rocks that intrude the Wrangellia Composite terrane and the preexisting continental margin (Himmelberg et al., 2004; Gehrels et al., 2009). The belt spans 1700 km from northern Washington through coastal Alaska and southern Alaska to the southern Yukon (Gehrels et al., 2009). The Coast Mountains batholith developed as oceanic lithosphere subducted eastward forming an arc from the Cretaceous to early Tertiary time, and includes two main phases of deformation and metamorphism (Gehrels et al., 2009). The first was a period of crustal shortening/tectonic overlap between the Wrangellia composite terrane and the preexisting continental margin, which occurred from ~65 to ~57 Ma (Monger et al., 1982; Gehrels et al., 2009; Himmelberg et al., 2004). During the first phase exhumation was slow, ~0.5 mm/yr (Rusmore et al., 2005). The second phase occurred between ~57 and ~48 Ma after a change in relative plate motions that caused rapid exhumation and extension (Rusmore et al. 2005; Gehrels et al., 2009).

All exposures of the Kootznahoo Formation were deposited on the Wrangellia composite terrane, which is inferred to have been more-or-less stationary since deposition of the Kootznahoo Formation (e.g. Cowan et al., 1997; but also see Epstein, this volume). Regardless of the geometry and continuity between present exposures of strata, the basin would have been flanked by the Coast Mountains batholith to the east and the CPW terrane to the west.

ZIRCON FISSION TRACK DATING

Fission-track dating in zircon is based on the determination of the density of fission tracks that result from the spontaneous fission of ^{238}U (Wagner and Den Haute, 1992). Zircon has a closure temperature of 240° C ± 50° C. Below this temperature, tracks are retained in the crystal and above this the tracks form, but then anneal quickly. Reheating of zircon above ~200-300°C can cause partial or total annealing of fission tracks (Bernet and Garver, 2005; Garver et al., 2005). Tracks form along the trajectory of ejected sub-equal charged particles that destroy the crystal lattice. Latent tracks are enhanced by chemical etching so that they are visible under an optical microscope. An age is determined through an age equation that takes into account the ratio of spontaneous fission tracks to the amount of ^{238}U per unit volume (induced tracks).

Using binomial peak fitting, the distribution of grain ages are deconvolved into grain-age populations through statistical techniques, which are presented through probability density plots (Bernet and Garver, 2005). Once populations are determined, their relationship to surrounding source areas is evaluated.

METHODS

Ten samples of medium- to coarse-grained sandstone weighing between 2 to 4 kg were collected from the Kootznahoo Formation in several areas near Kake, Alaska for detrital fission track analysis (DZFT). Six were collected from the section on Kupreanof Island and the other four were collected from the section in Little Pybus Bay on Admiralty Island (Fig. 1, Davidson et al., this volume). Samples collected include rocks from the base, middle and upper parts of the stratigraphic sections (Fig. 2, Davidson et al., this volume). Three samples were collected adjacent to young cross-cutting dikes to evaluate thermal resetting.

Zircons were extracted from the samples using standard zircon extraction methods (Bernet and Garver, 2005), and were mounted, polished and etched in a NaOH:KOH eutectic at 228° for 10-35 hr. Etched mounts were affixed to a low-Uranium mica flake and irradiated at the OSU reactor along with Corning (CN5) glass dosimeters. Spontaneous tracks in zircon and induced tracks recorded in the mica flake after neutron irradiation were counted at 1250x using an automated stage on a BMAX-60 Olympus microscope. Grains are selected for counting if they are oriented parallel to their c-axis, inclusion free, not strongly zoned, have even uranium distribution, large countable area and optical clarity. Grains were counted regardless of uranium concentration as long as tracks were distinguishable and well etched. Mica affixed to the dosimeter was counted to determine the fluence. A zeta calibration was determined by counting standards of known ages (Peach Springs Tuff, Fish Canyon Tuff). Grain age populations were determined using Binomfit and presented using Sigma Plot (Fig. 1).

