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Keck Geology Consortium
Geology Department, Pomona College
185 E. 6th St., Claremont, CA 91711
(909) 607-0651, keckgeology@pomona.edu, keckgeology.org

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EXHUMATION OF THE BARANOF SCHIST, ALASKA DETERMINED THROUGH DETRITAL ZIRCON FISSION TRACK DATING

KATE KAMINSKI, Union College
Research Advisor: John I. Garver

INTRODUCTION

The Alaska continental margin of the North Pacific lies on the boundary of the Pacific plate and North American plate. This margin is tectonically active, characterized by strike slip faulting on a number of key structures including the Border Ranges, Denali, Queen Charlotte, and Fairweather faults. During the Eocene, these faults – or their ancestors – may have accommodated northward translation of the Chugach Prince William terranes up to 1100 km (Cowan, 2003). It is hypothesized that the CPW was accreted at ~48ºN, the location of the Eocene Kula-Farallon-North America triple junction and the current latitude of Vancouver Island (Cowan, 2003; Pavlis & Sisson 2003).

The Baranof Schist is a meta-sandstone unit of the CPW, correlative to the Sitka Graywacke, that was heated through regional and thermal metamorphism of the Crawfish Inlet pluton at ~50 Ma (Loney et al., 1975; Zumsteg et al., 2003; Gasser et al., 2012). The flysch is inferred to have been deposited in a trench, accreted to an accretionary prism, and then intruded at depth. The cooling ages of the Baranof Schist determined through detrital zircon fission track dating allow us to understand the post-intrusive history of this belt. These data, when combined with data from other studies, reveal a cooling history similar to that of the Chugach metamorphic complex (CMC), an Eocene complex that experienced high-temperature, low-pressure metamorphism (Pavlis and Sisson, 2003). Likewise, the Leech River Schist near Vancouver, hypothesized to be another unit of the metamorphosed CPW, shows a history of rapid cooling immediately after metamorphism and was completely cooled by 34-36 Ma. The cooling curves of these three units imply that at ca. 50 Ma, there was a large-scale diachronous event that first involved the CMC, then the Baranof Schist, and finally the Leech River Schist. This project, through fission track dating of the Baranof Schist and data from other studies, aims to determine the relation of these three complexes and the thermal and tectonic evolution of the Baranof Schist.

TECTONIC AND GEOLOGIC BACKGROUND

The Chugach-Prince William terrane (CPW) is a Mesozoic and Cenozoic accretionary complex that extends 2200 km along the Alaska continental margin from Sanak Island to Chatham Strait in Southeast Alaska. The CPW was accreted along the margin from the Cretaceous to early Tertiary as a thick clastic package of trench-fill deposits and was intruded by near-trench plutons during subduction of the Kula-Farallon or Kula-Resurrection ridge in the Paleocene and Eocene (Haeussler, 2003; Cowan, 2003). Paleomagnetic data indicate that the CPW was not accreted at its present latitudinal position, but rather at a more southerly position of 48ºN or even farther south (Cowan, 2003). This hypothesis posits that the CPW was translated northward after 50 Ma along the continental margin a maximum of 1100 km, and this margin-parallel movement was accommodated through strike-slip motion along the Border Ranges fault (Cowan, 2003).

The accretionary complex of the CPW is composed of flysch and mélange, interpreted to be deep-water trench turbidites with minor amounts of mafic volcanics (Plafker et al., 1994). The Baranof Schist of the CPW is metamorphosed by the Crawfish Inlet pluton, a 47-53 Ma intrusive body of the Sanak-Baranof plutonic belt (Wackett et al., 2014). Plutons of the Sanak-Baranof belt occur across almost the entirety of the CPW and are composed of granitic plutons that range in age from 61 Ma on Sanak Island to ~50 Ma on Baranof Island. Magmatism across the belt decreases in age from west to east (Bradley et al., 2003).

The Baranof Schist correlates with the Leech River Schist to the south, a metamorphic complex of similar age on Vancouver Island (Cowan, 2003). The Leech River Schist is believed to be a portion of the CPW that was positioned adjacent to the Baranof Schist while both were intruded and metamorphosed simultaneously at ~50 Ma. The Leech River Schist, however, remained in place as the CPW was moved northward along the continental margin (Cowan, 2003). To the north and west, the Chugach metamorphic complex (CMC) is a unit of the CPW with a maximum depositional age of 60 Ma that experienced high-temperature, low-pressure metamorphism around 55 Ma, which was also translated north along with the CPW (Gasser et al., 2012).

