U/PB DETRITAL ZIRCON STUDY OF THE UPPER CRETACEOUS TO MIOCENE STRATA OF KODIAK ISLAND, ALASKA

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INTRODUCTION

U/Pb zircon dating is a reliable and widely used method for constraining the maximum deposition age for poorly fossiliferous units, and for understanding the derivation of source materials in sedimentary units (Gehrels, 2012). We collected and used U/Pb geochronology on rock samples of the sedimentary and metasedimentary formations on Kodiak Island in Alaska to understand the progression and evolution of source rocks for the Cretaceous-Tertiary Chugach-Prince William terrane in south-central Alaska.

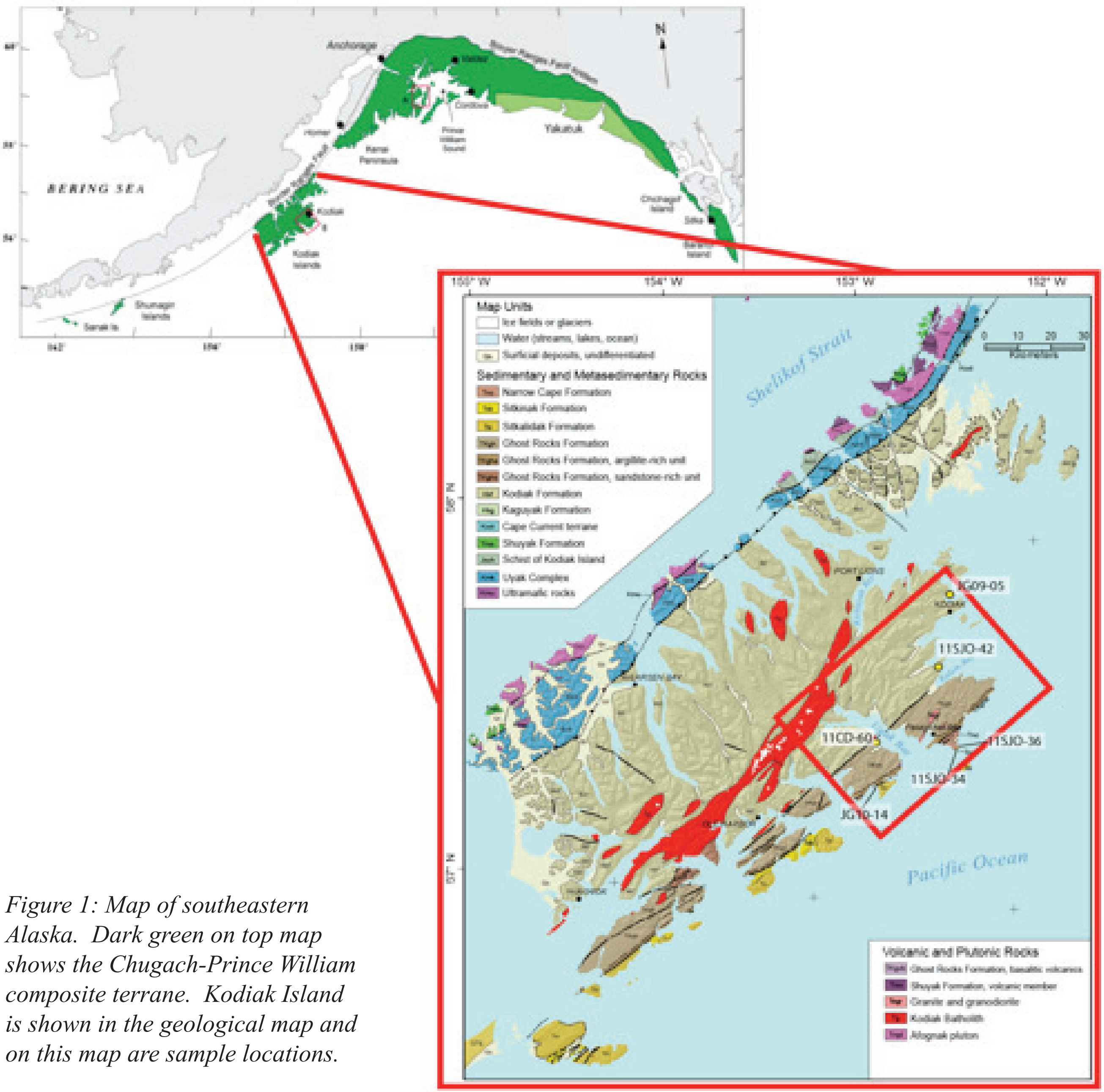

Figure 1: Map of southeastern Alaska. Dark green on top map shows the Chugach-Prince William composite terrane. Kodiak Island is shown in the geological map and on this map are sample locations.

Regional Tectonic Setting

The Chugach-Prince William (CPW) terrane is a composite terrane that represents a 2200 km long Campanian, Maastrictian, to Paleocene accretionary complex that includes metamorphic rocks, some volcanic rocks, mudstone, chert, and sandstone (Plafker et al., 1994). On Kodiak Island, the Maastrictian Kodiak Formation is in structural contact with the Paleocene Ghost Rocks. The Kodiak Formation is separated from inboard rocks of the Peninsular terrane by the Border Ranges fault (Pavlis and Roeske, 2007). Both the Kodiak Formation and Ghost Rocks were intruded by Paleocene magmatic belts (mainly around 59 Ma) (Farris et al., 2006). The Kodiak batholith intruded the Kodiak Formation of the Chugach terrane, and the trenchward belt intruded the Ghost Rocks of the Prince William terrane (Farris et al., 2007). Outboard of the Ghost rocks are turbidites of the Sitkalidak Formation, and this is unconformably overlain by the Miocene Narrow Cape Formation (see Clendenen et al., 2003).