RESULTS

Seven of the detrital fission track samples appear un-reset and three are thermally reset. As expected for a detrital population the majority of the un-reset samples fail χ^2 and therefore they represent a mixed suite of zircon from a heterogeneous sediment source (Table 1). The three reset samples pass χ^2 meaning they all belong to the same grain-age population, in this case temperatures were sufficient to anneal pre-existing fission tracks.

Grain-age populations (or component populations) for the un-reset samples were determined using binomial peak fitting and are shown in Table 2 and Figure 1. Three main detrital populations emerge at ~55, ~45, and ~34 Ma. Samples collected adjacent to, or from within, crosscutting dikes, show a reset population at ~23 Ma. Probability density plots of four representative samples from the Kootznahoo Formation are displayed in Figure 1. Sample LA05 was purposely collected next to a dike to understand the effect of thermal resetting on zircon and to constrain a minimum depositional age. This sample yields a reset age of 23.8 Ma.

Table 1: Zircon fission track data, Kootznahoo Formation

Sample	ρ_s	N_s	ρ_i	N_i	ρ_d	N_d	n	χ^2	Age*	-1σ	+1σ	U ± 2se
Kootznahoo Formation: Kupreanof Island												
LA12	8.53 x 10^6	3984	9.13 x 10^6	4267	2.9 x 10^5	2257	50	0.0	43.8	-1.8	+1.8	384 ± 17
LA10	7.31 x 10^6	2239	7.53 x 10^6	2306	2.9 x 10^5	2263	30	0.4	45.3	-1.9	+2.0	320 ± 17
LA03	9.92x 10^6	2922	8.04 x 10^6	2370	2.8 x 10^5	2273	30	39	56.9	-2.5	+2.6	357 ± 19
Kootznahoo Formation: Admiralty Island												
LA02	8.36 x 10^6	4049	7.72 x 10^6	3739	2.7 x 10^5	2289	50	0.0	39.5	-1.7	+1.8	349 ± 17
LA01	8.21 x 10^6	3126	8.99 x 10^6	3425	2.7 x 10^5	2298	40	0.0	39.5	-1.7	+1.8	411 ± 21
LA15	1.17 x 10^7	2710	1.36 x 10^7	3146	3.0 x 10^5	2246	30	1.3	42.7	-1.8	+1.9	562 ± 26
LA14	1.07 x 10^7	3151	9.19 x 10^6	2695	2.9 x 10^5	2249	29	11	57.5	-2.2	+2.3	383 ± 19
Kootznahoo Formation: Kupreanof Island, Thermally Reset Zircon												
LA09	4.76 x 10^6	1183	1.02 x 10^7	2542	2.8 x 10^5	2268	25	98	22.1	-1.1	+1.1	442 ± 22
LA08	5.22 x 10^6	723	9.93 x 10^6	1375	2.8 x 10^5	2273	15	5.9	24.7	-1.4	+1.5	434 ± 27
LA05	4.42 x 10^6	681	8.63 x 10^6	1331	2.8 x 10^5	2279	16	98	23.8	-1.3	+1.4	381 ± 25

Note: Samples are listed in stratigraphic order (high to low). In this table, Age* is the χ^2 age – which is the minimum population - if the χ^2 value is below 5, note that this age overestimates the minimum age compared to the young population determined by binomial peakfitting (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 334.4 ± 9.3 (± 1 se) is based on 7 determinations on standard samples from the Fish Canyon 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.

Table 2: Binomial component ages of detrital zircon fission-track, Kootznahoo Formation

Sample	Location	n	Age range (Ma)	P1	P2	P3
Kootznahoo Formation: Kupreanof Island						
LA12	Kupreanof	50	24-66	36.3 ± 3.1 33%	49.8 ± 2.7 67%	
LA10	Kupreanof	30	27-64	40.0 ± 4.3 50%	53.5 ± 4.9 50%	
LA03	Kupreanof	30	43-82	57.0 ± 2.6 100%		
Kootznahoo Formation: Admiralty Island						
LA02	Admiralty	50	25-92	34.6 ± 2.1 35%	49.5 ± 4.1 33%	73.3 ± 4.7 32%
LA01	Admiralty	40	25-65	34.2 ± 3.3 42%	46.4 ± 3.4 58%	
LA15	Admiralty	30	29-61	37.1 ± 3.5 43%	47.2 ± 3.7 57%	
LA14	Admiralty	29	45-80	54.3 ± 3.1 75%	68.1 ± 3.4 25%	
Kootznahoo Formation: Kupreanof Island, Thermally Reset Zircon						
LA09	Kupreanof	25	17-26	22.2 ± 2.1 100%		
LA10	Kupreanof	15	19-44	22.8 ± 1.8 81%	34.5 ± 5.8* 19	
LA05	Kupreanof	16	19-29	23.8 ± 1.4 100%		