FISSION TRACK DATING

Detrital zircon fission track dating is a thermochronologic method useful in determining cooling ages and related provenance and exhumation history of clastic rocks (Bernet and Garver, 2005). Zircon is a particularly effective mineral for fission track dating because it is common in igneous and sedimentary rocks and is resistant to weathering. When a zircon sample cools, its temperature passes below the effective closure temperature, ~240ºC ± 30ºC (Brandon et al., 1998). Below this temperature, fission tracks within the zircon are retained and the number of tracks in a grain is a function of uranium concentration and time since closure. This effective closure temperature depends on cooling rate and lies within the zircon partial annealing zone (zPAZ). The zPAZ is the temperature range in which fission tracks are typically retained in the crystal structure of a zircon, constrained to about 200-210ºC for damaged grains and 280 to 300ºC for grains with a nearly crystalline structure (Garver, 2005). At temperatures below the zPAZ, tracks are typically retained, while at temperatures above, tracks are annealed and lost.

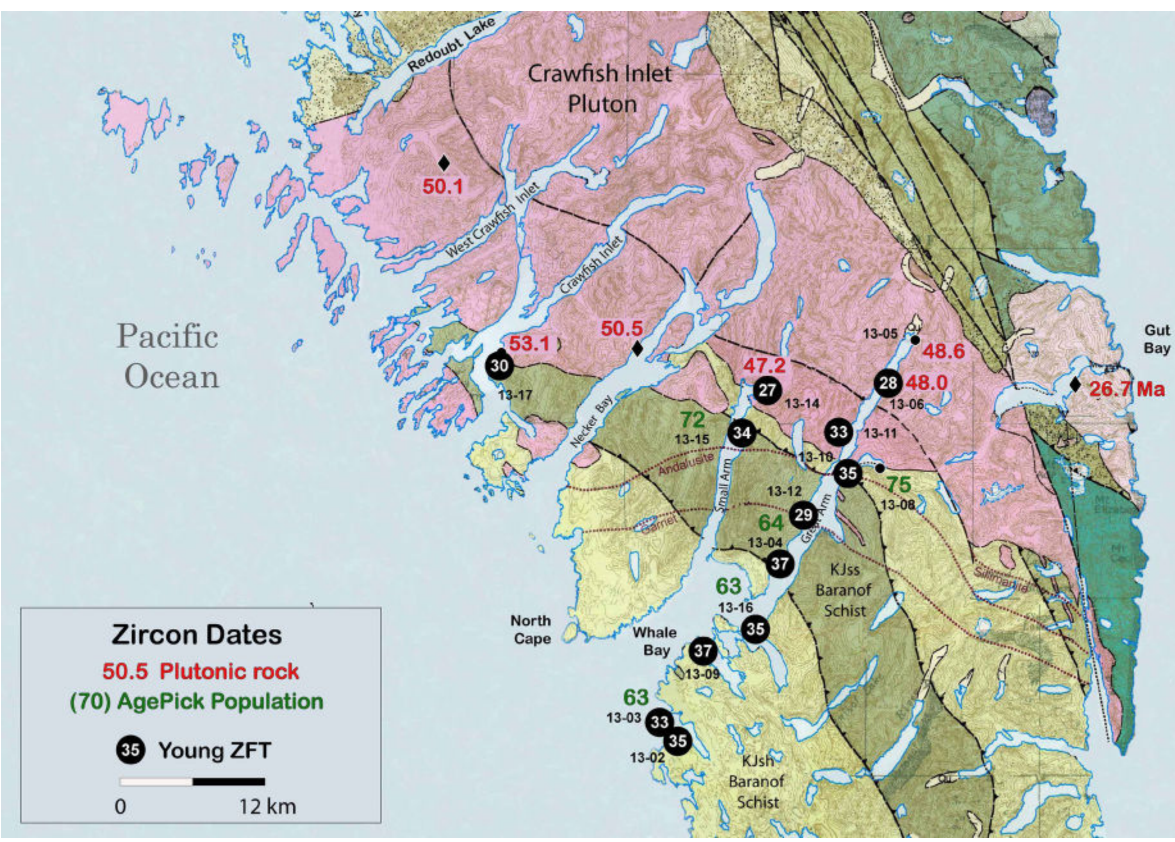

Figure 1. Sample map of the Whale Bay transect. Young zircon fission track ages place the cooling of the Baranof Schist at 37-27 Ma. AgePick dates are from Rick et al. (this volume). Cooling ages of the Crawfish pluton are from Wackett et al. (this volume) and the cooling age of the Gut Bay pluton is from Karl et al. (2014) (base map adapted from Karl et al., 2014).

