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## 2009-2010 PROJECTS

**SE ALASKA - EXHUMATION OF THE COAST MOUNTAINS BATHOLITH DURING THE GREENHOUSE TO ICEHOUSE TRANSITION IN SOUTHEAST ALASKA: A MULTIDISCIPLINARY STUDY OF THE PALEOGENE KOOTZNAHOO FM.**
*Faculty: Cameron Davidson (Carleton College), Karl Wirth (Macalester College), Tim White (Penn State University)*
*Students: Lenny Ancuta, Jordan Epstein, Nathan Evenson, Samantha Falcon, Alexander Gonzalez, Tiffany Henderson, Conor McNally, Julia Nave, Maria Princen*

**COLORADO – INTERDISCIPLINARY STUDIES IN THE CRITICAL ZONE, BOULDER CREEK CATCHMENT, FRONT RANGE, COLORADO.**
*Faculty: David Dethier (Williams)* *Students: Elizabeth Dengler, Evan Riddle, James Trotta*

**WISCONSIN - THE GEOLOGY AND ECOHYDROLOGY OF SPRINGS IN THE DRIFTLESS AREA OF SOUTHWEST WISCONSIN.**
*Faculty: Sue Swanson (Beloit) and Maureen Muldoon (UW-Oshkosh)*
*Students: Hannah Doherty, Elizabeth Forbes, Ashley Krutko, Mary Liang, Ethan Mamer, Miles Reed*

**OREGON - SOURCE TO SINK – WEATHERING OF VOLCANIC ROCKS AND THEIR INFLUENCE ON SOIL AND WATER CHEMISTRY IN CENTRAL OREGON.**
*Faculty: Holli Frey (Union) and Kathryn Szramek (Drake U. )*
*Students: Livia Capaldi, Matthew Harward, Matthew Kissane, Ashley Melendez, Julia Schwarz, Lauren Werckenthien*

**MONGOLIA - PALEOZOIC PALEOENVIRONMENTAL RECONSTRUCTION OF THE GOBI-ALTAI TERRANE, MONGOLIA.**
*Faculty: Connie Soja (Colgate), Paul Myrow (Colorado College), Jeff Over (SUNY-Geneseo), Chuluun Minjin (Mongolian University of Science and Technology)*
*Students: Uyanga Bold, Bilguun Dalaibaatar, Timothy Gibson, Badral Khurelbaatar, Madelyn Mette, Sara Oser, Adam Pellegrini, Jennifer Peteya, Munkh-Od Purevtseren, Nadine Reitman, Nicholas Sullivan, Zoe Vulgaropulos*

**KENAI - THE GEOMORPHOLOGY AND DATING OF HOLOCENE HIGH-WATER LEVELS ON THE KENAI PENINSULA, ALASKA**
*Faculty: Greg Wiles (The College of Wooster), Tom Lowell, (U. Cincinnati), Ed Berg (Kenai National Wildlife Refuge, Soldotna AK)*
*Students: Alena Giesche, Jessa Moser, Terry Workman*

**SVALBARD - HOLOCENE AND MODERN CLIMATE CHANGE IN THE HIGH ARCTIC, SVALBARD, NORWAY.**
*Faculty: Al Werner (Mount Holyoke College), Steve Roof (Hampshire College), Mike Retelle (Bates College)*
*Students: Travis Brown, Chris Coleman, Franklin Dekker, Jacalyn Gorczynski, Alice Nelson, Alexander Nereson, David Vallencourt*

**UNALASKA - LATE CENOZOIC VOLCANISM IN THE ALEUTIAN ARC: EXAMINING THE PRE-HOLOCENE RECORD ON UNALASKA ISLAND, AK.**
*Faculty: Kirsten Nicolaysen (Whitman College) and Rick Hazlett (Pomona College)*
*Students: Adam Curry, Allison Goldberg, Lauren Idleman, Allan Lerner, Max Siegrist, Clare Tochilin*