Note: Samples are listed in stratigraphic order (high to low). 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 334.9 ± 9.3 (± 1 se) was as computed from 7 determinations on standard samples (Fish Canyon Tuff, and Peach Springs Tuff). This table shows all binomial peak fitted ages using Binomfit 1.1.60.

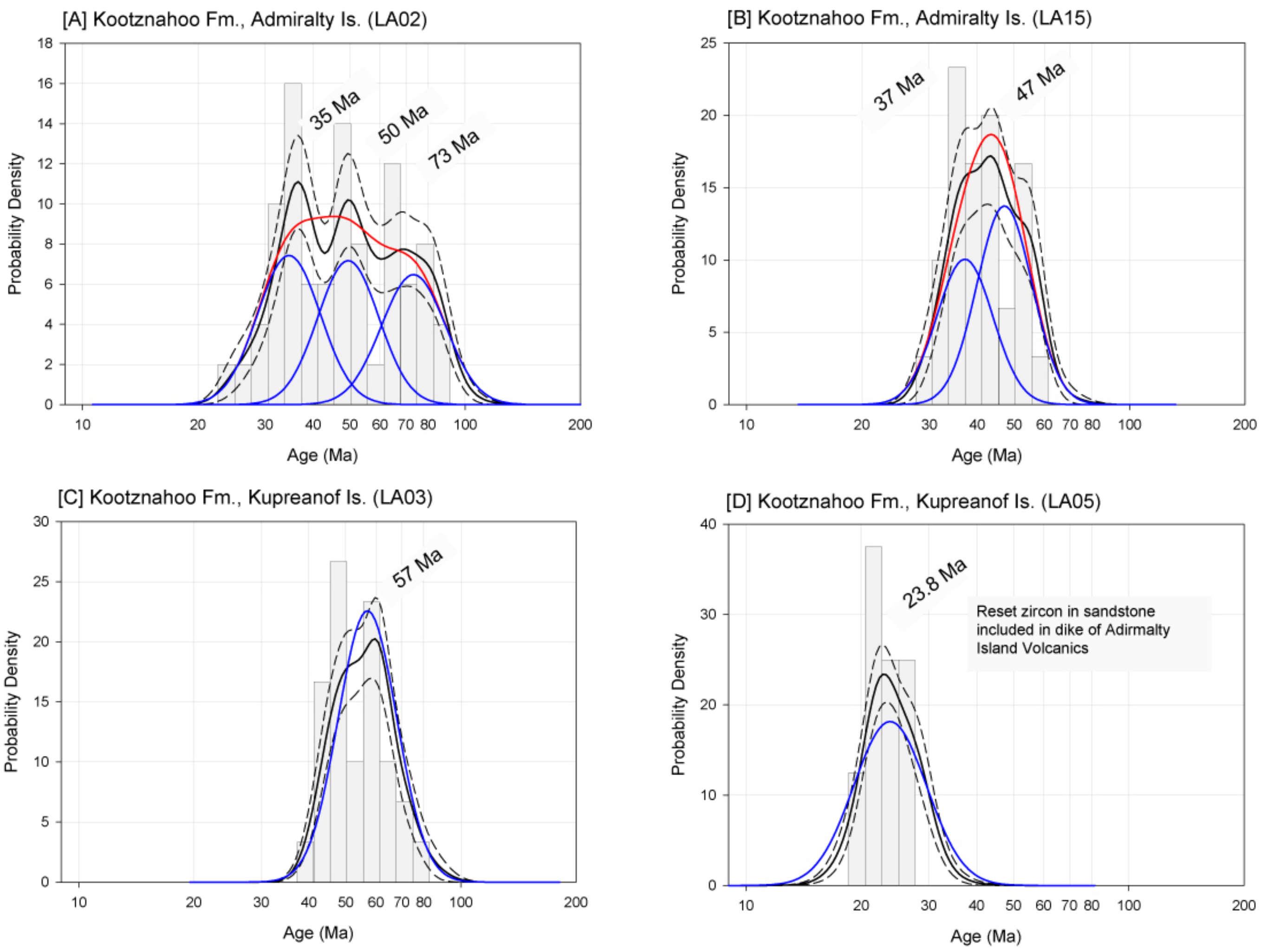

Figure 1. Representative probability density plots of single grain detrital fission track ages from the Kootznahoo Formation. [A] LA02, from the top of the section on Admiralty Island; [B] LA15, from the middle of the section on Admiralty Island; [C] LA03, from the base of the section on Kupreanof Island; and [D] represents reset zircon collected within a dike. In [A], [B], [C] and [D] the solid black line represents the probability density of all observations (dotted lines show 95% confidence interval). The blue peaks represent the statistically derived component populations modeled using a binomial peakfitting routine (BinomFit), and the red line is the model result. In plots [C] and [D], the model lacks a red line because only one population is present.

DISCUSSION

These ZFT data from the Kootznahoo Formation provide important constraints on: [1] depositional age; [2] age of thermal resetting and crosscutting intrusive dikes; and [3] provenance and cooling ages of adjacent terranes.

[1] Depositional age. The depositional age of the Kootznahoo Formation is poorly constrained and is largely based on the record of sparse and long-ranging terrestrial fossils inferred to be Paleocene through Miocene (Lathram et al., 1965; Brew et al., 1984). Brew and others (1984) suggest that the rocks in the Keku Straights section are all Paleocene, while the Little Pybus Bay section is latest Eocene through Miocene in age.