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
Whale Bay – Baranof Schist												
WB13-02A	5.59×10^6	1897	7.51×10^6	2550	2.710×10^5	2128	30	55.1	34.6	-1.5	+1.5	341.0±17.1
WB13-03A	6.38×10^6	2173	9.06×10^6	3086	2.713×10^5	2131	30	60.9	32.8	-1.3	+1.4	410.7±19.6
WB13-04B	8.00×10^6	2599	1.02×10^7	3299	2.718×10^5	2135	30	21.5	36.8	-1.5	+1.5	459.5±21.7
WB13-09A	7.31×10^6	2038	9.25×10^6	2578	2.723×10^5	2139	30	11.2	37.0	-1.6	+1.6	417.7±21.5
WB13-10A	8.55×10^6	2085	1.06×10^7	2579	2.727×10^5	2142	30	0.0	35.6	-1.5	+1.6	477.1±24.8
WB13-12A	6.41×10^6	1507	8.16×10^6	1919	2.733×10^5	2148	30	0.1	35.9	-1.7	+1.7	367.1±21.4
WB13-15A	6.05×10^6	1488	8.39×10^6	2062	2.740×10^5	2154	30	9.6	34.0	-1.6	+1.6	376.6±22.1
WB13-16A	6.76×10^6	1821	8.34×10^6	2248	2.743×10^5	2156	30	0.7	37.8	-1.7	+1.8	374.0±21.7
WB13-17B	8.45×10^6	1459	1.05×10^6	1809	2.748×10^5	2161	22	0.5	37.0	-1.8	+1.9	469.0±29.6
Whale Bay – Crawfish Inlet Pluton												
WB13-06A	7.69×10^6	2604	1.00×10^7	3402	2.720×10^5	2137	30	0.0	33.4	-1.4	+1.5	454.2±21.4
WB13-11A	1.05×10^7	2000	1.26×10^7	2411	2.730×10^5	2145	30	5.1	38.9	-1.7	+1.7	568.4±30.5
WB13-14A	6.26×10^6	1542	8.64×10^6	2129	2.737×10^5	2151	30	0.0	32.9	-1.5	+1.6	388.2±22.2

Note: In this table, Age* is the pooled age when the sample passes χ^2 and the χ^2 age 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 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.

Table 1. All samples from Whale Bay and corresponding fission track data and resulting ages.

METHODS

Twelve samples of the Baranof Schist were collected from outcrops along the shore of Whale Bay on Baranof Island (Fig. 1). Whole rock samples were collected from medium- to coarse-grained metasandstones and granites of the Crawfish Inlet pluton. Zircon extraction and sample mount preparation were conducted according to standard procedures as described in Bernet and Garver (2005) and sent for irradiation in the USGS nuclear reactor in Denver, Colorado.

After irradiation, samples were mounted for counting. The zeta calibration factor was calculated by counting tracks on standards of established ages and running the results through ZetaMean. In the unknown samples, 30 grains on each mount were counted using FTStage v2.0 software. The data were then run with the ZetaAge program using the determined zeta factor along with the fluence of the glass monitors to determine the cooling ages of the unknowns.

RESULTS

The twelve samples yield FT ages of 39-32 Ma across the entire transect, with no noticeable trend (Table 1, Fig. 1). Cooling ages were determined by the pooled ages of zircons within a single sample if a sample passed χ^2. Six of the twelve Whale Bay samples did not pass χ^2, indicating overdispersion. For these samples, the cooling ages were determined by using the χ^2 age, which isolates the young population of grains in the analysis and dismisses the older population, which in the case of these samples fell in the mid to late 40 m.y. These χ^2 ages place the young cooling ages at 37-27 Ma (Fig. 1).

