KECK GEOLOGY CONSORTIUM
PROCEEDINGS OF THE TWENTY-THIRD ANNUAL KECK RESEARCH SYMPOSIUM IN GEOLOGY

ISSN# 1528-7491

April 2010

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Editor & Keck Director
Franklin & Marshall College

Keck Geology Consortium
Franklin & Marshall College
PO Box 3003, Lanc. Pa, 17604

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2009-2010 PROJECTS

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Funding Provided by: Keck Geology Consortium Member Institutions and NSF (NSF-REU: 0648782) and ExxonMobil

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Funding provided by: Keck Geology Consortium Member Institutions and NSF (NSF-REU: 0648782)

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PROVENANCE OF THE LOWER KOOTZNAHOO FORMATION IN SOUTHEAST ALASKA

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INTRODUCTION

The Kootznahoo Formation in southeast Alaska is a Paleocene to lower Miocene fluvial deposit whose development and provenance are not well understood due to limited outcrops that are on multiple islands spread across a one hundred kilometer area (Dickinson and Pierson, 1988). It is unclear if the Kootznahoo Formation was deposited in smaller, segmented basins or in a single continuous basin within the Admiralty Trough (Dickinson and Pierson, 1988). Based on sandstone petrography and detrital zircon age analysis, the most likely sediment source for the lower Kootznahoo Formation is the Coast Mountain Batholith to the east, and the Kootznahoo Formation probably was deposited in a single basin.

GEOLOGIC HISTORY

In southeast Alaska, much of the Cordillera formed by accretion of juvenile and possibly far-traveled terranes (Coney et al., 1980; Haggart et al., 2006), which occurred during Mesozoic-early Tertiary times (Monger et al., 1982). The Stikine and Yukon-Tanana terranes were emplaced onto the North American passive margin in the mid-Jurassic (Fig. 1) as the Intermontane Superterrane (Gehrels et al., 2009) and in mid-Cretaceous to early Tertiary time, the Wrangellia Composite terrane (Ridgway et al., 2002) accreted to the new Jurassic continental margin (Fig. 1) (Monger et al., 1982). The latitude of these accretion events is still debated, for it remains unclear whether these terranes accreted to North America less than 200 km or as much as 4000 km south of their current location (e.g., Haggart et al., 2006).

Beginning in the mid-Jurassic, the Coast Mountain Batholith (CMB) (Gehrels et al., 2009), intruded into the Insular Belt (Irving et al., 1995) and the older, passive margin deposits of the Yukon-Tanana terranes (Gehrels et al., 2009). The CMB can be traced continuously for over 1700 km, from northern Washington, through coastal British Columbia and southeast Alaska, into the southwestern Yukon (Fig. 1) (Gehrels et al., 2009). The magmatic flux during batholith emplacement was variable, with high flux at 160-140 Ma, 120-78 Ma, and 55-48 (Gehrels et al., 2009).

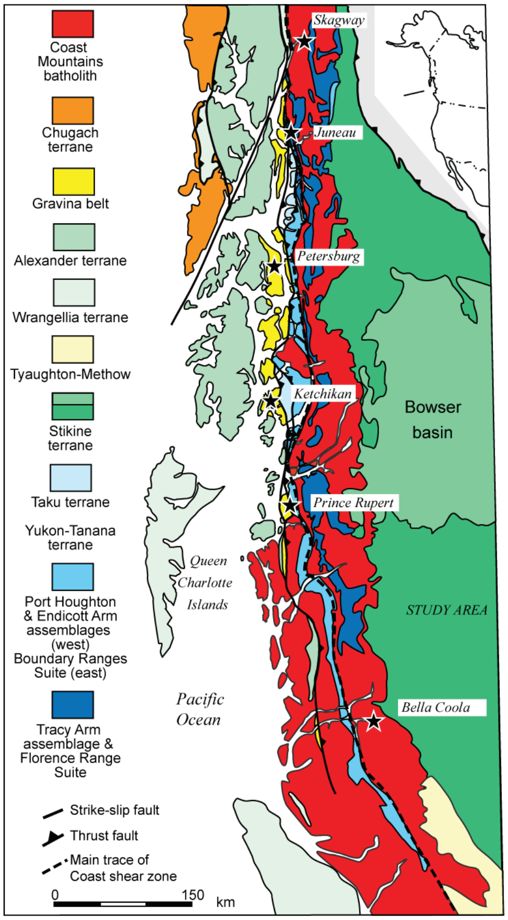

Figure 1: Simplified tectonic map showing the Coast Mountain Batholith, major terranes, belts, and faults of the Canadian/Alaskan Cordillera (Gehrels et al., 2009).