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# Keck Geology Consortium: Projects 2009-2010
# Short Contributions – SE ALASKA

## EXHUMATION OF THE COAST MOUNTAINS BATHOLITH DURING THE GREENHOUSE TO ICEHOUSE TRANSITION IN SOUTHEAST ALASKA: A MULTIDISCIPLINARY STUDY OF THE PALEOGENE KOOTZNAHOO FORMATION

***CAMERON DAVIDSON***, Carleton College
***KARL R. WIRTH***, Macalester College
***TIM WHITE***, Pennsylvania State University

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

***LEONARD ANCUTA***: Union College
Research Advisor: John Garver

## PALEOMAGNETISM AND GEOCHEMISTRY OF TERTIARY INTRUSIONS AND FLOWS ASSOCIATED WITH THE KOOTZNAHOO FORMATION NEAR KAKE, SOUTHEAST ALASKA, AND IMPLICATIONS FOR THE WRANGELLIA COMPOSITE TERRANE

***JORDAN EPSTEIN***: Carleton College
Research Advisor: Cameron Davidson

## U-PB DETRITAL ZIRCON GEOCHRONOLOGY AND PROVENANCE OF THE TERTIARY KOOTZNAHOO FORMATION, SOUTHEASTERN ALASKA: A SEDIMENTARY RECORD OF COAST MOUNTAINS EXHUMATION

***NATHAN S. EVENSON***: Carleton College
Research Advisor: Cameron Davidson

## INTERPRETATION OF THE KOOTZNAHOO FORMATION USING STRATIGRAPHY AND PALYNOLOGY

***SAMANTHA FALCON***: West Virginia University
Research Advisor: Dr. Helen Lang

**PALEOMAGNETISM OF EARLY CRETACEOUS TURBIDITES NEAR POINT HAMILTON, KUPREANOF ISLAND, ALASKA**

*ALEXANDER BRIAN GONZALEZ*: Amherst College
Research Advisor: Peter Crowley

**PROVENANCE OF THE LOWER KOOTZNAHOO FORMATION IN SOUTHEAST ALASKA**

*TIFFANY HENDERSON*: Trinity University
Research Advisor: Kathleen Surpless

**CHEMOSTRATIGRAPHIC ($\delta^{13}C$) ANALYSIS OF A PROMINENT PALEOSOL WITHIN THE PALEOGENE KOOTZNAHOO FORMATION, ADMIRALTY AND KUIU ISLANDS, ALASKA**

*CONOR P. MCNALLY*: The Pennsylvania State University
Research Advisor: Tim White

**USING STABLE AND CLUMPED ISOTOPE GEOCHEMISTRY TO RECONSTRUCT PALEOCLIMATE AND PALEOHYDROLOGY IN THE KOOTZNAHOO FORMATION, SE ALASKA**

*JULIA NAVE*: The Colorado College
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**PALEOMAGNETIC STUDY OF THE PALEOGENE KOOTZNAHOO FORMATION, SOUTHEAST ALASKA**

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# U-PB DETRITAL ZIRCON GEOCHRONOLOGY AND PROVENANCE OF THE TERTIARY KOOTZNAHOO FORMATION, SOUTHEASTERN ALASKA: A SEDIMENTARY RECORD OF COAST MOUNTAINS EXHUMATION

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Research Advisor: Cameron Davidson

## INTRODUCTION

Detrital zircon geochronology studies have been used to determine the provenance and depositional history of a number of sedimentary formations along the northern Cordilleran margin (e.g. DeGraaff-Surpless et al., 2003). In this study, I use U-Pb detrital zircon geochronology data and petrographic modal analysis of sandstones from the Paleocene-Miocene Kootznahoo Formation to constrain the exhumation history of the Coast Mountains batholith in Southeast Alaska.