The DZFT samples in this study help constrain the depositional age range of the Kootznahoo Formation because the depositional age must equal or post-date the youngest grain-age population of un-reset samples (Garver et al., 2000; Bernet and Garver, 2005). This young age can be used as an age proxy if there is active and significant volcanism or extremely rapid exhumation in the source terrane. The popu-

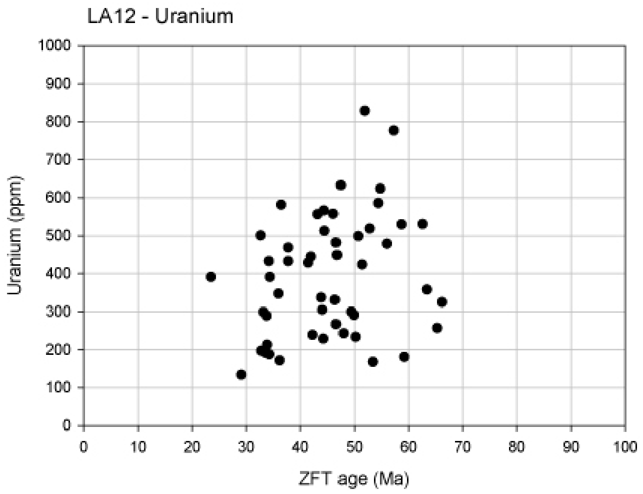

Figure 2. Scatterplot of uranium (ppm) concentration and ZFT age (Ma) of LA12. Young grains (~20 to ~40 Ma) have a wide range of uranium concentration from ~200 to ~650 ppm. The scatter shows no relationship between age and uranium concentration, which indicates no preferential resetting.

lation of grains at the base of the section (sample 09LA03) have a coherent population at 57 ± 2.6 Ma, the oldest recognized in the unit. Given fast exhumation rates, a lag time of 3 to 4 Ma could be possible (i.e. deposition of c. 53-54 Ma) (Bernet and Garver, 2005), but a conservative estimate constrains the maximum depositional age for the base of the section to be 50-54 Ma (Eocene). Higher in the section, the young population of grains in four samples range from at 34.2 ± 3.3 to 37.1 ± 3.5 Ma suggest much younger deposition. With fast exhumation of the source rock, this population may have been deposited at ~32 Ma, though deposition could have occurred later with slower exhumation rates.