Samples WB13-02A and -03A were taken from sandstones intruded by mafic dikes that are well exposed on the Meikof Islands. Sample WB13-02A produced a cooling age of 34.6 ± 3.0 Ma (2σ error), which is statistically indistinguishable from the 32.8 ± 2.8 Ma cooling age of a sample collected directly adjacent to a 0.3-0.45 basalt dike (WB13-03).

COOLING IN WHALE BAY

The results from these cooling ages can be interpreted in the context of other studies in the Whale Bay area. The maximum depositional age of the Baranof Schist is 60-79 Ma, showing that these rocks were deposited in the Cretaceous to Paleocene (Rick, this volume). Shortly after deposition, it was intruded by the Crawfish Inlet pluton between 53-47 Ma (Wackett et al., 2014). Cooling began soon after intrusion, as biotite K-Ar ages indicate the cooling in Whale Bay began 48-43 Ma (Karl et al., 2014). ZFT cooling ages with a slightly lower closure temperature (>250°C) from our samples in Whale Bay produce ages of 27-

37 Ma (Table 1), indicating that cooling had slowed considerably following an initially rapid cooling after crystallization of the Crawfish Inlet pluton (Fig. 2). The differences in cooling ages of the Baranof Schist are statistically insignificant, which likely indicates that the entire unit cooled at the same rate.

Half of the samples in Whale Bay did not pass χ^2, indicating that there are heterogeneous populations that demonstrate overdispersion. In these samples, there are remnant populations at 40 Ma or greater, while others define a young population at ~30 Ma. This overdispersion of grain ages is potentially due to differences in track retention in the zircons. Low-retentive zircons (LRZs), have partially damaged structures and anneal at low temperatures of 180-200ºC. High-retentive zircons (HRZs) are nearly crystalline and have less damage than LRZs and anneal at temperatures of 280-300ºC or greater (Bernet and Garver, 2005). Differences in annealing temperatures between LRZs and HRZs can cause partial annealing in some grains and full annealing in others. In Whale Bay, the intrusion of the Crawfish pluton may have heated the surrounding rocks to temperatures greater than 500ºC. This heating event would have been hot enough to reset all zircon, but overdispersion occurred during slow cooling that followed. HRZ record the initial rapid cooling (>40 Ma), whereas the LRZ grains had an effective closure temperature that was lower, and thus younger ages (~30 Ma).

POST-INTRUSIVE HEATING

The dike system at the end of Still Harbor produced ages of 32.8 Ma directly next to the dike and 34.6 Ma about 20-30 meters away from the dike. These dates are statistically indistinguishable from the ages of the Baranof Schist elsewhere in Whale Bay. There are several possibilities for this result. One is that the dikes are relatively old and predate rapid cooling in the belt (pre-45-48 Ma). A second is that they are nearly synchronous with this late-stage cooling (c. 33-35 Ma).

Two sources of possible late Eocene magmatism and heating are the Kano intrusions and Admiralty Island volcanics. The Kano Intrusions on the Haida Gwaii (Queen Charlotte) Islands occurred from ~27-39 Ma, which produced monzodioritic and granodioritic dikes (Madsen et al., 2006). The second event that could have produced intrusion and heating are the Admiralty Island volcanics, which are dated at ~35-20 Ma. Mafic dikes cutting the Kootznahoo Formation from this event are dated at 22 Ma (Ancuta, 2010).

CHUGACH METAMORPHIC COMPLEX

The Chugach metamorphic complex (CMC) to the NW in the Chugach Mountains has similar protolith rocks that show metamorphism began ca. 55-54 Ma with peak metamorphism likely occurring ca. 55-52 Ma (Gasser et al., 2012). The CMC experienced high-