The translation history of the CPW shows evidence of coast-parallel translation along its boundary as revealed by paleomagnetic anomalies and geologic evidence (see Cowan et al., 2003). Clendenen et al. (2003), however, argued that cooling ages imply no strike-slip translation. The Ghost Rocks paleomagnetic data and the tracing of magmatism produced by the Sanak-Baranoff belt infers that Kodiak Island traveled about 1400 to 2000 km north to where it is now from where it was since the Paleocene (Cowan et al., 2003).

U/Pb Detrital Zircon Dating

Zircon ($ZrSiO_4$) has many properties that are ideal for dating. Zircon is plentiful in a large range of rock types (Johnston et al., 2008), and also has a high amount of uranium (U) and very low amount of Pb during crystallization (Gehrels, 2012). Zircon, because of its high uranium concentration plays a fundamental part in the U-Pb decay system (Davis, Historical Development of Zircon Geochronology). Uranium-lead dating relies on a paired decay system because there are two primary isotopes: ^{238}U that decays to ^{206}Pb and ^{235}U that decays to ^{207}Pb.

Zircon is resistant to physical and chemical weathering and the mineral is able to document numerous growth and high-temperature episodes of Pb-loss because of its high closure temperature verses the dispersion of Pb. Thus, zircon retains most parent or daughter isotopes, and restricts their mobility making zircon an ideal closed system.

U/Pb detrital zircon ages are usually determined by one of the three following methods. First is *Isotope Dilution-Thermal Ionization Mass Spectrometry (ID-TIMS)* which yields the most precise ages (~0.1% at 2 σ) of the zircon grain as a whole, but is time con-