During the Cenozoic, a number of far-traveled allochthonous terranes were accreted to Southern Alaska (e.g., Plafker, 1987; Plafker et al., 1994). From Late Cretaceous to early Tertiary time, the Chugach-Prince William composite terrane accreted to the Wrangellia Composite terrane (Fig. 1) (Perry et al., 2009). Rocks of the Chugach terrane are locally metamorphosed due to a northwestward shift in Kula plate motion and/or the subduction of the Kula-Farallon spreading center beneath the accreted terrane from Late Paleocene to Miocene (Engebretson et al, 1985; Plafker, 1987; Lonsdale, 1988; Stock and Molnar, 1988; Atwater and Stock, 1998). Intrusion of dikes and plutons in the Chugach terrane at approximately 65-50 Ma were the result of the subduction of the spreading center between the Pacific and Kula-Farallon plates, and formed the Sanak-Baranof plutonic belt (Plafker et al., 1994; Bradley et al., 2003; Trop and Ridgway, 2007).

The Yakutat terrane arrived at its present position in southeast Alaska no later than the Pliocene (Perry et al., 2009). Recent research favors transport of the Yakutat parallel to the Alaskan continental margin 600 km south from a northern position, with sedimentary cover strata derived from local sources (Plafker et al., 1994). However, Middle Eocene and older basement rocks still have the possibility of being far-traveled (Perry et al., 2009). The Yakutat terrane's transport and collision resulted in the transition of the Queen Charlotte-Fairweather transcurrent fault in the east to the Alaska-Aleutian subduction zone in the west (Bruns, 1983; Fletcher and Freymueller, 1999, 2003), and resulted in dramatic surface uplift and erosional exhumation, forming the Chugach-St. Elias Range (Plafker, 1987; Meigs and Sauber, 2000; Montgomery, 2002; Spotila et al., 2004; Berger and Spotila, 2008; Berger et al., 2008).

Potential source regions of the Kootznahoo Formation are varied. A possible source is the nearby CMB, with abundant plutonism at 160-140 Ma, 120-78 Ma, and 55-48 (Gehrels, et al., 2009). Others could be the plutons of the Stikine terrane further to the east, with ages between 218-193 Ma and 179-166 Ma (MacIntyre et al., 2001), or the Chugach-Prince William composite terrane's Sanak-Baranof plutonic belt to the north with ages of 66-50 Ma (Bradley et al., 1993). The Taku terrane has older plutonic ages, between 349-387 Ma and 906-2643 Ma (Gehrels, 2002). The nearby Gravina Belt could also be a potential source, with ages that range between Late Jurassic and Early Cretaceous (Gehrels et al., 2009). Mafic terranes were not considered for potential sources, because sandstone petrography reveals few mafic grains, and mafic rocks generally do not contain significant zircon (Poldervaart, 1956; Watson, 1979).

The Kootznahoo Formation

The Kootznahoo Formation is a fluvial deposit located on the Wrangellia Composite terrane (Ridgeway et al., 2002), so sediment sources of the deposit can be very useful in discovering what areas the Wrangellia Composite terrane was close to during deposition. However, because of limited outcrops of the Kootznahoo Formation across a broad area (Fig. 2 in Davidson et al., this volume), correlation between the different sections of the Kootznahoo Formation is difficult (Dickinson and Pierson, 1988). The Kootznahoo Formation crops out in the Zarembo Island-California Bay area, Kootznahoo Inlet in west-central Admiralty, near Angoon, Pybus Bay and Little Pybus Bay in Admiralty, and the Keku Strait area (Fig. 2 in Davidson et al., this volume).

