A detrital record of Mesozoic island arc accretion and exhumation in the North American Cordillera: U-Pb geochronology of the Kahiltna basin, southern Alaska

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[1] The stratigraphic record of Mesozoic island arc accretion in the North American Cordillera is preserved in a discontinuous belt of clastic strata that are exposed inboard (cratonward) of the allochthonous Wrangellia composite terrane in southern Alaska, western Canada, and Washington State. LA-ICPMS analyses of eight samples (n = 714 detrital zircon grains) collected at different stratigraphic intervals from the Jurassic–Cretaceous Kahiltna assemblage in southern Alaska reveals a bulk U-Pb age distribution of Precambrian-Mesozoic age grains (Mz 74%, Pz 11%, Pc 15%). A comparison of U-Pb ages from older to younger stratigraphic intervals within the Kahiltna assemblage reveals three stages of exhumation and basin development during arc accretion. Stages include (1) an initial Late Jurassic–Early Cretaceous pre/early collisional phase during which detritus was derived almost solely from Middle–Late Jurassic and Early Cretaceous magmatic sources of the outboard Wrangellia composite terrane (Mz 100%, Pz 0%, Pc 0%), (2) a second Early Cretaceous syncollisional phase that reflects the introduction of Paleozoic and Precambrian detritus from the inboard Intermontane belt (Mz 84%, Pz 11%, Pc 5%) and an upsection increase in older detrital zircon grains compared to Mesozoic age grains (Mz 65%, Pz 11%, Pc 24%), and (3) a final Early–Late Cretaceous late/postcollisional phase that represents continued detrital contributions from Precambrian–Mesozoic source areas (Mz 19%, Pz 22%, Pc 59%) located inboard and outboard of the Kahiltna basin. Similar bulk trends in detrital zircon age populations have been reported from along-strike, age-equivalent strata of the Gravina belt (Mz 74%, Pz 20%, Pc 6%) in southeastern Alaska suggesting that similar provenance trends may exist in basins along this >2000 km-long collisional zone. Citation: Hampton, B. A., K. D. Ridgway, and G. E. Gehrels (2010), A detrital record of Mesozoic island arc accretion and exhumation in the North American Cordillera: U-Pb geochronology of the Kahiltna basin, southern Alaska, Tectonics, 29, TC4015, doi:10.1029/2009TC002544.

1. Introduction

[2] The addition of allochthonous material to a continental margin represents a punctuated tectonic event in the history of an orogenic belt that is often best preserved in the stratigraphic record of a sedimentary basin. In collisional plate margin settings defined by continent-scale suture zones and strike-slip faults, both the obliquity of convergence during subduction and the overall protracted nature of accretion can result in a progressive pattern of ocean basin closing and subsequent exhumation of a suture zone over a scale of millions of years [e.g., Graham et al., 1975; Ingersoll et al., 1995, 2003]. Exhumation associated with accretor events may be long-lived (>30 Myr) and result in thick successions of synorogenic clastic strata (>5 km) that record the provenance and depositional history of accretion through time. The application of U-Pb dating of detrital zircons from sedimentary basins in suture zone settings provides a sensitive tool for understanding long-term interactions between accreting allochthonous material along the outboard margin of a basin and sources areas along the inboard (cratonward) margin of a basin [e.g., Gehrels et al., 1995; DeGroff-Surpless et al., 2003; Weislogel et al., 2006; Leier et al., 2007]. Comparison of relative contributions from exhuming source areas adjacent to long-lived, regional-scale, sedimentary basins provides a valuable approach to constrain spatial and temporal detrital trends throughout a basin and progressive exhumation history along continental margins.

[3] An unresolved problem in the evolution of the North American Cordillera is the accretory history along the northern Cordillera continental margin since the end of the Triassic. Mesozoic clastic marine strata are exposed throughout western Washington, southwestern British Columbia and Yukon Territory, and southern Alaska (Figure 1) and occur along the suture between metamorphic and igneous units of the Intermontane belt and allochthonous igneous island arc material of the Wrangellia composite terrane [e.g., Berg et al., 1972; Brandon et al., 1988; Rubin and Saleeby, 1991; McClelland et al., 1992; Cohen et al., 1995; Kapp and Gehrels, 1998; Kalbas et al., 2007]. The accretion of the Wrangellia composite terrane to the North American Cordillera represents the largest addition of juvenile crust to the western margin of North American in the past 200 Myr [Coney et al., 1980; Plafker and Berg,
The detrital record of this accretionary event is potentially preserved in a >2000 km long discontinuous belt of Jurassic–Cretaceous strata that are located along the inboard (cratonward) side of the Wrangellia composite terrane. [4] In southern Alaska, exhumation associated with accretion of the Wrangellia composite terrane is recorded in Upper Jurassic–Cretaceous strata of the Kahiltna assemblage [Ridgway et al., 2002; Hampton et al., 2007], the Nutzotin Mountains sequence [Manuszak et al., 2007], and the Gravina belt [Kapp and Gehrels, 1998; Gehrels, 2001]. Upper Jurassic–Cretaceous sedimentary basins in southern Alaska and farther south along the margin are closely linked both stratigraphically and compositionally to the Wrangellia composite terrane, and potentially contain the stratigraphic record of exhumation associated with island arc accretion to the inboard Intermontane belt.

[5] A key debate surrounding the Mesozoic exhumation history of the northern Cordilleran is the classification of Upper Jurassic–Cretaceous strata as related to either precollisional, syncollisional, or postcollisional processes. A range of different models have been proposed for the tectonic setting of these sedimentary basins that include (1) preaccretionary basins that are related to the oceanic Wrangellia composite terrane and formed and evolved far outboard of the continental margin [Jones et al., 1977, 1982; Coney et al., 1980], (2) syncollisional basins that are related to collisional processes between the Wrangellia composite terrane and the Mesozoic continental margin [Pavlis, 1982; McClelland et al., 1992; Ridgway et al., 2002; Trop and Ridgway, 2007], and (3) postcollisional to postcollisional sedimentary basins associated with strike-slip faulting in the suture zone and translation between the arc and margin [Wallace et al., 1989]. This study summarizes the spatial and temporal distribution of U-Pb detrital zircons ages in the Upper Jurassic–Cretaceous Kahiltna assemblage in southwestern and south central Alaska. We present an overview here on how detrital zircon provenance comparisons between different stratigraphic intervals in synorogenic strata can be used as powerful tool for constraining the timing and nature of exhumation and basin fill during protracted accretionary events along collisional convergent margins.

