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THERMAL EVOLUTION OF THE SITKA GRAYWACKE, BARANOF ISLAND, ALASKA, REVEALED THROUGH ZIRCON FISSION TRACK DATING

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INTRODUCTION

The southern margin of Alaska is dominated by one of the world's thickest accretionary complexes, the Cretaceous to Eocene Chugach-Prince William (CPW) composite terrane. The CPW extends from the Sanak Islands to Baranof Island with the Border Ranges fault as the northern boundary. The CPW terrane is comprised mainly of sandstone, mudstone, and minor volcanic rocks that were incorporated into the accretionary wedge during subduction along the northwestern margin of North America during the Cretaceous and early Tertiary (*Plafker et al., 1994; Cowan, 2003)*. The depositional ages of the units of the CPW are mainly Maastrichtian to Paleocene and Eocene (inboard to outboard). The CPW was diachronously intruded by the Sanak-Baranof plutons, a 2100 km-long belt of near-trench granodiorite plutons that are inferred to be from ridge subduction (*Bradley et al., 2003)*. The pluton ages become progressively younger from west (~61 Ma) to east (~50 Ma).

The Sitka Graywacke is the westernmost and youngest unit of the CPW accretionary complex and it is well exposed on Baranof Island in SE Alaska (*Loney et al., 1975*; *Haeussler et al., 2006)*. The Sitka Graywacke is a turbidite sequence of interbedded sandstone and shales that lies along the western coast of Baranof Island, especially in Sitka Sound. Using U/Pb dating of detrital zircon, Haeussler et al. (2006) and Rick (this volume) show that the graywacke in the Sitka Sound region can be divided into an older inboard Albian age belt near Sitka, and a younger outboard Campanian-Maastrichtian belt. An important issue surrounds the metamorphism and subsequent cooling and exhumation of these rocks. In this paper, I present new detrital zircon fission track (DZFT) data from the Sitka Graywacke in Sitka Sound and show that these rocks cooled through the DZFT closure temperature (~250°C) between 29-34 Ma.

GEOLOGIC BACKGROUND

Southern Alaska has long been a site of the collision of a number of far-traveled allochthonous terranes (*Plafker et al., 1994)*. The Yakutat terrane is currently attached to the Pacific plate and is being underthrust beneath the CPW at about 0.56 mm/year to the north (*Perry et al., 2009*). The CPW formed a backstop for the collision of the Yakutat terrane, which allowed for dramatic surface uplift and erosional exhumation (*Enkelmann et al. 2009, 2010*). The Yakutat terrane was transported northwestward parallel to the Alaskan continental margin and has been subducting beneath the CPW since the Pliocene. Transport and collision have resulted in the transition of the Queen Charlotte-Fairweather transcurrent fault in the east to the Alaskan-Aleutian subduction zone in the west (*Plafker et al., 1994)*. Reconstruction of magnetic anomalies and development of subduction of the Kula-Farallon spreading center support the hypothesis of a southern provenance for the clastic rock cover sequence. Basement rocks of the Yakutat terrane were likely placed as far south as northern California or southern Oregon in the Eocene (~45 Ma) (*Cowan, 2003;*

Perry et al., 2009). Therefore, it is likely that there was ~1500-2000 km of northward margin-parallel translation along the Cordilleran margin of the Yakutat terrane.

The Sanak-Baranof belt (SBB) is a diachronous series of granodiorite plutons that intrude the CPW along the 2000 km long belt. The plutons have progressively younger ages from 61 Ma in the west on Sanak Island to ~50 Ma in the east on Baranof Island. U/Pb dating of zircon in the Crawfish Inlet pluton, the easternmost pluton of the SSB, yield crystallization ages of 47-53 Ma on Baranof Island (*Karl et al., 2014; Wackett et al., 2014)*. Before intrusion of the SBB plutons, the Sitka Graywacke was buried and metamorphosed to prehnite-pumpellyite and perhaps lower greenschist facies conditions *(Loney et al., 1975*). The intrusion of the Crawfish Inlet pluton and associated plutons of the SBB locally increased temperatures to produce amphibolite grade schists containing biotite + andalusite + cordierite ± garnet ± sillimanite (*Zumsteg et al., 2003; Kaminski et al., 2014)*.