The Keku Strait area includes the Kadake Bay-Port Camden area on Kuiu Island and the Hamilton Bay and Dakaneek Bay area on Kupreanof Island. The lower part of the Kootznahoo Formation crops out in this area, and is mostly poorly-sorted light brown or gray fluvial sandstone with a few beds of dark gray shale and abundant carbonized wood fragments (Fig. 3 in Davidson et al., this volume) (Dickinson and Vuletich, 1990). The shale is platy and contains abundant plant fossils (Dickinson and Vuletich, 1990). The formation is intruded and overlain by Tertiary gabbro, microgabbro, and basalt (Dickinson and Pierson, 1990). One sample for this study came from Little Pybus Bay on Admiralty Island (Fig. 2 in Davidson et al., this volume). This area consists of mostly of conglomerate, with arkosic and lithic sandstone, and minor amounts of shale (Dickinson and Vuletich, 1990). Leaf fossils suggest a Paleocene age for this area of the Kootznahoo Formation (Wolf, in Lathram and others, 1965).

METHODS

Petrography

Thin sections were cut from 12 samples within the lower part of the Kootznahoo Formation, stained to distinguish potassium feldspar, then six of these samples were point counted using a petrographic microscope and automated stage. Six samples had more than 20-25% matrix, making quantitative point-counting unreliable because much of the matrix could be pseudo-matrix due to the alteration of original framework grains during diagenesis. Sandstone modal point counting methods, developed by Dickinson (1970), were used to obtain quantitative detrital modesand the modal point counts were plotted on ternary diagrams developed by Dickinson et al. (1983) that give the likely tectonic provenance of the sediment.

Detrital Zircon Separation Procedure and Analysis

The zircon grains were separated from sandstone by standard crushing, density, and magnetic separation techniques using the facilities at Carleton and Macalester Colleges. The zircon splits were then sent to the LaserChron Center at the University of Arizona in Tucson, where they were mounted in 1 cm diameter epoxy plugs and then polished to half-thickness so the approximate center of the grains were exposed at the surface of the mount. The analysis and data reduction of zircon age dating was done using Gehrels et al.'s (2006) techniques.

RESULTS

Sandstone Petrography

Texturally, all twelve samples from the lower Kootznahoo Formation were grain supported and immature, with little to no observable porosity (Tables 1 and 2). The QFL diagram shows that the source of the Kootznahoo Formation was most likely characterized by basement uplift, with some dissected arc contribution (Fig. 2). However, the high percentage (>20-25%) of matrix in half the samples could have resulted from diagenesis, so what is now clay matrix could have been unstable volcanic lithics at deposition (e.g., Bywater and Elliot, 2007). With more volcanic lithics present in the sample, the point count data would be pulled toward the lithic pole, suggesting a source region with a greater dissected arc component. Considering all this, it is possible that the source of the Kootznahoo Formation included

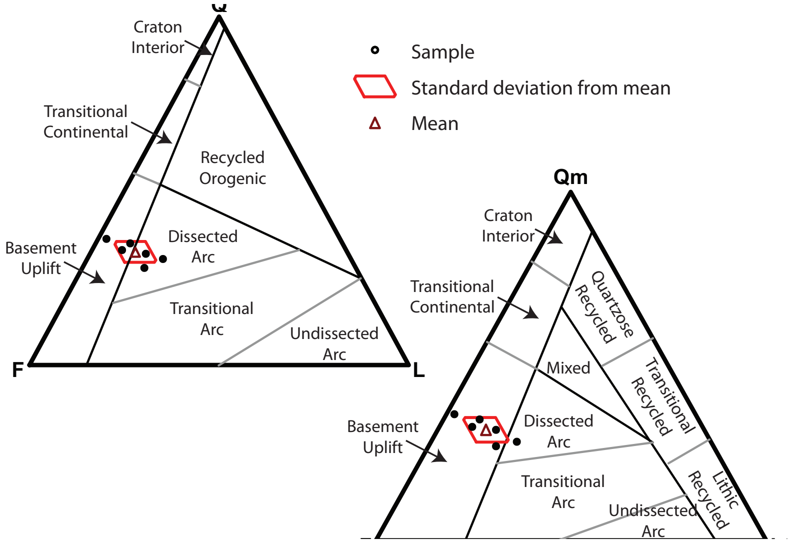

Figure 2: Ternary diagrams showing the proportions of quartz (Q), feldspar (F), and lithics (L) or monocrystalline quartz (Qm), feldspar (F), and lithics, including polycrystalline quartz (Lt) found in the sandstone from point counting (following method of Dickinson et al., 1983). Source is between basement uplift and dissected arc in left graph, and mainly in basement uplift on the right graph.