2. Geologic Background

[6] The Kahiltna assemblage crops out in a >400 km long belt throughout south central and southwestern Alaska (Figures 1 and 2) and has been mainly described from previous studies in the context of regional geologic mapping projects [e.g., Csejty et al., 1978, 1992; Reed and Nelson, 1980; Jones et al., 1982; Smith et al., 1988; Bundtzen et al., 1997]. The unit consists of a 3–5 km thick succession of mainly submarine fan strata [e.g., Wallace et al., 1989; Eastham, 2002; Hampton et al., 2007; Kalbas et al., 2007] that represent >45 Myr of continuous clastic sedimentation. Thick successions of synorogenic strata together with occurrences of Late Jurassic–Cretaceous (Kimmeridgian–Cenomanian) marine macrofossils from the Kahiltna assemblage [Eakins et al., 1978; Reed and Nelson, 1980; Jones et al., 1980, 1983; Wallace et al., 1989; Bundtzen et al., 1997] are cited as evidence that sedimentation persisted in the Kahiltna basin from Late Jurassic to at least the beginning of Late Cretaceous time.

[7] The Wrangellia composite terrane consists primarily of volcanic, sedimentary, and metasedimentary strata of the Peninsular terrane (southwestern and south central Alaska), the Wrangellia terrane (south central and southeastern Alaska and southwestern British Columbia), and the Alexander terrane (southeastern Alaska and northwestern British Columbia) (Figure 1) [Jones et al., 1977; Gehrels and Saleeb, 1987; Pfafker and Berg, 1994]. Magmatic events associated with the Wrangellia composite terrane are represented by a number of arc-related rocks that are outlined in Figure 1c. In southern Alaska, the Kahiltna assemblage crops out in the suture zone between oceanic to transitional crust of the Wrangellia composite terrane and predominately pericratonic crust of the Yukon–Tanana composite terrane (Figure 2).

[8] The Yukon–Tanana composite terrane in east central and southeastern Alaska consists primarily of Paleozoic and...
Figure 2
Mesozoic metasedimentary and igneous rocks that represent pericratonic crustal material that have been inboard (cratonward) of the Wrangellia composite terrane since middle Mesozoic time. The Yukon-Tanana composite terrane, together with the Stikinia, Quesnellia-Slide Mountain, and Cache Creek terranes of southwestern Yukon Territory and western British Columbia, have been referred to collectively as the Intermontane belt or “superterrane” in previous studies [Monger et al., 1982; Saleeby, 1983; Wheeler and McFeeley, 1991]. The inboard, northern and eastern margins of the Intermontane belt are bounded by the Tintina fault while the outboard, southern and western margins are bordered by the Wrangellia composite terrane (Figure 1). Amalgamation of terranes that make up the Intermontane belt and subsequent accretion of these terranes to the North American margin may have begun as early as Permian time with the final stages of accretion by Middle Jurassic time [Monger and Berg, 1987; Mihalynuk et al., 1992; Plafker and Berg, 1994; Gehrels, 2001]. Thus, the southern and western outboard margin of the Intermontane belt in Alaska and western Canada likely represented the Cordillera continental margin by Middle Jurassic time. Precambrian-Cretaceous magmatic source areas of the Intermontane belt are outlined in Figure 1c and provide a general summary of potential sources for detrital zircons that are present in the Kahltna assemblage.

3. Methodology

This study presents U-Pb ages from detrital zircon grains with magmatic origin (inferred here by U/Th values <5) that were collected within the context of eight measured stratigraphic sections from throughout the Upper Jurassic–Cretaceous Kahltna assemblage of southern Alaska (Figures 2 and 3). Thick stratigraphic successions (3–5 km thick) and regional lateral extent (>400 km), together with the long-lived depositional history of the Kahltna assemblage (>45 Myr) make it one of the more ideal basins in the northern Cordillera for examining the stages of exhumation and deposition associated with Mesozoic island arc accretion. A comparison of detrital trends from the northern Cordillera allows for an initial test of existing precollisional, syncollisional, and postcollisional models of basin evolution and ultimately provides a first-order constraint on the timing and extent of exhumation associated with accretion of the Wrangellia composite terrane.

Detrital zircons were separated from eight sandstone samples of the Kahltna assemblage in the Alaska Range suture zone (Figures 2 and 3). Samples were collected at different stratigraphic intervals in the Kahltna assemblage along a >250 km long transect across the northern Talkeetna Mountains, the Clearwater Mountains, and the southern and western Alaska Range. Refer to Figure 2 for a geographic location of these samples in the Alaska Range suture zone and Figure 3 for the stratigraphic location of samples in the context of measured sections.

A total of 714 detrital zircons were analyzed using laser ablation inductively coupled plasma mass spectrometry (LA-ICPMS) at the Arizona LaserChron Center (http://sites.google.com/a/laserchron.org/laserchron/home) utilizing methods described by Gehrels et al. [2006, 2008]. Individual grains were analyzed with a Micromass Isoprobe multicollector ICPMS equipped with nine faraday collectors, an axial Daly detector, and four ion-counting channels. The Isoprobe is equipped with a New Wave DUV 193 laser ablation system with an emission wavelength of 193 nm. The analyses were conducted on 35–50 micron spots with an output energy of ~40 mJ and a repetition rate of 8 Hz. Each analysis consisted of one 20 s integration on the backgrounds (on peaks with no laser firing) and twenty 1 s integrations on peaks with the laser firing. The depth of each ablation pit is ~20 µm. The collector configuration allows simultaneous measurement of 204Pb in a secondary electron multiplier while 206Pb, 207Pb, 203Pb, 132Xe, and 235U are measured with Faraday detectors. All analyses were conducted in static mode.