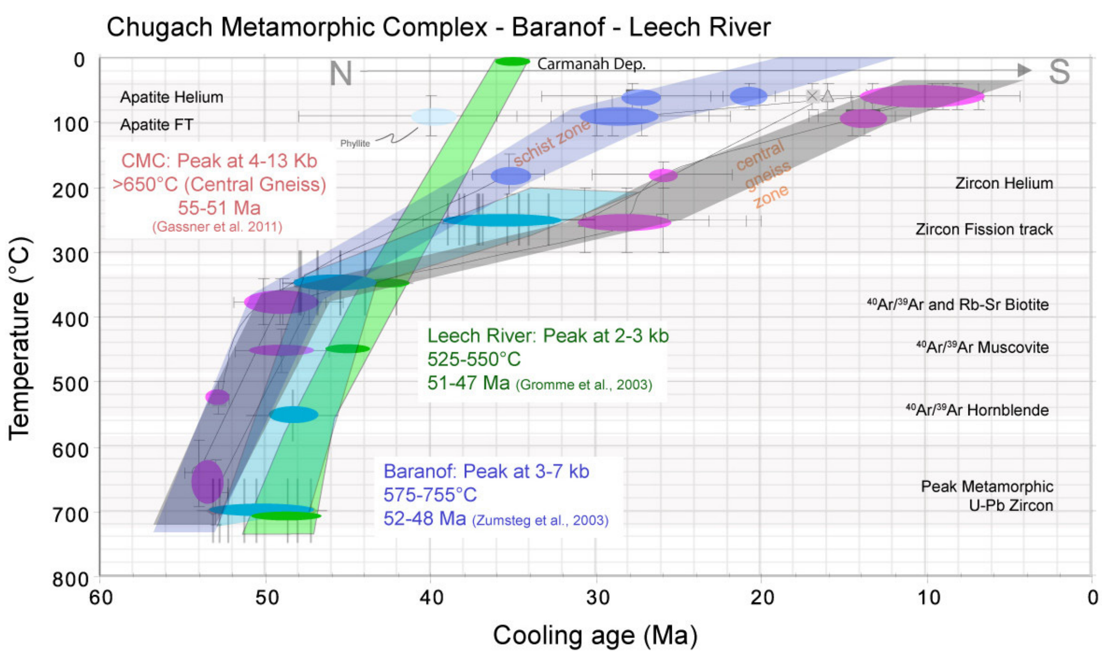

Figure 2. Cooling curves of three CPW complexes. The ellipses in each cooling curve simplify the error and data range of each group; most dates are statistically indistinguishable across the belt.

temperature, low-pressure metamorphism during peak metamorphism then cooled soon after, ca. 51-46 Ma (Gasser et al., 2012). The metamorphism of the CMC occurred several million years earlier than that of the Baranof Schist, but they both exhibit a similar cooling curve (Fig. 2). Both units show rapid (~120ºC/myr) cooling, then after about 5-6 myr, these rates decrease significantly (~7ºC/myr). The schist and gneiss zones of the CMC cooled at slightly different rates, indicating that the units were possibly of different thicknesses and thus metamorphosed at different depths, or the geothermal gradient shifted to change the temperatures at each depth.