## GEOLOGIC/TECTONIC SETTING

The Cretaceous to recent geologic history of the Western Cordilleran margin is marked by a number of changes in the tectonic regime, beginning with a shift to a compressive regime in the mid-Cretaceous that caused the collapse and partial subduction of the sediments of the Gravina Basin by approximately 90 Ma (Gehrels et al., 2009). During the 30-35 million years that this compressive regime persisted, regional metamorphism and crustal thickening occurred along the margin (Crawford et al., 1999; McClelland and Mattinson; 2000). These processes were accompanied by eastward-migrating trend of high-flux magmatism, comprised of subduction-generated plutons of the Coast Mountains batholith (CMB, also known as the Coast Plutonic Complex) that sutured the Wrangella Composite Terrane (WCT) to the margin (Gehrels et al., 2009).

By 65 Ma, crustal instability and changes in the degree of tectonic convergence created an extensional regime in the CMB and its margin-related host rocks. During the Paleocene, the Coast Shear Zone (CSZ) developed as a major structure to accommodate exhumation in the overthickened crust of the CMB (Klepeis et al., 1998; McClelland and Mattinson, 2000). Extensive foliated tonalite plutons aged 65-50 Ma emplaced along the eastern margin of the CSZ served to "lubricate" uplift along the structure (Ingram and Hutton, 1994). Further uplift and exhumation of the CMB and CSZ-related magmatic bodies and host rocks occurred via brittle structures in a transtensional tectonic setting after 45 Ma (Hyndman and Hamilton, 1993; Davidson et al., 2003).

## THE KOOTZNAHOO FORMATION

The Kootznahoo Formation is composed of conglomerate, sandstone, and shale deposited in a fluviodeltaic to marginal marine environment, in a basin that was elongated approximately parallel to the strike of the Coast Shear Zone between 56°50'N and 57°50'N, approximately 50 km to the east (Dickinson and Pierson, 1988). The depositional age of the Kootznahoo Formation is reported to be Paleocene to Oligocene on Kupreanof Island, and Paleocene to Eocene in Little Pybus Bay on Admiralty Island (Lathram et al., 1965; Fig. 2, Davidson et al., this volume).

### Petrographic Analysis of Kootznahoo Sandstones

Ten thin sections of sandstones from upper the upper half of the Kootznahoo stratigraphy in the Keku Strait area and Little Pybus Bay were subjected to optical framework modal analysis after the methods of Dickinson (1970). Sections were stained with sodium cobaltinitrate to facilitate feldspar identification. At least 350 framework grains were identified in each sample, with less than 10% of analyzed grains classified as matrix or unknown material.

Kootznahoo Formation sandstones are texturally submature feldspathic arenites; most samples consist of poorly sorted, angular to sub-rounded grains of feldspar and quartz with little silt/clay matrix. Framework compositions of upper Kootznahoo Formation sandstones are plotted on ternary diagrams in Figure 1. Most compositions plot in the basement uplift or dissected arc fields on a QFL diagram (Fig. 1a), suggesting that these sandstones were sourced from the erosion of cratonic basement or the denuded plutonic roots of a magmatic arc. The volcaniclithic rich sample 09NE12, the only composition to plot in the undissected arc field, was taken from the volcaniclastic sediments in the uppermost portions of the Keku Strait section (Fig. 3, Davidson et al., this volume).

Two samples from upper Little Pybus Bay (filled circles on Fig. 1) form a group that is separated from the cluster of lower Keku Strait samples (open circles). These samples are distinguished from other arkosic samples on the basis of their low K-feldspar content (a difference most easily seen in Fig. 1b). There is little textural petrographic evidence for the loss of K-feldspar during transport or diagenesis, suggesting that this difference is primary, and reflects differences in source regions.

## U/PB DETRITAL ZIRCON GEOCHRONOLOGY

Zircon grains were mounted and subjected to single-grain LA-ICPMS U-Th-Pb isotopic analysis at the University of Arizona. Analyses were conducted using a beam diameter of ~30 um, generating a pit depth of ~12 um. Interpreted ages are based on 206Pb/238Pb age for <960 Ma grains and 206Pb/207Pb age for >960 Ma grains.