The minimum depositional age is constrained by dikes that cross-cut and intrude the upper portions of the strata, and give DZFT cooling ages of 22.1± 2.1 to 23.8 ± 1.4 Ma. Given an upper bound of deposition between ~23 to ~34 Ma suggests the upper part of the Kootznahoo Formation is Oligocene. Given all of these data, conservative estimates of the upper and lower bounds on depositional ages suggest the Kootznahoo Formation in this area is Eocene-Oligocene in age. This age holds true for both the Keku Straights Section and the Little Pybus Bay section as similar age populations exist in both sections (Table 2.). Note that in this analysis, young single grain ages were not used to constrain the depositional age, as single grain error is high, and instead these constraints are based on populations of grain ages.

[2] Dikes and thermal resetting. Sandstones adjacent to dikes were sampled to understand how localized heating affected the DFT ages in the sedimentary rocks in addition to constraining depositional age. An important question in this study was whether the young cooling ages in some of the samples represent thermal resetting of zircon. The thermal influence of dikes appears to be relatively localized to within meters of the dike. Sample LA09 was collected adjacent to a dike (fully reset), and sample LA10 was collected nine meters from the same dike in the same bed and shows no reset grains (Table 2.). Significant burial of sediments can also cause heating and thermal maturation of basin strata.

Sediments of the Kootznahoo Formation away from the dikes did not likely experience significant enough heating to cause resetting. If the young populations were the result of thermal annealing a relationship between uranium content and age would be expected (Garver et al., 2005). There is no such relationship in zircon from the Kootznahoo Formation. This notion is also supported by vitrinite reflectance values of %Ro = 0.61, corresponding to maximum heating of ~100ºC (White and Mitchell, 2004), which is well below values of %Ro = 2.95 to 4.0 that result variable resetting in the Chugach terrane (Garver et al., 2010). Results from Nave (this volume) on isotope temperature estimates from cements and nodules indicate temperatures did not exceed 120ºC. Considering the young detrital zircon age population is not likely the result of resetting it must be evaluated when evaluating adjacent sources that shed sediment into the basin.

[3] Provenance and cooling ages of adjacent terranes. Given the distribution of ZFT populations we entertain a hypothesis that two distinct sediment sources may have contributed detritus to the Kootznahoo Formation. This hypothesis emerges from the observation that the Admiralty trough is flanked by

two significant thermotectonic source terranes: the Coast Mountains batholith complex to the east and the Chugach terrane to the west. The Coast Mountains batholith (CMB) was exhumed and cooled rapidly between ~65 and ~48 Ma (Rusmore et al., 2005; Gehrels et al., 2009), and likely contributed a significant amount of sediment to the formation. ZFT grain-age populations inferred to be associated with the CMB are located at the base of the section (57 Ma) and in the middle of the section (47 Ma) (see Figure 1). The CMB input is clear and was expected as the amount of granitic and metamorphic debris observed in conglomerates (Plafker et al., al. 1989).

A question that is less clear is whether the western flanking Chugach terrane supplied detritus to the basin. Higher in the stratigraphic section of the Kootznahoo Formation, a distinct and prominent younger population emerges at 35 and 37 Ma. The CPC could not produce these young cooling ages as rapid and dramatic exhumation likely ceased at ~48 Ma (Gehrels et al., 2009; Rusmore et al., 2005). Significant cooling in the Chugach terrene occurred between 40 and 30 Ma (Cowan, 2003; Garver et al., 2010). This interval of exhumation in the Chugach terrane may have supplied sediments to the Kootznahoo Formation and produced the young DZFT populations. Recent work by Garver (2010) suggests that exhumation (10-20 km) in the Chugach terrane was almost as profound as Coast Mountains exhumation, suggesting the Chugach terrane was capable of supplying a large amount of detritus to the formation. The 50 Ma DZFT population may be the result of mixing of sediments from both the CPC and Chugach terranes.

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