To the east of Baranof Island is a Tertiary basin referred to as the Admiralty Trough *(Ancuta, 2010).* The strata of the Kootzanhoo Formation were deposited in this elongated basin that is presently 320 km long and 50 km wide and extends from northern Admiralty Island to the southeastern side of Prince of Wales Island (*Ancuta, 2010).* Sediments of the Kootznahoo Formation record mixing of material from the Coast Mountains Batholith Complex (CMBC) to the east and the CPW terrane to the west *(Ancuta, 2010).* In these strata, a young population of ZFT cooling ages (35-39 Ma) may represent uplift and exhumation of the CPW terrane along the western basin margin, or they may represent active volcanism in the adjacent source area (*Ancuta, 2010).* Garnet-bearing schist clasts in the upper strata of the Kootznahoo Formation may have been eroded from the Baranof Schist of the CPW terrane on Baranof Island *(Ancuta, 2010)*.

It has been proposed that the entire CPW terrane was translated 1100 km northward along dextral strike-slip faults since 50 Ma, and movement likely involved slip on the Border Ranges fault system (*Cowan, 2003*). Cowan (2003) suggests that the rocks of the CPW terrane now located on southern Baranof Island were contiguous with similar rocks on southern Vancouver Island and were intruded, metamorphosed, and deformed at 50 Ma. The schists on Baranof were then displaced northward by an extensive fault system that may include the offshore Queen Charlotte-Fairweather fault and Chatham Strait-Denali system, Peril Strait fault, and the Border Ranges fault system (*Cowan, 2003).* Northward motion of the CPW terrane relative to North America can be related to the southward migration of the SBB magmatism within the terrane if a ridge-trench intersection were located at approximately 48°N (*Cowan, 2003)*.

FISSION TRACK DATING

Fission track dating of zircon ($ZrSiO_4$) is an important method for studying sediment provenance and the exhumation of orogenic belts (*Bernet and Garver, 2005*). The high abundance of zircon in igneous, metamorphic, and sedimentary rocks due to its resistance to weathering and abrasion makes them excellent for determining single grain ages (*Bernet and Garver, 2005)*. A fission track is formed by the natural fission of ^{238}U, which spontaneously fissions into two sub-equal fragments, leaving a narrow trail of damage along its trajectory that is ~10 μm long (*Wagner and van den Haute, 1992)*. The effective closure temperature is the temperature of near full track retention and depends on the cooling rate. In typical geologic settings, zircon has an effective closure temperature of about 250 ± 40°C (*Brandon et al., 1998*). This temperature estimate is sensitive to the rate of cooling and radiation damage in the zircon crystal. Higher radiation lowers the closure temperature, often causing the tracks to become annealed and resetting the grain at temperatures of approximately 200°C or below (*Garver et al., 2005*).

METHODS

Eleven samples of medium- to coarse-grained sandstone from the Albian and Campanian-Maastrichtian belts of the Sitka Graywacke near Sitka were collected and processed. Collectively, the sample sites create northwest/southeast and southwest/northeast trending transects in and around Sitka Sound (Fig. 1). Samples were processed for zircon fission track dating according to the standard extraction procedures (see also *Bernet and Garver,* *2005*). Following extraction, the zircon grains from unknowns and standards were mounted in 2x2 cm^2 PFA Teflon® squares at 330°C *(Bernet and Garver, 2005*). The mounts were etched in a NaOH-KOH eutectic (228°C) solution for 22 hours. The samples were stacked and taped and placed in a Triga Poly tube with a glass dosimeter at the front, middle, and back of the stack of samples. The tube of samples was sent to the USGS Triga reactor in Denver Colorado where it was irradiated with 2 x 10^{15} n/cm^2 in October, 2013.