A total of 1169 U-Pb isotopic ages of zircon grains

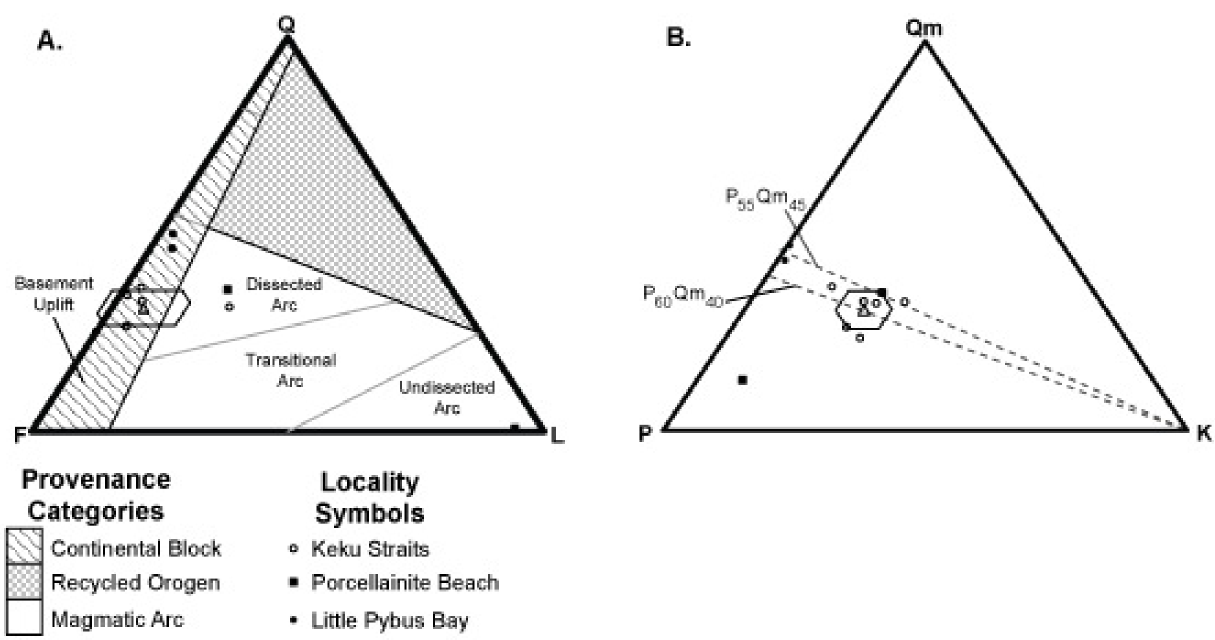


*Figure 1. Ternary diagrams of modal petrographic analyses from the Upper Kootznahoo Formation. Plots drafted after Dickinson (1970). A.) QFL plot of modal analysis data. End members are total quartz (Q), total feldspar (F), and total lithic fragments (L). Polygon with triangle at center represents the region enclosed by one standard deviation of the average components of analyses from samples from Kupreanof Island (excepting 09NE12, which plots in the undissected arc field. Note that most samples from in the basement uplift field. B.) QPK plot of modal analysis data. End members are total quartz (Q), plagioclase (P) and K-feldspar (K). Analyses from Little Pybus Bay (closed circles) are located on or near the Q-P axis of this plot, reflecting their K-poor composition. Dashed lines trace compositions with given relative P-Qm content.*

from twelve Kootznahoo Formation sandstone samples were obtained for this study. All <500 Ma analyses are concordant to slightly discordant. 1158 (99%) of all analyzed grains are of Paleozoic age or younger, and 1108 (95%) are younger than 200 Ma. All ages younger than 200 Ma are plotted in Figure 2. Pronounced peaks in this portion of the cumulative dataset include a very narrow peak at 30-24 Ma, moderately narrow peaks at 65-50 Ma and 93-85 Ma, and a broad peak at 190-160 Ma. No populations older than 200 Ma form comparable peaks. Grains of Proterozoic age and older (n=12), are generally moderately to highly discordant.