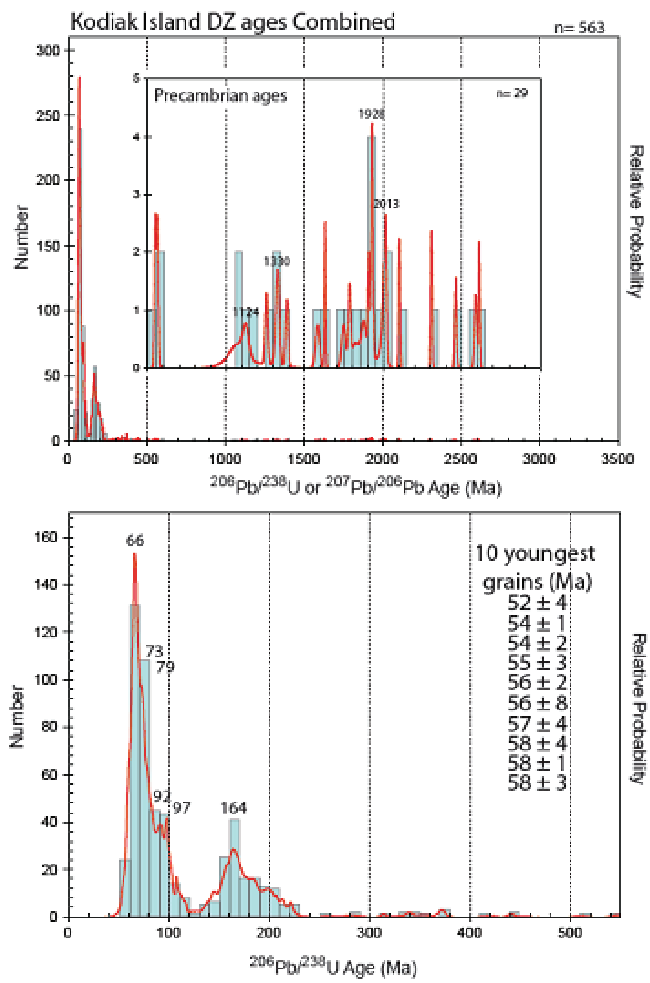

Figure 2: Probability Density plot (red line) and histogram (blue bars) showing age distribution of combined data. Top highlights oldest Precambrian grains (n=29), and bottom shows youngest peaks produced with a list of the 10 youngest grains collected. Figure by Hannah Hilbert-Wolf.

suming and has to be conducted in a clean lab (Gehrels et al., 2010). *Secondary Ion Mass Spectrometry (SIMS or Ion Probe)* is another technique used to date U/Pb zircons and this method is performed on a polished crystal surface held in place by epoxy, and uses standard zircon samples of the same known age in addition to the unknown samples (Gehrels et al., 2010). This method is not as precise as ID-TIMS, but still very accurate (~1.2% at 2sigma) using a beam with a diameter of 10-35μ and about 1μ pit depth (Gehrels et al., 2010). SIMS would best be used when dating a zircon crystal that is more intricate and has a high spatial resolution requisite (Gehrels et al., 2010). In this zircon study, we used *Laser-Ablation Inductively coupled Plasma Mass Spectrometry (LA-ICPMS)*. The methodology of LA-ICPMS is very similar to SIMS, and the precision is the same (~2% at 2 σ); however, a beam with a 10-50μ diameter at about 12μ pit depth is used, so the resolution is not as high (Gehrels et al., 2010). The primary advantage is that many more detrital zircons can be analyzed using LA-ICPMS (~40 grains per hour) compared to ID-TIMS (1 grain/hr) and SIMS (4 grains/hr). A drawback to using LA-ICPMS is the large Ar gas flow rates plasma ionization requires at high temperature and atmospheric pressure (Gehrels et al., 2010). This situation interferes with the ^{204}Pb by causing high Pb and Hg background counts (Gehrels et al., 2010).

METHODS

The stratitgraphic units sampled on Kodiak Island include the Maastriction Kodiak Formation, Paleocene Ghost Rocks Formation, Upper Eocene Sitkalidak Formation, Oligocene Sitkinak Formation, and the Miocene Narrow Cape Formation. We collected six samples (one per formation) of medium- to coarse-grained sandstones and a conglomerate. Before zircons were sent to the Arizona LaserChron Center for mounting and polishing, each sample was crushed and ground, then zircons were separated using standard techniques in order to segregate the zircons from each sample (Bernet and Garver, 2005). Once the zircons were separated, they, along with the Sri Lankan and Baintree Complex zircon standards, were mounted in a one inch epoxy diameter disc (Gehrels et al., 2008). Backscattered electron (BSE) images are taken of the grains (at Carleton College) and used to map and label which zircon grain was analyzed (Figure 2).