Correction for common Pb was done by measuring 206Pb/204Pb, with the composition of common Pb from Stacey and Kramers [1975] and uncertainties of 1.0 for 206Pb/204Pb and 0.3 for 207Pb/206Pb. Fractionation of 206Pb, 238U and 206Pb, 207Pb during ablation was monitored by analyzing fragments of a large concordant zircon crystal that has a known (ID-TIMS) age of 563.5 ± 3.2 Ma [Gehrels et al., 2008]. Typically this reference zircon was analyzed once for every four unknowns. The uncertainty arising from this calibration correction, combined with the uncertainty from decay constants and common Pb composition, contributes ~1% systematic error to the 206Pb/238U and 206Pb/207Pb ages (2-sigma level). The preferred ages are based on 206Pb/238U ratios for <1.0 Ga grains and on 206Pb/207Pb for >1.0 Ga grains. A summary of measured isotopic ratios and ages are reported in Data Set S1 in the auxiliary material. Analyses are shown on an Pb/U Concordia diagram (Figure 4) and on an relative probability plots (Figure 4, 5, and 6) (see Ludwig [2008] for use of plotting program). The latter is generated by summing the individual probability distributions for all grains in a sample. U and Th concentrations are calibrated by analysis of NBS SRM 610 trace element glass.

3.1. U-Pb Detrital Zircon Age Distribution

Detrital zircon age data from the Kahltna assemblage reveal numerous occurrences of concordant to slightly dis-
Figure 3. Measured stratigraphic sections, detrital zircon sample locations, biostratigraphic age constraint, and maximum depositional ages (MDA) from the Upper Jurassic–Cretaceous Kahiltna assemblage. Ages reflect the maximum depositional age for each sample as determined from the youngest single grain, youngest graphical peak age, and weighted mean age of the youngest cluster of three or more grains. Refer to Figure 2 for location of measured sections and detrital zircon samples in the Alaska Range suture zone.
cordant Mesozoic, Paleozoic, and Precambrian age zircons (Figure 4a). Mesozoic (Mz) age grains are the most abundant with less abundant occurrences of Paleozoic (Pz) and Precambrian (Pc) age grains (Mz 74%, Pz 11%, Pc 15%; Figure 4b). The majority of Mesozoic grains have ages that fall between 250 and 100 Ma with primary peak occurrences at 201, 156, and 123 Ma (Figures 4b and 5). The majority of Paleozoic age grains are between 450 and 300 Ma with a primary peak occurrence at 364 Ma (Figures 4b and 5). The majority of Precambrian age grains fall between 2.1 and 1.7 Ga and 2.8–2.3 Ga with isolated peak occurrences at 1793, 1929, and 2647 Ma. The remainder of Precambrian grains are scattered between 0.7 and 0.6, 1.7–1.1, and 2.8–3.1 Ga (Figures 4b and 5). All age comparison is based on the geologic time scale of Gradstein et al. [2004].

3.2. U-Pb Maximum Depositional Ages in Stratigraphic Context

The thickness (3–5 km thick), regional extent (>400 km), and long-lived depositional history (>45 Myr) of the
Figure 5
Kahiltna assemblage allow for detrital zircon age populations to be evaluated within a basin-scale context. By using existing age constraint from the Kahiltna assemblage together with maximum depositional ages determined from the youngest cluster of zircon grains, samples can be assigned to a given stratigraphic interval in the Kahiltna basin (Figures 3 and 6). The rationale behind this approach is that, in addition to the total bulk distribution of detrital zircon ages from the Kahiltna assemblage (Figure 4), it allows for a spatial and temporal comparison of detrital zircon provenance throughout the history of the basin by comparing age populations between individual samples at different stratigraphic intervals. Ultimately, a comparison of upsection changes in detrital zircon contributions offers insight into regions that were being exhumed throughout various stages Mesozoic arc accretion.

[15] In order to promote reproducibility and determine the most reliable maximum depositional age (MDA) for each sample at a given stratigraphic interval, we report three alternate measures of maximum depositional age as outlined by Dickinson and Gehrels [2009], that include the youngest single grain age (YSG), the youngest graphical peak age (YPK), and calculated weighted mean age (WMA) of the youngest cluster of three or more grains (Figures 3 and 6). The youngest graphical age peak represents a maximum in age probability that comprises contributions (at 2-sigma) from three or more grain analyses. The weighted mean age incorporates both analytical and systematic error and is reported at 2-sigma uncertainty using the youngest cluster of three or more grain ages. Although it has been demonstrated that the youngest detrital age in a sample can be a statistically robust and valid procedure to constrain maximum depositional age [Dickinson and Gehrels, 2009], we rely on the youngest graphical age peak and weighted mean age as a conservative, first-order constraint on the depositional age of each sample. It is worth noting that for the majority of samples from the Kahiltna assemblage, the youngest grain, peak age, and weighted mean age fell within a 10 Myr age range (Figures 3 and 6). Maximum depositional ages for each sample are presented in context with previously reported, biostratigraphic ages determined from marine macrofossil occurrences from throughout the Kahiltna assemblage (Figures 3, 5, and 6).

[16] The oldest sample in this study (BC-16) was collected from the easternmost exposures of the Kahiltna assemblage in the northeastern Talkeetna Mountains-Clearwater Mountains region (Figures 2 and 3). Late Jurassic–Early Cretaceous (Kimmeridgian–Valanginian; 155.7–136.4 Ma) marine fossils have been used to constrain the age of strata in this region [Jones et al., 1980; Silberling et al., 1981a, 1981b; Smith et al., 1988; Csejty et al., 1992] (Figure 3). We report a maximum depositional age for this sample as follows: for sample BC-16, youngest single grain age is 139 ± 2 Ma, youngest peak age is 141 Ma, and weighted mean age is 140 ± 2 Ma (Figure 6). The maximum depositional age from the youngest peak and weighted mean age is earliest Early Cretaceous (Berriasian–Valanginian; 145.5–136.4 Ma). This maximum depositional age is the oldest that we report from the Kahiltna assemblage and corresponds with the upper age range from Late Jurassic–Early Cretaceous macrofossils reported from this region. This sample was likely collected from the basal–most stratigraphy in the Kahiltna basin and effectively represents some of the oldest known strata of the Kahiltna assemblage in southern Alaska.