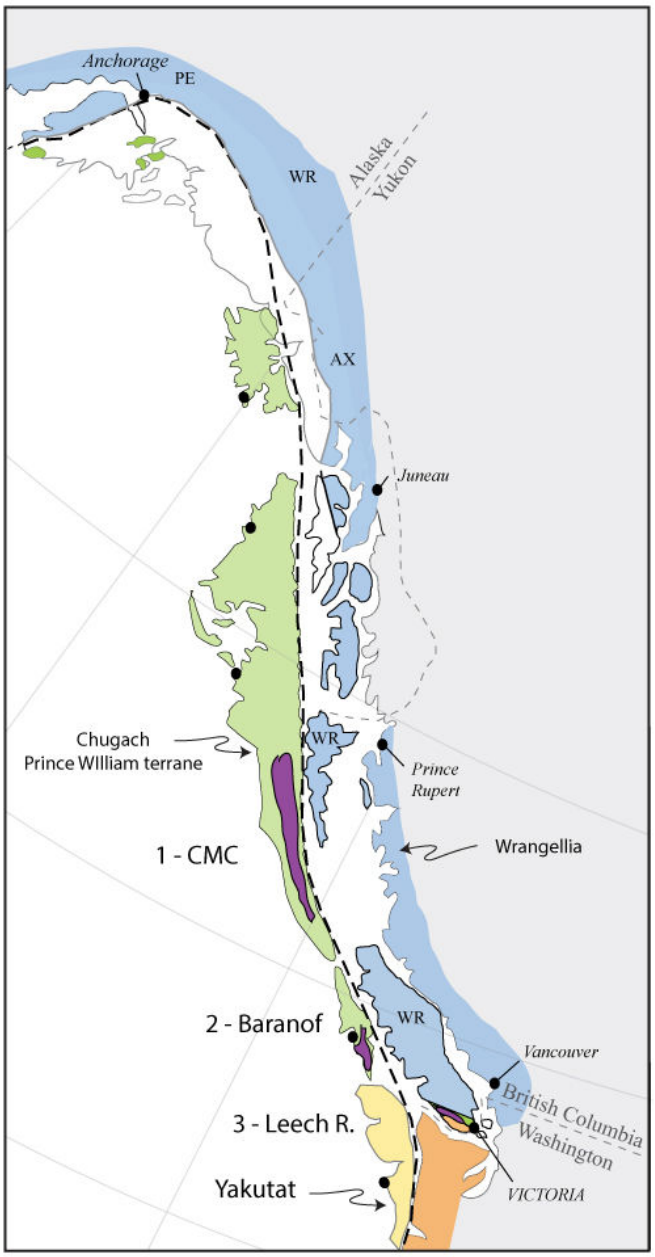

Figure 3. Proposed positions of the Chugach Metamorphic Complex (CMC), the Baranof Schist, and the Leech River Schist during the Eocene before tectonic translation (adapted from Cowan, 2003).

NORTH PACIFIC RECONSTRUCTION

Cooling ages from the Baranof Schist, CMC, and Leech River Schist (LRS) indicate that all three complexes experienced a similar but diachronous high T/P metamorphism and thus may be formed progressively along the same margin (Cowan, 2003). All three complexes consist of metasediments that were accreted along the continental margin before 50 Ma and were likely positioned in a coherent belt (Fig. 3). Around 52 Ma, heating occurred first in the CMC then moved south ca. 50-51 Ma to the Baranof Schist, and finally further south to the LRS ca. 50-49 Ma. Though heating and cooling occurred consecutively across the belts, the full cooling histories are slightly different. The CMC and Baranof Schist exhibit similar cooling rates, first cooling very rapidly and then much more slowly. The LRS, though possibly contiguous with the Baranof Schist at deposition, shows rapid, full cooling and surface exposure by 35 Ma, when it is blanketed by strata of the Carmanah Formation (Fig. 2; Groome et al., 2003). This markedly different cooling rate may be due to the tectonic history of the LRS after intrusion. The LRS was intruded by the Walker Creek intrusions ca. 51 Ma, which are interpreted to have been the result of the subduction of the Kula-Farallon ridge (Groome et al., 2003). During cooling, the Crescent terrane collided with the LRS and presumably forced it to exhume rapidly, thus causing rapid cooling rates as well as simultaneously causing the LRS to jump onto the stationary North American Plate (Groome et al., 2003; Madsen et al., 2006). Meanwhile, the Baranof Schist and CMC had escaped this fate and had been translated northwards along strike-slip faults.

Metamorphism of the CMC, Baranof Schist, and the LRS is attributed to subduction of the Kula-Farallon ridge, potentially indicating that these complexes were at one point located near each other and affected by the same heating events (Pavlis and Sisson, 2003; Zumsteg et al., 2003; Groome et al., 2003). The progression and continuity of the early intrusion and rapid cooling suggests an initially contiguous belt that was since disrupted (Cowan, 2003).

CONCLUSIONS

Fission track cooling ages from the Baranof Schist indicate a distinct cooling pattern that can be related to adjacent metamorphic belts in the CPW terrane. These data suggest continuity of this belt, which favors a hypothesis of northward translation of the CPW. We hypothesize that the Baranof Schist, CMC, and LRS were at one point a contiguous belt ~48ºN and experienced heating consecutively as a result of the subduction of the Kula-Farallon ridge. After metamorphism, translation of the Baranof Schist and CMC along the continental margin was accommodated first by dextral strike-slip motion of the Border Ranges and then Queen Charlotte-Fairweather fault systems.

Further work in this study to elucidate the tectonic history of the Baranof Schist involves determining the amount of movement that occurred on the faults along the continental margin to accommodate the northward translation of the CPW. Additionally, an important task is to complete the low-temperature cooling curve of the Baranof Schist to better relate the post-metamorphic cooling to adjacent belts. These additional data on the history of the Baranof Schist may lend insight to the cause of cooling in the units of Whale Bay, whether it was due to erosional exhumation, changes in the geothermal gradient, or a combination of both.

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