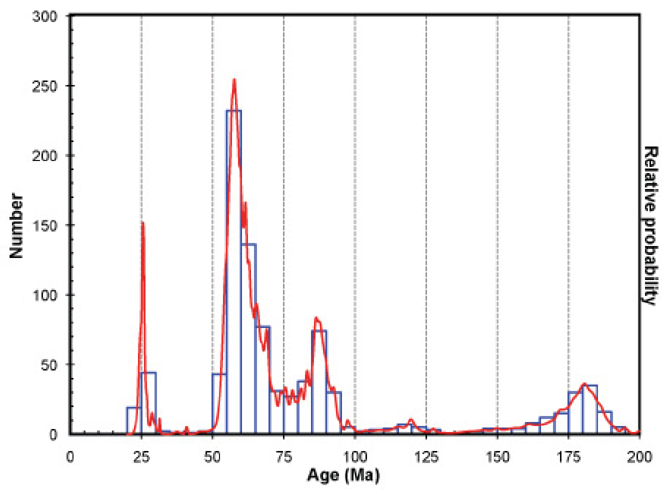


*Figure 2. Probability plot showing all Kootznahoo Formation detrital zircon ages younger than 200 Ma. Zircons in this age range compose 95% of all analyzed grains. Note the pronounced peaks at 30-24 Ma, 65-52 Ma, 93-85 Ma, and 190-160 Ma. Each of these populations, with the exception of the 30-24 Ma peak, corresponds to magmatic "flare-ups" described by Gehrels et al. (2009). This suggests that the Kootznahoo Formation is derived primarily from the exhumation and erosion of the CMB.*

Several changes in the distribution of DZ age peaks can be observed as we move from the base to the top of the Keku Strait stratigraphy (Fig. 2, Davidson et al., this volume). The sample at the base of Hamilton Bay (09TH01, Fig. 3) is the only sample in this study that does not display a major age peak at 72-50 Ma. This sample also lacks the 190-160 Ma peak present in most other samples. 09TH01, along with the other basal sample in the Keku Strait, 09TH10 (Fig 3), and 09LA05, are the only samples from the Keku Strait area that have a pronounced 95-85 Ma peak – a trait shared with both samples from Little Pybus Bay (09LA01, 09LA14). Approximately half of the zircons aged 95-80 Ma in samples 09TH01 and 09TH10 display U/Th ratios that suggest that they crystallized in a metamorphic environment (Williams, 2001). Such grains are found only in