[17] West of the oldest sample from the northeastern Talkeetna Mountains-Clearwater Mountains region, four samples (EFC-071102-04, HPC-072802-02, TCB-205, AC-072002-01) were collected from the northwestern Talkeetna Mountains (Figures 2 and 3). Late Jurassic–Early Cretaceous (Kimmeridgian–Valanginian; 155.7–136.4 Ma) marine fossils have been used to constrain the age of the Kahiltna assemblage in the northwestern Talkeetna Mountains [Jones et al., 1980; Silberling et al., 1981a, 1981b; Smith et al., 1988; Csejty et al., 1992] (Figure 3). For each of these samples, maximum depositional ages are as follows: for sample EFC-071102-04, youngest single grain age is 106 ± 7 Ma, youngest peak age is 115 Ma, and weighted mean age is 116 ± 1 Ma; for sample HPC-072802-02, youngest single grain age is 117 ± 6 Ma, youngest peak age is 121 Ma, and weighted mean age is 123 ± 2 Ma; for sample TCB-205, youngest single grain age is 119 ± 2 Ma, youngest peak age is 124 Ma, and weighted mean age is 125 ± 2 Ma; for sample AC-072002-01, youngest single grain age is 119 ± 2 Ma, youngest peak age is 124 Ma, and weighted mean age is 120 ± 3 Ma (Figure 6). The range of maximum depositional ages from these samples spans part of the Early Cretaceous (Barremian–Aptian; 130.0–112.0 Ma) and is younger than the previously reported biostratigraphic age range of Late Jurassic–Early Cretaceous (Kimmeridgian–Valanginian; 155.7–136.4 Ma). These new age constraints suggest that the upper age for the Kahiltna assemblage in the northwestern Talkeetna Mountains may be as young as latest Early Cretaceous (Aptian–Albian; 125.0–99.6 Ma) [Hampton et al., 2007].

[18] One sample (BC3-792) was collected from the western end of the Kahiltna assemblage in the southwestern Alaska Range. Early Cretaceous (Valanginian–Barremian; 140.2–125.0 Ma) marine fossil occurrences have been used to determine the age of the Kahiltna assemblage in the

Figure 5. Relative age probability diagrams for each individual sample from the Kahiltna assemblage. Plots are shown by their spatial distribution from west to east throughout the Alaska Range suture zone. Percentage distribution of zircon ages has been determined after grouping samples by their geographic location (e.g., Alaska Range southwest, Alaska Range central, northwestern Talkeetna Mountains, and northwestern Talkeetna Mountains-Clearwater Mountains). Preexisting biostratigraphic age ranges are included for each geographic location. All age comparison is based on the geologic time scale of Gradstein et al. [2004]. Refer to Figures 2 and 3 for samples locations in the southern Alaska Range, northern Talkeetna Mountains, and Clearwater Mountains.
southwestern Alaska Range [Reed and Nelson, 1980; Bundtzen et al., 1997]. The maximum depositional age for this sample is as follows: for sample BC3-792, youngest single grain age is 106 ± 4 Ma, youngest peak age is 199 Ma, and weighted mean age is 117 ± 5 Ma (Figure 6). Due to the relatively low number of Early Cretaceous age grains (n = 4) in this sample there is a discrepancy between the Early Jurassic peak age as compared to the Early Cretaceous youngest single grain and weighted mean ages. In this instance, given that this sample was collected within the context of a measured stratigraphic section that contains the biostratigraphic occurrences of Early Cretaceous macrofossils, we have adopted the Early Cretaceous weighted mean age to reflect the maximum depositional age for this sample. Thus these strata are taken to be Early Cretaceous (Aptian; 125.0–112.0 Ma) and are inferred to represent the upper age equivalent to Early Cretaceous strata of the Kahiltna assemblage in the northwestern Talkeetna Mountains.

[19] Two samples (OC1-630, RG-146) were collected from Kahiltna basin strata exposed in the central Alaska Range (Figures 2 and 3). Late Jurassic–Cretaceous (Kimmeridgian–Cenomanian; 155.7–93.5 Ma) marine fossils that occur in this part of the Kahiltna assemblage have been used to constrain the age of the Kahiltna assemblage in this region [Jones et al., 1980, 1983]. The maximum depositional ages for this part of the Kahiltna assemblage are as follows: for sample OC1-630, youngest single grain age is 112 ± 1 Ma, youngest peak age is 112 Ma, and weighted mean age is 113 ± 2 Ma; for sample RG-146, youngest single grain age is 85 ± 2 Ma, youngest peak age is 98 Ma, and weighted mean age is 102 ± 2 Ma (Figure 6). Based on the occurrence of peak ages of Early–Late Cretaceous and the occurrence of macrofossils as young as earliest Late Cretaceous, we report a maximum depositional age of Early Cretaceous (Aptian; 125.0–112.0 Ma) for sample OC1-630 and Early–Late Cretaceous (Albian–Cenomanian; 112.0–93.5 Ma) for sample RG-146. Sample OC1-630 corresponds with the Early Cretaceous age sample from the southwest Alaska Range (BC3-792) and the four coeval samples from the northwestern Talkeetna Mountains (EFC-071102-04, HPC-072802-02, TCB-205, AC-072002-01). The youngest sample from the study (RG-146) is from the uppermost stratigraphic intervals of the Kahiltna basin and is taken to represent the

**Figure 6.** Relative age probability plots showing Phanerozoic zircon ages and a summary of maximum depositional ages (MDA) for each individual sample from the Kahiltna assemblage. Plots are shown by their spatial distribution from west to east throughout the Alaska Range suture zone. Preexisting biostratigraphic age ranges are included for each geographic location and are presented with maximum depositional ages that include the youngest single grain (YSG), the youngest graphical peak age (YPK), and weighted mean age (WMA) from the youngest cluster of three or more grains. All age comparison is based on the geologic time scale of Gradstein et al. [2004]. Refer to Figures 2 and 3 for sample locations in the southern Alaska Range, northern Talkeetna Mountains, and Clearwater Mountains.
youngest known part of the Kahiltna assemblage in south central Alaska.