Sample	Qm	Qp	P	K	Lv	Ls	Lm	Mica	Amph	Chert	Cem/Mat	Unknown	Total # Counted
09TH10	31%	0%	34%	16%	6%	1%	2%	3%	0%	0%	7%	2%	400
09TH12*	22%	0%	8%	5%	12%	0%	15%	0%	0%	0%	35%	0%	0
09TH01	26%	0%	14%	17%	3%	0%	3%	5%	1%	0%	28%	3%	100
09TH02	22%	1%	24%	15%	3%	1%	11%	7%	1%	1%	13%	2%	400
09TH03	19%	1%	27%	13%	4%	0%	8%	3%	0%	0%	24%	3%	200
09TH04	22%	1%	13%	12%	7%	0%	17%	5%	0%	0%	23%	1%	302
09TH05	22%	1%	21%	9%	3%	1%	6%	11%	1%	1%	25%	1%	400
09TH06	27%	0%	33%	12%	5%	1%	7%	6%	1%	0%	9%	1%	400
09TH07	27%	0%	32%	14%	1%	0%	0%	8%	0%	0%	16%	2%	400
09TH08	25%	0%	31%	14%	2%	0%	4%	8%	0%	1%	13%	3%	400
09TH11	25%	0%	18%	6%	5%	6%	6%	0%	0%	0%	31%	3%	100
09TH13	33%	2%	15%	6%	3%	1%	14%	4%	0%	1%	21%	2%	400

*Table 1: Table shows composition percentages of all samples. The samples that were point-counted and used in the ternary diagram are highlighted in yellow; the samples from Admiralty Island are highlighted in blue (*percentages derived from estimates, not quantitative point counting).*

Sample	Grain Shape	Mean Grain Size (mm)
09TH10	angular to sub-angular	Medium lower (0.30)
09TH12	angular to sub-rounded	Medium lower (0.30)
09TH01	sub-angular	Fine upper (0.24)
09TH02	angular to sub-angular	Coarse upper (0.80)
09TH03	angular to sub-angular	Medium upper (0.45)
09TH04	sub-angular to sub-rounded	Coarse upper (1.00)
09TH05	sub-angular to sub-rounded	Medium upper (0.40)
09TH06*	angular to sub-angular	Medium upper
09TH07	sub-angular	Coarse lower (0.50)
09TH08	angular to sub-angular	Coarse lower (0.60)
09TH11	sub-angular	Coarse lower (0.50)
09TH13	sub-angular to sub-rounded	Coarse lower (0.50)

*Table 2: Table shows the textural characteristics of all samples. The samples that were fully counted and used in the ternary diagram are highlighted in yellow; the samples from Admiralty Island are highlighted in blue (*no grain size measurements were taken).*

both basement uplift and dissected arc components.

Detrital Zircon Geochronology

The detrital zircon age data are shown on relative probability density curves made by calculating a normal distribution for each analysis based on the reported age and uncertainty, summing the probability distributions of all acceptable analyses into a single curve, and dividing the area under the curve by the number of analyses (Fig. 3). With one exception, the detrital zircon age spectra for the lower Kootznahoo Formation are remarkably similar. The one outlier of the six samples is the basal sample 09TH01, taken from Hamilton Bay where the Kootznahoo rests unconformably on Triassic volcanic rocks (Figs. 2 and 3 in Davidson et al., this volume). It has one main age peak in the Late Cretaceous, at 85-90 Ma, with relatively few other ages. Sample 09LA14 was taken from the sandstone layer above the basal unconformity at Little Pybus Bay on Admiralty Island where the Kootznahoo Formation was deposited on Triassic rocks, and sample 09TH10 was taken from just above an unconformity on Kupreanof Island where the Kootznahoo Formation was deposited on Cretaceous rocks. Both samples are characterized by large age peaks between 55 and 70 million years, although 09LA14 also has minor peaks at 80-90 Ma that are represented by just a few grains in sample 09TH10. The third highest in section is sample 09LA05, taken from Dakaneek Point, which has a main age peak of 60-65 Ma, with lesser peaks between 50 and 95 Ma. It also has a small population of ages around 180 Ma. Sample 09LA08 from Dakaneek Bay has an age peak of 55-60 Ma, a small population of 175-190 Ma zircon, and fewer ages between 75 and 95 Ma than the lower-middle sample. The 55-60 Ma age is prominent in the high-