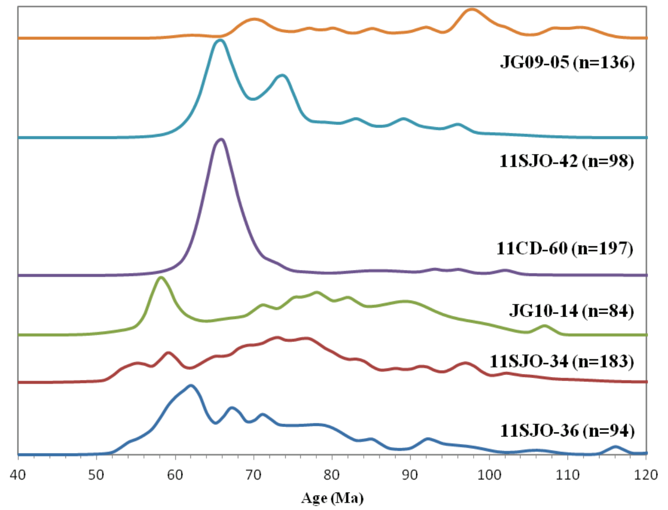

Figure 3: Grain age distribution of all zircon analyzed in this study. These units were individually mixed to produce an estimate for the sedimentary provenance of the middle Miocene Narrow Cape Formation. Relative probability on the y-axis.

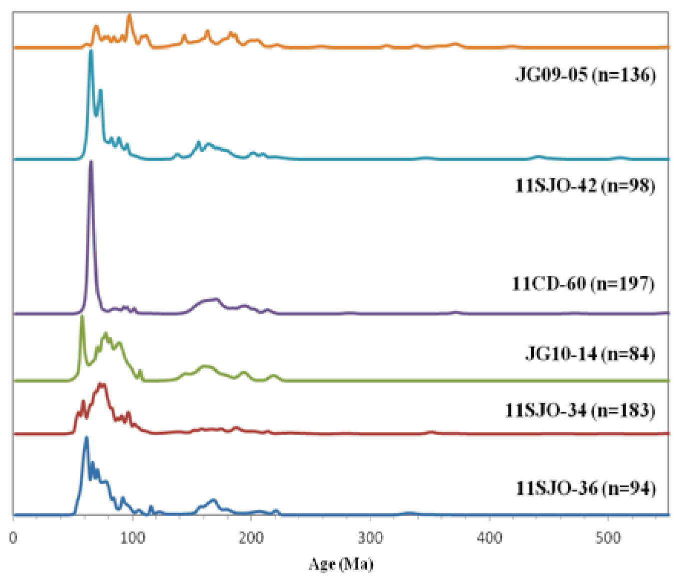

Figure 4: Probability Density plot verses age of selected DZ age distributions (oldest sample top to youngest sample bottom). Top shows ages in the Phanerozoic.

In total, about 100 grains from each sample were analyzed. Random selections of clusters of five zircon grains (using a random walk from a starting point) were ablated one at a time with a standard Sri Lanka sample in between each group of five unknowns. The Sri Lanka standard was analyzed between every five grains to calibrate machine response. The unknown grains were analyzed randomly in an effort to cover