4. Provenance

[20] Previous studies have provided a wealth of isotopic age constraint for many of the regional and long-lived magmatic events in the North American Cordillera (Figure 1c) making it one of the better constrained orogenic belts in terms of Phanerozoic magmatic history. Low ratios of uranium-thorium (<5) recorded from detrital zircon grains within the Kahiltna assemblage suggest that ages reflect timing of magmatism and initial crystallization rather than thermal resetting from regional metamorphism. By correlating U-Pb detrital zircon ages from the Kahiltna assemblage with previously reported ages from magmatic provinces throughout the Cordillera we are able to examine the relative contributions from sources located inboard and outboard of the Kahiltna basin during accretion of the Wrangellia composite terrane. Detrital contributions of recycled zircon grains from Precambrian-Mesozoic sedimentary and metasedimentary sources from throughout the Cordillera likely make up a significant percentage of grains from the Kahiltna assemblage and will be addressed later in this text.

[21] It is important to note that the Kahiltna basin occurs in a suture zone setting in southern Alaska and the northern margin of the basin is bound by the ~1200 km long Denali strike-slip fault. Up to 400 km of dextral displacement has been proposed for the Denali fault since Late Cretaceous time based on geologic studies [Eibach, 1976; Nokleberg et al., 1985; Plafker and Berg, 1994; Wyld et al., 2006; Trop and Ridgway, 2007] and conservative estimates from paleomagnetic data sets indicate 1650 ± 890 km of displacement relative to stable North America between 80 to 55 Ma [Stamatakos et al., 2001]. Given this wide range of proposed displacement for regions outboard of the Tintina and Denali fault systems (Figure 1a), the following text attempts to account for all known significant, long-lived, pre-Cenozoic magmatic sources in northwestern British Columbia, southwestern Yukon Territory, and southern Alaska.

4.1. Primary Magmatic Source Areas of the Northern Cordillera

[22] Pre-Cenozoic magmatic source areas in the western parts of the North American Cordillera range from latest Proterozoic to Late Cretaceous in age (Figure 1). However, with the exception of latest Neoproterozoic–Cambrian age zircons (555–520 Ma) from the Alexander terrane in southeastern Alaska [Gehrels and Saleeby, 1987; Gehrels, 1990], of yet no magmatic source areas have been reported from the Wrangellia composite terrane that are older than Paleozoic. Some of the oldest Paleozoic and Mesozoic sources consist of Ordovician–Early Devonian (480–410 Ma) and Permian–Triassic plutonic suites (~280–220 Ma) from the Alexander terrane in southeastern Alaska [Gehrels and Saleeby, 1987; Gehrels, 1990]. Additional Late Paleozoic source areas associated with the Wrangellia composite terrane include isolated Devonian plutonic rocks [Muller, 1980; Brandon et al., 1986; Dodds and Campbell, 1988] as well as Pennsylvanian–Permian plutonic suites (320–285 Ma) associated with the Skolai arc and Strelna assemblage [Nokleberg et al., 1986; Aleinikoff et al., 1988; Dodds and Campbell, 1988; Gardner et al., 1988; Beard and Barker, 1989; Plafker et al., 1989].


[24] Documented occurrences of Mesozoic magmatic source areas in the Intermontane belt include Middle Triassic–Late Jurassic igneous rocks (245–145 Ma) of the Stikine, Cache Creek, and Quesnellia–Slide Mountain terranes in southwestern Yukon and western British Columbia, and the Stikinia terrane in western British Columbia [Mortimer et al., 1990; Greig et al., 1992; Mihalyuk et al., 1992; Sevigny and Parrish, 1993; Ghosh, 1995; Greig and Gehrels, 1995; Johnston et al., 1996; Currie and Parrish, 1997; Childe, 1996; Childe and Thompson, 1997; Devell et al., 2000; Palloy et al., 1997, 2000; Maclntyre et al., 2001; Villeneuve et al., 2001; Erdmer et al., 2002]. Coeval Mesozoic plutonism is recorded in Late Triassic–Early Jurassic age igneous rocks (215–175 Ma) of the Yukon–Tanana composite terrane of east central Alaska [e.g., Aleinikoff et al., 1981; Wilson et al., 1985; Foster et al., 1994; Dusel-Bacon et al., 2002]. Early–mid Mesozoic magmatic source areas associated with the Wrangellia composite terrane consist primarily of the Late Triassic–Jurassic Talkeetna arc (201–153 Ma) of the Peninsular terrane [Onstott et al., 1989; Palloy et al., 1999; Rious et al., 2007] in south central and southwestern Alaska and equivalent rocks of the Bonanza arc (202–160 Ma) of the Wrangellia terrane in southwestern British Columbia [Friedman et al., 1990; Monger and McNicol, 1993; DeBar et al., 1999; Palloy et al., 2000]. While the Wrangellia composite terrane does contain some Permian–Triassic magmatic source areas, there are currently no reported magmatic events associated with Wrangellia that can account for detrital zircon ages in the Kahiltna assemblage that occur between 220 and 205 Ma.

[25] The remainder of Mesozoic magmatic source areas in the northern Cordillera consist primarily of the Middle Jurassic–Early Cretaceous Chitina arc (175–135 Ma) [Plafker et al., 1989; Nokleberg et al., 1994; Roeske et al., 1988; Brandon et al., 1986; Dodds and Campbell, 1988].
Potential source areas associated with the Wrangellia composite terrane include the Skolai arc and Strelina assemblage (320–285 Ma) in south central Alaska as well as latest Neoproterozoic–Cambrian (555–520 Ma), Ordovician–earliest Devonian (480–410 Ma), and Permian–Triassic plutonic rocks (280–220 Ma) associated with the Alexander terrane in southeast Alaska and southwest parts of the Yukon Territory (Figure 1). The Devonian age Steele Creek and Mount Constantine gabbro and SaltSpring plutons are also possible sources associated with Wrangellia and the Alexander terrane [MuLLer, 1980; Brandon et al., 1986; DoddS and campbell, 1988]. Paleozoic source areas associated with the Intermontane belt include Permian age plutonic rocks (275–255 Ma) of the Quesnellia–Slide Mountain terrane in southwest Yukon and British Columbia, Devonian–Mississippian plutonic suites (380–330 Ma) of the Quesnellia–Slide Mountain terrane and Yukon–Tanana composite terrane in southwest Yukon and east central Alaska (Figure 1).