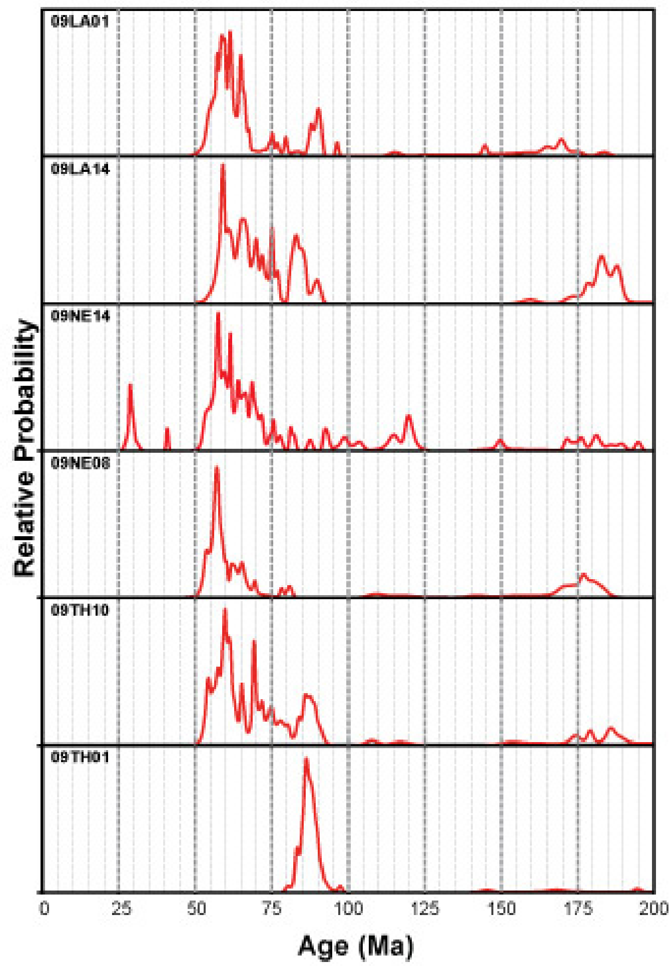


*Figure 3. Stacked probability plot of selected Kootznahoo DZ age distributions. The uppermost two plots are samples from Little Pybus Bay on Admiralty Island; all other plots represent samples from the Keku Strait area on Kupreanof Island. The arrangement of samples from each locality reflects stratigraphic relations - lowest stratigraphic samples are on the bottom. In the Keku Strait samples, note differences between the bottom sample, 09TH01, and 09TH10. The observed decline of the 90-80 Ma peak and the abrupt appearance of zircons younger than 80 Ma represent the initial unroofing of the CMB east of the Coast Shear Zone.*

| Sample | Location | n | Youngest Grain | Youngest Population |
|---|---|---|---|---|
| ***Kootznahoo Formation: Kupreanof Island*** | | | | |
| NE12 | Kupreanof | 94 | 23.5 ± 0.8 Ma | 25 Ma (n = 58) |
| NE14 | Kupreanof | 99 | 27.8 ± 0.8 Ma | 29 Ma (n = 6) |
| LA10 | Kupreanof | 98 | 31.2 ± 0.2 Ma | 57 Ma (n = 35) |
| NE06 | Kupreanof | 98 | 54.3 ± 1.5 Ma | 58 Ma (n = 33) |
| NE08 | Kupreanof | 98 | 52.9 ± 0.9 Ma | 59 Ma (n = 38) |
| TH08 | Kupreanof | 97 | 53.4 ± 0.6 Ma | 58 Ma (n = 35) |
| LA08 | Kupreanof | 96 | 54.0 ± 2.1 Ma | 58 Ma (n = 37) |
| LA05 | Kupreanof | 96 | 53.6 ± 2.2 Ma | 58 Ma (n = 29) |
| TH10 | Kupreanof | 96 | 53.3 ± 1.3 Ma | 60 Ma (n = 26) |
| TH01 | Kupreanof | 96 | 80.2 ± 0.7 Ma | 87 Ma (n = 58) |
| ***Kootznahoo Formation: Little Pybus Bay, Admiralty Island*** | | | | |
| LA01 | Admiralty | 99 | 52.0 ± 1.9 Ma | 59 Ma (n = 28) |
| LA14 | Admiralty | 100 | 55.1 ± 3.1 Ma | 59 Ma (n = 19) |

**Note:** The ages of both the youngest grains and the youngest populations of sample 09TH10 up through 09NE06 (the sample below the 54 Ma tuff layer) are relatively homogenous. Also note that, though the youngest grain in 09LA10 is 31 Ma, because there are only two such aged grains in the sample, the youngest population is 57 Ma.

*Table 1. U/Pb Maximum Depositional Ages of the Kootznahoo Formation*

trace amounts in all other samples.
Detrital zircon age distributions of the samples from Dakaneek, Davidson, and Big John bays (Fig. 2, Davidson et al., this volume) are relatively homogenous in age distribution (e.g. 09NE08, Fig. 3). This homogeneity is reflected in the maximum depositional ages determined from youngest grains and populations in these samples (Table 1). Two grains <40 Ma in age first appear in the sample from Point Camden (09LA10), and the proportion of young ages increases abruptly in 09NE14 (Fig. 3).