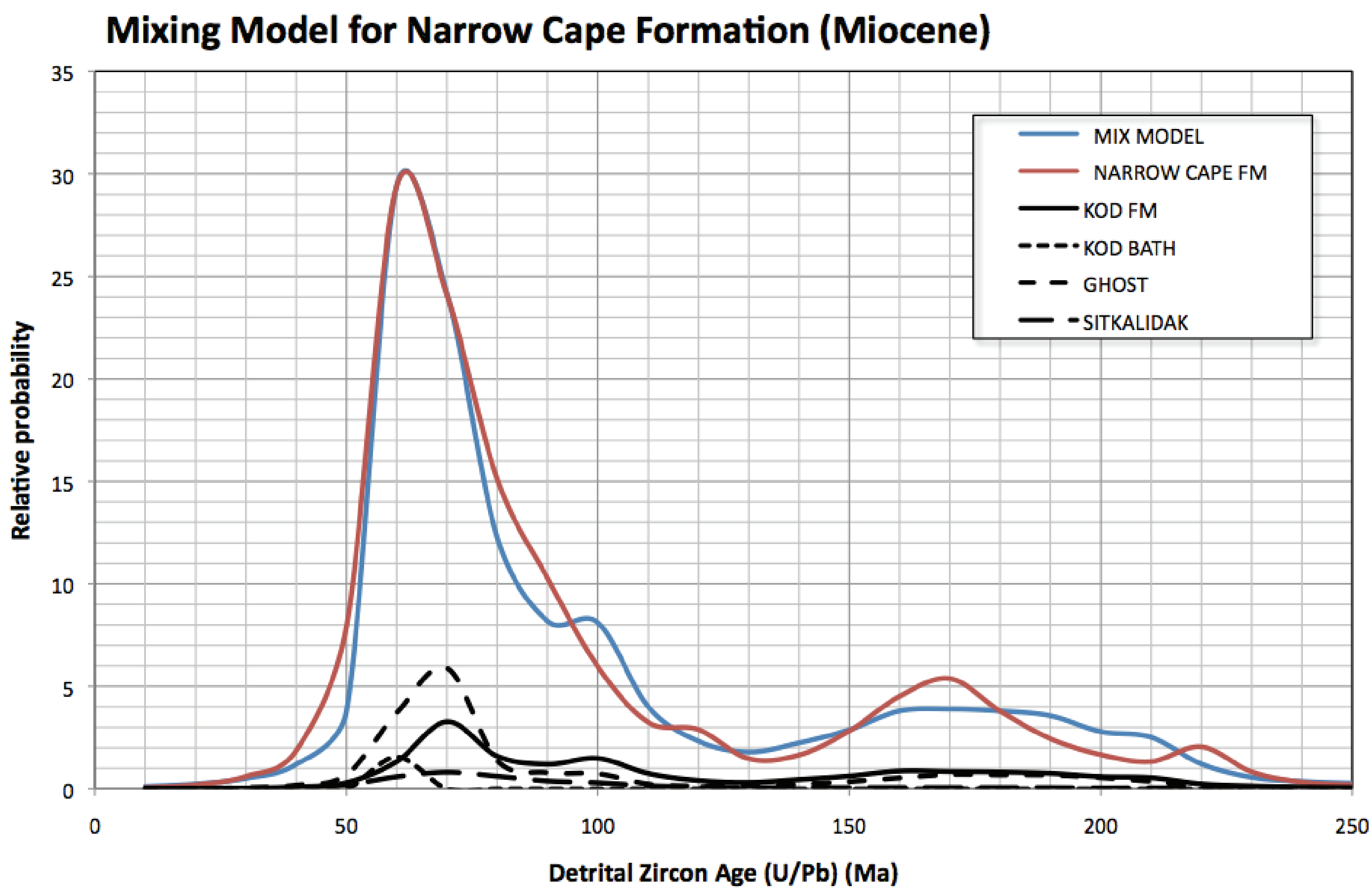

Figure 5: Zircon mixing model for the Miocene Narrow Cape Formation. The observed grain-age distribution (blue) is modelled (red) by mixing Kodiak Formatin (12%), Ghost Rocks (5%), Kodiak Batholith (42%) and Sitkalidak Formation (41%). This pattern cannot be matched without using a significant amount of recycled zircon from the adjacent Sitkalidak Formation.

all present age concentrations and remove any bias from data collection. The ratio we recorded for the unknown grains is $^{238}U/^{207}Pb$, and for the Sri Lanka samples we measure the $^{206}Pb/^{207}Pb$ ratio. We record $^{238}U/^{207}Pb$ for the unknowns in order to produce an age roughly around its initial ratio but for all grains greater than 1.0 Ga, the $^{206}Pb/^{207}Pb$ age is generally reported (Johnston, et al., 2008). After sample analyses, the data were transferred into an Excel macro and spreadsheet. The programs calculate different age populations and significant age peaks with a minimum of three common analyses (Johnston et al., 2008); data probability density plot, histograms, and Concordia plots.