5. Discussion

[30] The bulk occurrence of Precambrian–Mesozoic age zircons from the Kahltna assemblage (Figure 4) infers that exhumation along the northern Cordillera throughout the Jurassic–Cretaceous sedimentary cycle of the Kahltna basin involved detrital contributions from the Intermontane belt and the Wrangellia composite terrane. Moreover, a comparison of detrital zircon age populations from individual samples at specific stratigraphic intervals throughout the Kahltna assemblage reveals an upsection trend in provenance suggestive of differential contributions from outboard and inboard source areas from the early to late stage of basin development.
5.1. Upsection Trends in Provenance as a Proxy for Mesozoic Exhumation

[31] Existing biostratigraphic age constraint and new maximum depositional ages from the Kahiltna assemblage allow us to examine changes in provenance during individual stages of sedimentation and evolution of the Kahiltna basin (Figure 7). The oldest stratigraphic interval in the Kahiltna assemblage that was sampled for this study is located in the easternmost part of the Alaska Range suture zone (Figures 2 and 3) and is interpreted here to represent the lowermost, basal stratigraphy in the Kahiltna basin (Figure 7). Detrital zircon age populations from this stratigraphic interval reveal that 100% of zircon grains are Mesozoic in age and fall between an age range of 140–180 Ma (Figures 5, 6, and 7). Possible sources for this detritus include the Talkeetna, Chitina, Chisana arcs of the Wrangellia composite terrane in southern Alaska as well as age-equivalent magmatic source areas of the Yukon–Tanana, Quesnellia–Slide Mountain, Cache Creek, and Stikinia terranes of the Intermontane belt (Figure 1).

[32] It could be argued that the occurrence of 100% Mesozoic age zircons at this stratigraphic interval represents the initial exhumation of Mesozoic source areas both inboard and outboard of the Kahiltna basin. However, given the multiphase history of exhumation in the North American Cordillera throughout the Phanerozoic it seems unlikely that regions inboard of the Kahiltna basin have not undergone extensive phases of exhumation and hence, would have been exhumed to much deeper levels to expose Paleozoic and Precambrian age grains. Geologic time scale based on that of Gradstein et al. [2004].

Figure 7. Summary of relative age probability plots and age percent distribution showing the temporal, upsection trends in detrital zircon ages from base to top of the Upper Jurassic–Cretaceous Kahiltna assemblage. Samples have been grouped according to their maximum depositional age. Trends in detrital zircon ages from base to top of the Kahiltna basin show a relative decrease upsection in Mesozoic age grains with a relative increase in Paleozoic and Precambrian age grains. Geologic time scale based on that of Gradstein et al. [2004].
stratigraphic interval was derived almost solely from the Wrangellia composite terrane.

[33] The four samples collected from the northwestern Talkeetna Mountains are inferred to be stratigraphically younger than the Late Jurassic–Early Cretaceous strata described above based on Early Cretaceous (Barremian–Aptian; 130.0–112.0 Ma) maximum depositional ages (Figures 3, 6, and 7). Detrital zircon age populations from this stratigraphic interval of the Kahiltna assemblage reveal a range of Mesozoic, Paleozoic, and Precambrian age zircon grains (Mz 84%, Pz 11%, Pc 5%) (Figure 7). Similarly, two samples from the Alaska Range share roughly coeval Early Cretaceous (Aptian; 112.0–125.0 Ma) maximum depositional ages with these samples and reflect a similar upsection trend in varying percentages of Mesozoic, Paleozoic, and Precambrian age zircons (Mz 56%, Pz 11%, Pc 24%) (Figure 7). Collectively, these six samples are interpreted to represent a younger stratigraphic interval of the Kahiltna assemblage where detritus was being derived from a much more extensive drainage network and diverse set of source regions that include both the outboard Wrangellia composite terrane and inboard Intermontane belt.

[34] The youngest stratigraphic interval sampled from the Kahiltna assemblage is from the central Alaska Range (Figure 3) and is interpreted to represent the uppermost stratigraphy of the Kahiltna basin exposed in the Alaska Range suture zone based on a Early Cretaceous (Albian–Cenomanian; 112.0–93.5 Ma) maximum depositional age (Figures 3, 6, and 7). Detrital zircon age populations from the uppermost stratigraphic interval in the Kahiltna basin show a relative decrease in Mesozoic age zircons and increase in the percentage of Paleozoic and Precambrian age grains (Mz 19%, Pz 22%, Pc 59%) compared to older stratigraphic intervals (Figure 7). Provenance trends from this uppermost stratigraphic interval of the Kahiltna assemblage are interpreted to reflect significant detrital contributions from extensive source network throughout the inboard Intermontane belt and relative decreased contributions from the outboard Wrangellia composite terrane.

5.2. Mesozoic Record of Exhumation and Basin Fill During Arc Accretion

[35] The Jurassic–Cretaceous tectonic history of arc accretion along the western margin of the North American Cordillera has received a considerable amount of study over the past several decades and remains a topic of ongoing debate [e.g., Berg et al., 1972; Pavlis, 1982; Gehrels and Saleeby, 1987; Brandon et al., 1988; Rusmore et al., 1988; Wallace et al., 1989; Rubin et al., 1990; McClelland et al., 1992; Monger et al., 1994; Pflafer and Berg, 1994; Umhoefer et al., 2002; Cohen et al., 1995 Kapp and Gehrels, 1998; Mahoney et al., 1999; Gehrels, 2001; Ridgway et al., 2002; Trop et al., 2002, 2005; Dickinson, 2004; Clift et al., 2005; Hampton et al., 2007; Kalbas et al., 2007; Manuszak et al., 2007; Trop and Ridgway, 2007]. A range of end-member models have been proposed to explain the tectonic significance of Upper Jurassic–Cretaceous siliciclastic strata that occur inboard of the Wrangellia composite terrane and outboard of the Intermontane belt. Proposed depositional models for the Kahiltna basin and age equivalent strata in parts of southern Alaska include sedimentation occurring prior to and unrelated to arc accretion, sedimentation occurring coeval and as a direct result of subduction and arc accretion, and sedimentation occurring after arc accretion as a result of strike-slip basin development in a suture zone setting [e.g., Wallace et al., 1989; Kapp and Gehrels, 1998; Gehrels, 2001; Ridgway et al., 2002; Hampton et al., 2007; Kalbas et al., 2007; Manuszak et al., 2007; Trop and Ridgway, 2007].