Detrital zircon samples from Little Pybus Bay (Fig. 2, Davidson et al., this volume) have a similar distribution of age peaks and have similar maximum depositional ages (Table 1) as those samples from Kupreanof Island (Fig. 3). I use the Kolgomorov-Smirnov (K-S) test, a non-parametric goodness-of-fit test, to compare the DZ age distributions of Admiralty Island samples with those from Kupreanof Island (Guynn, 2006). K-S results (Table 2) suggest that sample 09LA14 (base of the Little Pybus Bay section) is relatively dissimilar to all Keku Strait samples, with the exception of 09TH10. Sample 09LA14, from the uppermost beds of arkosic Kootznahoo sandstone in Little Pybus Bay, displays a nearly equal level of similarity with 09NE14 (from the upper portions of the Keku Strait section) as it does with three samples from near the base of the Keku Strait section. Results suggest that the two samples from Little Pybus Bay are significantly dissimilar from each other.

| | 09NE14 | 09LA10 | 09NE06 | 09NE08 | 09TH08 | 09LA08 | 09LA05 | 09TH10 |
|---|---|---|---|---|---|---|---|---|
| **09LA01** | *0.514* | 0.090 | 0.017 | 0.179 | *0.400* | *0.484* | *0.421* | 0.042 |
| **09LA14** | 0.051 | 0.000 | 0.006 | 0.000 | 0.000 | 0.000 | 0.033 | *0.245* |

**Note:** The intersection of each row and each column represents the similarity value that a comparison the two given samples yields. Similarities <0.05 suggest that the samples of concern are derived from two different parent zircon populations (source areas). Italicized values represent the relatively high similarity values for each sample from Little Pybus Bay.

*Table 2. K-S Comparisons of DZ age distributions from Little Pybus Bay and Keku Strait*

## DISCUSSION

Results of petrographic analysis and the U/Th ratios of detrital zircon grains suggest that Kootznahoo Formation sediments were drawn from a local, primarily plutonic source. During the inferred period of Kootznahoo Formation deposition, portions of the CMB were experiencing rapid exhumation (Rusmore et al., 2005; Butler et al., 2002).

Gehrels et al. (2009) propose three periods of high magmatic flux in the past 200 Ma (at 160-140 Ma, ~120-80 Ma, and 55-48 Ma), and regional metamorphic events that facilitated zircon growth at 88-76 Ma and 62-52 Ma. Gehrels et al. (2009) separate magmatic activity into three spatiotemporal groups. The eastern magmatic belt, located east of the CSZ was stationary during the emplacement of its constituent plutons 225-100 Ma, while after 110 Ma, plutons of the western magmatic belt (located west of the CSZ), and the <100 Ma magmatic belt define a trend of eastward magmatic migration that crossed the CSZ at ~80 Ma.

Comparisons of these plutonic age distributions with our DZ age distributions suggest that all of the major <200 Ma zircon populations are likely sourced from the CMB. Accessory populations older than 200 Ma can be accounted for with zircons derived from CMB host rocks, including the Gravina belt, and the Alexander, Taku, Yukon-Tanana, and Stikine terranes.

Changes in the DZ age peak distribution suggest that the unroofing of the Paleocene-age portions of the CMB is recorded in the lower portions of the Keku Strait stratigraphy. McClelland and Mattinson (2000) suggest that partial subduction of the Wrangellia composite terrane (WCT) caused delamination and rapid rebound of crustal material west of the nascent CSZ at 85-65 Ma. This crustal rebound was manifested as west-side up exhumation, bringing late Cretaceous-age plutons emplaced in the WCT and metamorphosed Gravina belt rocks to the surface. Zircons of sample 09TH01 appear to be sourced entirely from material west of the CSZ – note that the 65-50 Ma and 190-160 Ma populations associated with plutons emplaced east of the CSZ and the magmatic Eastern belt (Gehrels et al., 2009) are not present in 09TH01. This result suggests that these strata are the oldest encountered in the Kootznahoo Formation in this study. After 65 Ma, collapse of the overthickened crust east of the CSZ accompanied a shift to east side-up motion across the CSZ (Klepeis et al., 1998; Crawford et al., 1999), bringing to the surface plutonic material emplaced during the Paleocene.