To analyze whether the Narrow Cape Formation was derived by mixing the older units, the probability density plots of the Kodiak, Ghost Rocks, Sidkalidak, Narrow Cape, and Kodiak Batholith (ages from Farris et al., 2007) were combined and normalized to calculate a mixing model. To evaluate success of this model, the residual sum of the result and the observed grain-age pattern were minimized in the estimation models. By calculating the smallest residual sum, we can determine which model or hypothesis best fits the data.

RESULTS

As expected for detrital suites of zircon grains, each sample yields wide ranging ages, and in this case from about 55 Ma to 2306 Ma (Figure 3). The youngest population of grains in the Kodiak Formation (Camp-Maastrictian) yields a young component of grain ages of 63-64 Ma, with other prominent peaks ranging from 70 to 371 Ma. The Kodiak Formation includes Precambrian peaks ranging from 1199 Ma to 2306 Ma.

The tectonically adjacent but more outboard Ghost Rocks Formation (probably Paleocene) contains grains primarily in the Cretaceous to early Triassic, but with a prominent youngest population at 63-64 Ma in one sample from Ugak Bay and Precambrian grains in this unit yield peaks ranging from 1038 Ma to 1517 Ma.

The more outboard Sitkalidak Formation (Upper Eocene) has youngest grains between 53-54 Ma, young populations of 55 Ma and 59 Ma and this unit also yields older component ages of 69 Ma to 235 Ma, and 11 Precambrian grains with peaks at 1013 Ma, 1058 Ma, and 1989 Ma. The Miocene Narrow Cape Formation lies unconformably above the Sitkalidak Formation and is the youngest of the rocks collected in the section. Although this shallow marine unit is predominately composed of sandstones, it also contains minor conglomerates that have clasts of sandstones and granites. We assume that the provenance was probably of the nearby and adjacent Kodiak Formation, Ghost Rocks Formation, and Kodiak Batholith. This formation has youngest grains between 54-56 Ma, much older than its know depositional age of Middle Miocene. It has prominent grain-age populations in the Paleocene, mid-Cretaceous, mid-Jurassic, and early Triassic: the youngest coherent component is 62 Ma, with the oldest population at 221 Ma. These data show that in most cases a maximum age deposition for each of these formations can be constrained through detrital zircon dating. The mixing model from the Narrow Cape Formation required use of a significant component of Sitkalidak Formation, as well as Ghost Rocks Formation, Kodiak Formation, and the Kodiak Batholith.

DISCUSSION

These data show that in most cases a maximum depositional age for each of these formations can be constrained by these detrital zircon ages. A key distinctive attribute of these data is that older formations (Kodiak) contain a significant number of Precambrian grains, which may mean they were derived from a broader source area and these Precambrian ages are consistent with a general northern Laurentian source.

Key points from these data are:

1) Young zircon populations compare well to the depositional age for the Kodiak and Ghost Rocks. The closeness of young population to age of deposition would suggest that an active volcanic source fed the accretionary complex. Similar results come from the age-correlative Valdez Group near Anchorage (Kochelek et al., 2009) and the Orca Group (Hilbert-Wolf, this volume).

2) The Kodiak Formation and the Ghost Rocks may have a common source terrain because there is similarity in peak ages, but if this is the case, the volcanic carapace to the volcano-plutonic dominated later (Ghost Rocks) and the contribution from diverse terrains (older than Cretaceous) decreased through time. This source is compatible with the evolution of the Coast Range (Gehrels et al., 2009), which is also similar to models based on sandstone composition and chemistry (Nilsen and Zuffa, 1982; Sample and Ried, 2003).

3) Precambrian grains, especially common in the older Kodiak Formation, are mainly around 1900 to 2000 Ma, and 1124 and 1330 Ma, and these are broadly consistent with grains derived from western Laurentia, and could have a number of different possible source terrains.

4) The distribution of detrital zircons in the Narrow Cape Formation can be modeled using adjacent units. This unit must be locally derived.

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