[36] Collectively, data from individual stratigraphic intervals in the Kahiltna assemblage show distinct temporal trends in provenance. One of the more noticeable of these trends is the relative decrease from base to top of the Kahiltna assemblage in the occurrence of Mesozoic age detrital zircons as compared to Paleozoic and Precambrian age zircons (Figure 7). Preaccretionary models for basin development would have the Kahiltna basin closely associated with the Wrangellia composite terrane and far outboard of the Intermontane belt and North American Cordillera [Jones et al., 1977, 1982; Coney et al., 1980]. Detrital trends from the Kahiltna could support this model in the earliest stages of basin development, however the occurrence of Paleozoic and Precambrian detritus associated with the Intermontane belt and North American miogeocline in the younger parts of the Kahiltna basin require some contributions from an inboard source by at least the middle stages of the Early Cretaceous (Hauterivian-Barremian; 136.4–125.0 Ma).

[37] Postaccretionary models for basin development would have Upper Jurassic–Cretaceous strata developing in a series of strike-slip basins in the suture zone between the Wrangellia composite terrane and Intermontane belt. In this model, sedimentation would record postaccretionary exhumation of the Wrangellia composite terrane and Intermontane belt within narrow, strike-slip related basins. The occurrence of Mesozoic, Paleozoic, and Precambrian detrital zircons in the younger stratigraphic intervals from the Kahiltna assemblage would support the unroofing pattern expected from a postaccretionary model. However, while the occurrence of 100% Mesozoic age detrital zircon grains in the basal stratigraphic intervals of the Kahiltna assemblage does not discount this type of model, it does require some explanation as to why the Wrangellia composite terrane was the sole source for detritus during the earliest stages of basin development if the terrane had already collided with the continental margin.

[38] Based on the upsection trends in detrital zircon age distribution from the Upper Jurassic–Cretaceous strata of the Kahiltna assemblage we suggest a three-stage model for basin development, exhumation, and sediment dispersal during the Late Jurassic–Cretaceous accretion of the Wrangellia composite terrane to the Intermontane belt and North American Cordillera (Figures 7 and 8).

5.2.1. Stage 1: Late Jurassic–Early Cretaceous

[39] Detrital zircon ages from the basal stratigraphic intervals of the Kahiltna assemblage reveal a narrow range of possible source regions that appear to be limited to Middle Jurassic–Early Cretaceous magmatic sources in the
Figure 8. A three-stage conceptual model for sedimentary basin evolution associated with the accretion of the Wrangellia composite terrane to the Intermontane belt and North American Cordillera during Jurassic–Cretaceous time. The tectonic configurations of two parallel, north dipping subduction zones are based on reconstructions of Trop and Ridgway [2007].
Wrangellia composite terrane (Figures 1, 7, and 8a). During the initial Late Jurassic–Early Cretaceous phase of basin development the proximity of the Wrangellia composite terrane to source areas of the Intermontane belt is poorly constrained. Provenance trends suggest that during Late Jurassic–Early Cretaceous time the Kahiltna basin was in close proximity to, and receiving detritus solely from Mesozoic sources associated with the Wrangellia composite terrane (Figures 7 and 8). The Late Jurassic–Early Cretaceous stage of deposition is interpreted to be part of a retroarc foreland basin that formed along the inboard margin of the Wrangellia composite terrane just prior to and/or during the initial stages of exhumation associated with arc collision and suturing to the Intermontane belt [Ridgway et al., 2002; Trop and Ridgway, 2007] (Figures 8a and 8b).

5.2.2. Stage 2: Early Cretaceous

Detrital zircon ages from Lower Cretaceous strata of the Kahiltna assemblage reflect a wide range of possible source areas during arc accretion that include Precambrian, Paleozoic, and Mesozoic magmatic source areas from the inboard Intermontane belt and outboard Wrangellia composite terrane (Figures 1, 7, and 8b). Occurrences of Paleozoic and Precambrian grains in younger stratigraphic intervals of the Kahiltna assemblage provide a strong argument to link the Kahiltna basin to inboard source areas in the Intermontane belt by at least the middle stages of the Early Cretaceous (Hauterivian–Barremian; 136.4–125.0 Ma). The upsection increase in Paleozoic and Precambrian detritus recorded at this stratigraphic interval is interpreted to represent the initial detrital contributions from the inboard Intermontane belt to the Kahiltna basin during the Early Cretaceous phase of exhumation and basin development. Provenance trends from Lower Cretaceous strata of the Kahiltna assemblage are interpreted to reflect a collisional stage in the development of the Kahiltna basin in which source regions in the Wrangellia composite terrane and Intermontane belt were being exhumed, eroded, and subsequently deposited in the Kahiltna basin (Figure 8b). In this interpretation, the Kahiltna basin would have transitioned from a retroarc foreland basin to a remnant ocean basin where it was receiving detritus from an along-strike suture between the Wrangellia composite terrane and Intermontane belt (Figure 8b).

5.2.3. Stage 3: Early Cretaceous–Late Cretaceous

Detrital zircon ages from the youngest stratigraphic intervals of the Kahiltna basin are reflective of source areas that include both the inboard Intermontane belt and outboard Wrangellia composite terrane (Figures 1, 7, and 8c). Provenance trends from Upper Cretaceous strata of the Kahiltna assemblage are interpreted to reflect exhumation during the final stages of accretion of the Wrangellia composite terrane to the Intermontane belt (Figure 8c). By the beginning of Late Cretaceous time, the Kahiltna basin was likely in the mature stages of remnant ocean basin development in which the basin was receiving detritus from exhumed regions of the Intermontane belt with relative decreased contributions from the Wrangellia composite terrane. If the Kahiltna assemblage represents sedimentation in a closing ocean basin between the Wrangellia composite terrane and Intermontane belt, then Late Cretaceous basin development was likely characterized by the transition from the final stages of a closing remnant ocean basin to a flexure-induced collisional foreland basin and/or strike-slip basin (Figure 8c). In this scenario, Upper Cretaceous nonmarine strata that have been reported at the top of the Kahiltna assemblage [Hampton et al., 2007] may represent the initial stages of crustal shortening, peripheral foreland basin development, and subsequent strike-slip faulting in the suture between the Wrangellia composite terrane and Intermontane belt.