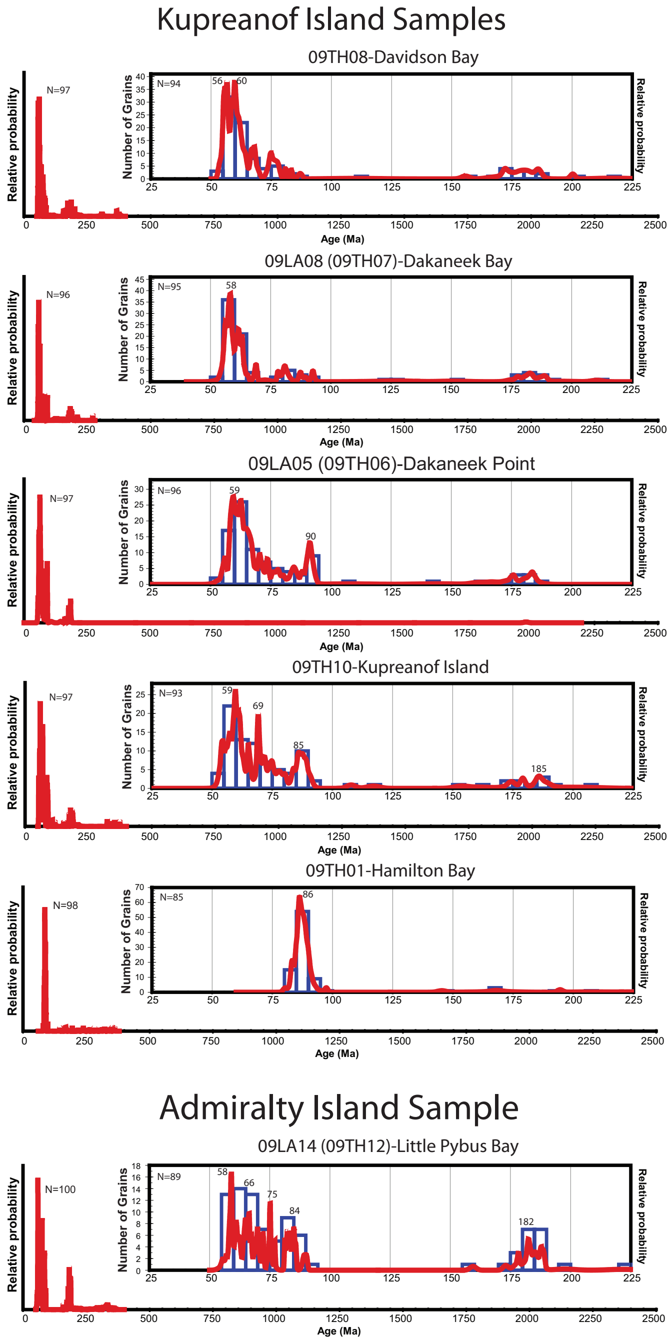

Figure 3: Two relative probability density curves are plotted for each sample; one shows age peaks from the present to 2,500 Ma, incorporating all ages, and the other is from 25 Ma to 225 Ma, showing an expanded view of the main peaks in the sample.

est sample in this stratigraphic section, 09TH08 from Davidson Bay, along with a small population of ages around 175-180 Ma, though this sample has even fewer ages between 75 and 90 Ma. Overall, the age distributions are very similar in all the samples, even the sample from Little Pybus Bay, with the exception of sample 09TH01 (Fig. 3).