Based on consideration of DZ peak and maximum depositional age (MDA) differences between 09TH01 and 09TH10, I suggest that 09TH01 was deposited 65-60 Ma. 09TH10, the other basal sample and inferred second-oldest sample in the Keku Strait stratigraphy, was deposited no earlier than 60 Ma (Table 1). The presence of a 53.5 ± 0.6 Ma tuff date (Fig. 2, Davidson et al., this volume) located approximately 300 meters upsection of 09TH10 suggests that a period of rapid subsidence and sedimentation occurred in the Keku Strait area of the Kootznahoo basin between 60 and 54 Ma. The MDAs and statistical similarity of 09LA14 and 09TH10 suggest that deposition may have been continuous between the Little Pybus Bay and Keku Strait portions of the basin during this period. The differences in total stratigraphic thickness in these localities may point to erosional removal of sediment, or a slower average sedimentation rate in Little Pybus Bay.

All samples located above the 54 Ma tuff in the Keku Strait stratigraphy contain grains aged <35 Ma. These younger grains, which are the primary components of DZ age distributions above 09NE14, are likely derived from nearby Oligocene-age volcanic rocks such as the Admiralty Island Volcanics (Ford et al., 1996), or perhaps from the outboard Chugach-Prince William terrane (Ancuta, this volume). A relatively short stratigraphic distance of approximately 50-60 meters separates these samples. As the correlation between the top of Big John Bay South and the base of the Port Camden composite is indirect, it is possible that section is missing at this point in the stratigraphy. If no section is missing due to faulting, then the difference in MDA of these strata suggests that the 50-60 m of section between samples 09LA10 and 09NE14 represents at least 20 Ma. This suggests that a regionally important unconformity may exist between the top of the Keku Strait and bottom of the Port Camden sections and could be present in Little Pybus Bay (Fig. 2, Davidson et al., this volume). I suggest that the statistical similarity between 09LA01 and 09NE14 indicates a depositional link, and that both were deposited above the unconformity. The unique, K-feldspar poor petrographic character of upper Little Pybus Bay samples, suggests that this correlation should be considered with caution.

The basin-wide subsidence that facilitated continued sedimentation in Keku Strait and Little Pybus Bay, as well as the eruption of volcanic rocks from which these sediments were derived, likely occurred as a result of a shift to a transtensional tectonic regime at 45-40 Ma (Hyndman and Hamilton; 1993). The episode of slow subsidence or uplift that preceded this shift is attributed to the subduction of an oceanic ridge (e.g. Bradley et al, 2003; Madsen et al., 2006). The model proposed by Madsen et al. (2006) suggests that a migrating oceanic ridge related to the Resurrection microplate (Haeussler et al., 2003) passed the region of Kootznahoo Formation deposition at ~53 Ma, a timing that matches well with the timing of inferred uplift that is observed in the Kootznahoo stratigraphy.

## CONCLUSIONS

U/Pb detrital zircon age distributions and modal petrographic analyses of sediments from the Kootznahoo Formation suggest that its arkosic sediments were sourced from the uplift and exhumation of the Coast Mountains batholith during the Paleogene. Changes in the detrital zircon age distributions of the lower portions of the Kootznahoo stratigraphy on Kupreanof Island suggest that the Kootznahoo Formation records the unroofing of the Paleocene plutonic belt emplaced east of the Coast Shear Zone. A regionally important erosional unconformity is inferred from maximum depositional ages and an Ar/Ar date suggesting a ~20 Ma period of non deposition which may be related to uplift and erosion associated with the subduction of an oceanic ridge.

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