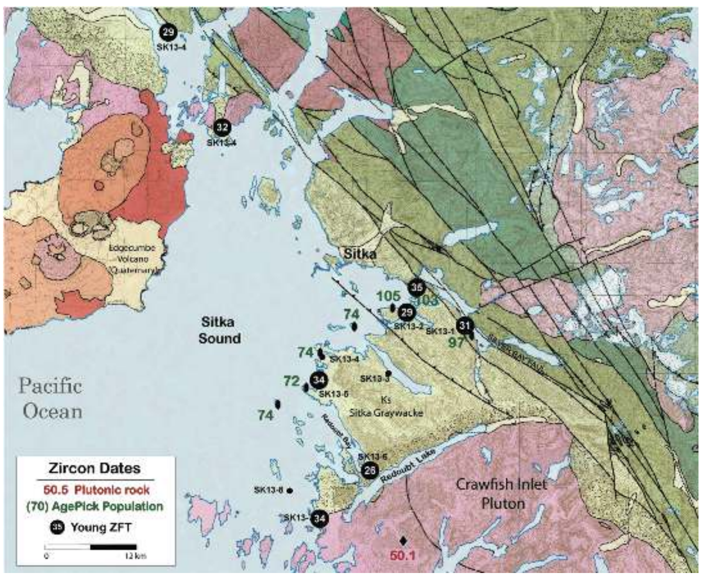

Figure 1: Area of study on Baranof Island, Alaska and sample sites with DZFT ages (Ma) and maximum depositional ages (Ma) from detrital zircon U/Pb dates (Rick et al., 2014). The Crawfish Inlet pluton is labeled and shown in pink with detrital zircon U/Pb dates (Roig, this volume). Map modified from Karl et al., in press.

COUNTING FISSION TRACKS

Using both transmitted and reflected light, the natural spontaneous fission tracks on the zircon grains and the induced tracks on the mica were counted at 1250x using an Olympus® BMAX-60 microscope. Before counting, marked grains were evaluated for countability based on the following: sufficient countable area, etched tracks oriented parallel to the c-axis, no inclusions, little zonation, even uranium distribution, and optical clarity (*Bernet and Garver, 2005*). Spontaneous and induced tracks were counted in ten grains for nine standards of known age for the Fish Canyon Tuff and Peach Springs Tuff units to calculate a zeta calibration factor. Induced tracks in the mica attached to the glass dosimeters were also counted to determine fluence. The zeta calibration factor, correct fluence, and track counts were used to calculate a grain age using the 'ZetaAge' program (from M.T. Brandon, Yale University). For each unknown sample, between 30 and 40 grains were counted for fission tracks.

RESULTS

A total of seven samples were analyzed using ZFT dating. One sample, ST13-10, failed χ^2 and was plotted using Binomfit. For all other samples that passed χ^2, the pooled ages are used, indicating considerable age dispersion that reflects source heterogeneity (*Bernet and Garver, 2005*). U/Pb ages of detrital zircon yield an Albian to Maastrichtian depositional age for the Sitka Graywacke (*Haeussler*

Table notes: In this table, the age is pooled if the sample passes χ^2 and the χ^2 age is used if it fails. 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 inducted 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 (±1s) were determined using the Zeta method, and calculated using the computer program and equations in Brandon (1992).

Table 1: Zircon fission track data – Baranof Island

Sample	ρ_s	N_s	ρ_i	N_i	ρ_d	N_d	n	χ^2	Age*	-1σ	+1σ	Uranium
Sitka Sound - Sitka Graywacke												
ST13-01	3.46 x 10^6	1305	5.26 x 10^6	1981	2.145 x 10^5	1961	40	17.0	31.4	-1.5	+1.5	301.4±17.8
ST13-02	3.46 x 10^6	1303	5.71 x 10^6	2148	2.148 x 10^5	1965	40	29.1	29.0	-1.3	+2.8	326.9±18.6
ST13-05	4.71 x 10^6	1723	6.74 x 10^6	2464	2.155 x 10^5	1971	39	86.4	33.5	-1.5	+1.5	384.5±20.5
ST13-06	3.63 x 10^6	1042	6.60 x 10^6	1895	2.158 x 10^5	1974	29	22.5	26.4	-1.3	+1.3	375.9±21.4
ST13-07	4.21 x 10^6	1468	6.53 x 10^6	2274	2.162 x 10^5	1977	40	77.7	31.0	-1.4	+1.4	371.5±19.8
ST13-10	4.21 x 10^6	1147	6.36 x 10^6	1731	2.165 x 10^5	1980	30	1.2	31.9	-1.5	+1.6	361.2±20.9
ST13-11	5.56 x 10^6	1770	7.19 x 10^6	2287	2.168 x 10^5	1984	30	28.8	37.3	-1.6	+1.7	407.6±21.5