DISCUSSION

Detrital zircon age results show that the source of sediment for this stratigraphic section of basal to mid-Kootznahoo Formation stays consistent through time, with the same peak ages occurring in samples throughout the section and throughout the region (Fig. 3). For all the samples above sample 09TH01, the maximum depositional age for the Kootznahoo Formation is the Paleocene, with the youngest peaks at approximately 60 Ma, consistent with the earlier Paleocene depositional age estimate for fossil flora (Lathram et al., 1965). The basal sample 09TH01 could have an older maximum depositional age based on the detrital zircon U-Pb ages (approximately 85 Ma, Fig. 3), but fission track zircon dates give a cooling age of the source of 57 Ma (Ancuta, this volume), which is consistent with the younger maximum depositional age for the overlying samples.

Based on the detrital zircon age results and sandstone petrography, the most likely primary sediment sources for the Kootznahoo Formation are the western and eastern portions of the Coast Mountain Batholith (CMB). The basal sample (09TH01) had only one main age peak at 86 Ma and was likely derived from the 100-80 Ma magmatism of the western portion of the CMB that was emplaced after accretion of the Wrangellia Composite terrane (Gehrels et al., 2009). These plutons were probably the first source of sediment for the Kootznahoo Formation. When this lowest part of the Paleocene Kootznahoo Formation was being deposited, another flux of magmatism in the axial portion of the CMB occurred at 60-48 Ma during regional extension and exhumation (Gehrels et al., 2009). Because it was farther east and younger than the Cretaceous magmatism, it likely could not contribute sediment to the Kootznahoo Formation until after the older, western portion of the CMB source was eroded. The Cretaceous 86 Ma age peak occurs in the younger Kootznahoo samples, but becomes less significant as this source erodes and more eastern sources supply sediment to the basin. Another possibility for the single Cretaceous age peak in this basal sample is that this particular location in Hamilton Bay was supplied by a smaller drainage system within the larger whole, so there was a more localized source at this location. A sediment source dominated by the CMB is supported by sandstone petrography, with all the analyzed samples showing at least 60% quartz, plagioclase, and potassium feldspar, and little to no chert (Table 1).

An alternative sediment source for the Kootznahoo Formation is the Chugach-Prince William composite terrane's Sanak-Baranof plutonic belt, with ages of 66-50 Ma (Bradley et al., 1993). The CMB is more likely to be the main sediment source because it is closer to the Kootznahoo Formation than the Sanak-Baranof plutonic belt. The ages of the plutons of the Stikine terrane, 218-193 Ma and 179-166 Ma (MacIntyre et al., 2001), were not a seen in significant numbers in the Kootznahoo Formation. The Taku terrane to the far east contains older ages, between 349-387 Ma and 906-2643 Ma (Gehrels, 2002), which are completely absent in the lower Kootznahoo Formation. The ages of the nearby Gravina Belt range between Late Jurassic and Early Cretaceous (Gehrels et al., 2009), and are almost completely absent in the detrital zircon age spectra from this section of the Kootznahoo Formation (Fig. 3). This may have been due to the Behm Canal structural zone juxtaposing the Gravina Belt east (Brew and Ford, 1998), away from depositional basin of the Kootznahoo Formation. However, it is possible that the Gravina Belt was a source that simply does not show up in detrital zircon analysis, as it is composed of mafic volcanic rocks (McClelland et al., 1992) that do not produce any significant amount of zircon (Poldervaart, 1956; Watson, 1979). Petrography shows that generally, all samples that had high matrix had less than 60% quartz, plagioclase, and potassium feldspar, so perhaps these samples had volcanic mafic grains that became pseudo-matrix. It is possible the Gravina Belt contributed to the Kootznahoo Formation, with most evidence of volcanic sources having been erased through diagenesis.

The most likely major sources of sediment for the lower part of the Kootznahoo Formation are the western and axial portions of the CMB, with unroofing of the axial portion of the CMB evident after depostion of the basal sample. Finally, the same relative age peaks are seen in all samples from all locations, including the Little Pybus Bay sample located significantly north of the other samples. Because of this consistency through time and spatially in the basin, it is likely the Kootznahoo Formation was deposited in a large, single basin.

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