5.3. Spatial Trends in Provenance From Mesozoic Basins of Southern Alaska

The Gravina belt of southeastern Alaska is exposed along strike of the Kahiltna assemblage and is also located in the suture between the outboard Wrangellia composite terrane and inboard Intermontane belt (Figures 1 and 9). Collectively, the Gravina belt consists of Upper Jurassic–Cretaceous marine siliciclastic and volcaniclastic strata that are age-equivalent with the Kahiltna assemblage of southwestern and south central Alaska. We present a summary of previously reported U-Pb detrital zircon data from the Gravina belt [Kapp and Gehrels, 1998; Gehrels, 2001] as a reference for comparing with provenance trends from the Kahiltna assemblage.

Detrital zircon data from the Gravina belt include total of 332 grains and reveal a bulk distribution of Mesozoic (74%), Paleozoic (20%), and Precambrian (6%) age grains. The majority of Mesozoic grains have ages between 180 and 120 Ma with a primary peak occurrence at 154 Ma and a smaller isolated peak at 203 Ma. The youngest grain from this sample set is 110 ± 2 Ma and the youngest graphical peak is at 111 Ma (Figure 9). Paleozoic grain occurrences are primarily scattered between 350 and 250 Ma with a primary peak at 340 Ma, and a range of 450–400 Ma with a primary peak at 417 Ma. Precambrian grains in the Gravina belt are scattered between 2600 and 550 Ma with no elevated occurrences or primary peaks at any particular age range. Note that overall the detrital zircon populations between the Kahiltna assemblage and the Gravina belt are
Figure 9
somewhat comparable with both units having similar percentages of Mesozoic, Paleozoic, and Precambrian age detrital zircon grains (Figure 9).

[44] The distribution of detrital zircon ages in both the Gravina belt and Kahiltna assemblage suggest similar provenance trends that may reflect a shared history of Mesozoic exhumation and basin development. While we present one interpretation for stages of exhumation and basin development based on provenance trends from the Kahiltna assemblage, a comparative study of basin provenance from Jurassic–Cretaceous strata that are exposed along the >2000 km long collisional zone is needed to better understand the timing and mechanisms associated with accretion of the Wrangella composite terrane to the North American Cordillera.

6. Conclusions

[45] U-Pb LA-ICPMS analyses of detrital zircons from synorogenic strata provide a sensitive provenance tool for understanding long-term trends in exhumation and sediment dispersal along collisional plate boundaries. In this study the technique has been applied to address a long-standing debate in the timing, trends in exhumation, and basin development associated with Mesozoic arc accretion along the western margin of the North American Cordillera. This study summarizes U-Pb detrital zircon data from base to top of the Kahiltna assemblage which makes up the northernmost occurrence of a >2000 km long discontinuous belt of Upper Jurassic–Cretaceous strata that are exposed inboard (cratonward) of the Wrangellia composite terrane from southern Alaska to southwestern British Columbia and northwestern Washington.

[46] Upper Jurassic–Cretaceous strata of the Kahiltna assemblage contain Mesozoic, Paleozoic, and Precambrian age detrital zircons (Mz 74%, Pz 11%, Pc 15%) that were derived from source areas that included the outboard Gravina composite terrane and inboard Intermontane belt. The majority of grain occurrences are between 250 and 100, 450–300, 2100–1700, 2800–2300 Ma with primary Phanerozoic peak occurrences at 125, 156, 201, and 364 Ma and isolated Precambrian peak occurrences at 1793, 1929, and 2647 Ma. Age population trends from the Kahiltna assemblage are similar in overall percentage distribution with detrital zircon ages from Upper Jurassic–Cretaceous strata of the Gravina belt (Mz 74%, Pz 20%, Pc 6%) that are exposed along strike in southeast Alaska.

[47] By comparing upsection trends in detrital zircon age population at different stratigraphic intervals throughout the Kahiltna assemblage we are able to examine the range of possible regions inboard and outboard of the basin that were being exhumed and contributing detritus to the Kahiltna basin at a given point in time during the accretion of the Wrangellia composite terrane. This approach provides a valuable test that can be applied to any sedimentary basin with the adequate age constrain and is especially useful in testing existing tectonic models for the accretory history of the North American Cordillera. Upsection trends in detrital zircon ages from the Kahiltna assemblage are interpreted here to represent three stages of exhumation and basin development during the Late Jurassic–Cretaceous accretion of the Wrangella composite terrane to the Intermontane belt.

[48] Stages include an initial Late Jurassic–Early Cretaceous phase of exhumation and basin development during which arc accretion was characterized by retroarc foreland basin development along the inboard margin of the Wrangellia composite terrane. During this stage, the Kahiltna basin was receiving a majority of detritus from Mesozoic magmatic sources of the Wrangellia composite terrane (Mz 100%, Pz 0%, Pc 0%). This initial stage was followed by a second Early Cretaceous stage of basin development that was characterized by continued exhumation of the outboard Wrangellia composite terrane and initial detrital contributions from Precambrian–Mesozoic sources areas of the inboard Intermontane belt (Mz 84%, Pz 11%, Pc 5%; Mz 65%, Pz 11%, Pc 24%). The tectonostratigraphic context for the Early Cretaceous development of the Kahiltna basin would represent a remnant ocean basin setting where detritus was being transported from the along-strike suture between the Wrangellia composite terrane and Intermontane belt. The final stage of basin development was characterized by continued Early to Late Cretaceous exhumation in the Intermontane belt with relative decreased in Mesozoic detrital contributions from the Wrangella composite terrane (Mz 19%, Pz 22%, Pc 59%). In the final stage of this collisional model, the Kahiltna assemblage was likely transitioning from a remnant ocean basin setting to the initial stages of a Late Cretaceous peripheral foreland basin and/or strike-slip basin.

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