et al., 2006; Rick, this volume). The grain-age populations are younger than the time of deposition, revealing that annealing and thermal resetting occurred after deposition. All samples have a significant primary population (ρ_1) ranging in age from 29 to 35 Ma (Table 1).

DISCUSSION

The DZFT results show remarkable uniformity of cooling through ~250°C of the Sitka Graywacke in the Sitka Sound area during the Oligocene (29-34 Ma) (Fig. 1). The Baranof Schist to the south is inferred to be the metamorphosed equivalent of the Sitka Graywacke (*Loney et al., 1975);* these rocks show regional metamorphism of biotite grade with cordierite + andalusite ± garnet ± sillimanite along the margin of the Crawfish Inlet Pluton (*Zumsteg et al., 2003*; *Kaminski et al., 2014*). Based on the detrital zircon U/Pb data, the depositional ages of the Sitka Graywacke and Baranof Schist fall into three time slices: Albian (95-105 Ma), Campanian-Maastrichtian (75-65 Ma), and Paleocene (60-65 Ma) (*Rick, this volume*); the samples dated in this study come from the older two units (Fig. 1). Crystallization ages for the Crawfish Inlet and Krestof plutons are 47-53 Ma, indicating that the accretionary wedge locally experienced high T/P metamorphism associated with plutonism (*Wackett et al., 2014*). An important finding is that both the high-grade Baranof Schist and the lower-grade Sitka Graywacke give essentially identical cooling ages despite the striking differences in metamorphic grade (*Kaminski, this volume*). Thus, the consistent cooling ages across the different metamorphic grades suggest that the Sitka Graywacke stayed above ~250°C for ~ 15 m.y. since the intrusions of the plutons, and then cooled together at 29-35 Ma.

The ZFT dates from the Sitka Graywacke may indicate detachment and exhumation as strike-slip faults reworked the outer British Columbia margin in the mid-Tertiary. An important question is whether the cooling ages are associated with post-intrusive cooling or erosional exhumation. Nearby flanking sedimentary sequences indicate that cooling in the Late Eocene and Oligocene could have been driven by erosional exhumation. The younger population of ZFT cooling ages (35-39 Ma) in the upper part of the Kootznahoo Formation in the Admiralty trough has garnet-bearing schist clasts that may have been derived from erosional exhumation of the adjacent Baranof block *(Ancuta, 2010)* during strike-slip motion along the North American margin. Cowan (2003) suggests that the CPW terrane that is now located on southern Baranof Island may have originally been adjacent to terranes on southern Vancouver Island when they were intruded, metamorphosed, and deformed at ~50 Ma.

CONCLUSIONS

The ZFT results reveal that the Sitka Graywacke cooled through ~250°C between 29-34 Ma. Zircons with Eocene to Oligocene cooling ages and garnet-bearing schist clasts may have eroded from the Baranof block and been deposited into the adjacent Admiralty trough to the east forming the upper Kootznahoo Formation. The Baranof block was likely affected by vertical displacement that was driven by dextral strike-slip motion along extensive fault systems that formed during the major reorganization of north Pacific plate motions in the Eocene. Future studies may involve further sampling and ZFT dating from the eastern side of Baranof Island and studies of the metamorphic history of the units adjacent to the plutons. If other sample areas provide evidence for lower-temperature cooling ages, there may be further insight on the tectonic and metamorphic history of this region.

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