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**U-Pb and Hf isotopic analyses of detrital zircons from the
Taku terrane, southeast Alaska**

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Abstract

The Taku terrane consists of metamorphosed Carboniferous through Triassic marine clastic strata, volcanic rocks, and limestone which occur along the western margin of the Coast Mountains in southeastern (SE) Alaska. These rocks are juxtaposed along mid-Cretaceous thrust faults over Jura-Cretaceous basinal strata of the Gravina belt to the west and beneath Proterozoic through Carboniferous metamorphic rocks of the Yukon-Tanana terrane to the east. This paper presents U-Pb ages and Hf isotope analyses of detrital zircons from the Taku terrane, and compares these values with information from the adjacent Wrangellia, Alexander, and northern and southern portions of the Yukon-Tanana terrane (YTTn and YTTs). These comparisons suggest that: (1) Carboniferous strata of the Taku terrane were shed mainly from mid-Paleozoic igneous rocks of YTTs; (2) Permian strata of the Taku terrane were shed from mid-Paleozoic igneous rocks and intraformational Lower Permian volcanic rocks of YTTs as well as Upper Permian volcanic rocks exposed in YTTn; and (3) Triassic sandstones were shed from mid-Paleozoic igneous rocks of YTTs, whereas conglomerates were shed mainly from mid-Paleozoic arc rocks in YTTn. Hf isotope analyses of Paleozoic zircons record increasing continental input during Silurian-Devonian and Permian phases of magmatism. Similarities in isotopic characteristics, combined with stratigraphic and geochemical information presented by previous workers, suggest that strata of the Taku terrane accumulated on (and partly as lateral equivalents of) rocks of YTTs, and that the combined assemblages formed outboard or along strike of YTTn.

Keywords: Taku terrane, Tectonics, U-Pb geochronology, Hf isotope geochemistry

50 Introduction

51 The Taku terrane consists of upper Paleozoic-lower Mesozoic metavolcanic and
52 metasedimentary rocks that occur along the western margin of the Coast Mountains in
53 southeastern (SE) Alaska and coastal British Columbia (Berg et al. 1978; Monger and
54 Berg 1987; Fig. 1). These rocks occupy a critical position in the northern Cordillera
55 because they occur between inboard rocks of the Yukon-Tanana and Stikine terranes,
56 which are thought to have formed along the Cordilleran margin, and outboard rocks of
57 the Alexander and Wrangellia terranes that apparently formed in the paleo-Arctic ocean
58 basin (Nelson et al. 2013). The nature, age, and location of this fundamental native-exotic
59 terrane boundary has been controversial because it is uncertain whether rocks of the Taku
60 terrane correlate with inboard units of the Yukon-Tanana or Stikine terranes versus
61 outboard units of the Alexander or Wrangellia terranes.

62 Determining the nature, age, and location of this tectonic boundary is challenging
63 because the Taku terrane is presently bounded on both sides by regionally continuous
64 mid-Cretaceous thrust faults (Figs. 1 and 2; Rubin et al. 1990; Rubin and Saleeby, 1991,
65 1992; McClelland et al. 1991, 1992; Gehrels et al. 1992; Saleeby 2000), and stratigraphic
66 continuity with adjacent assemblages has nowhere been documented. In much of SE
67 Alaska, the Taku terrane is structurally overlain by rocks of the Yukon-Tanana terrane,
68 which is bound to the east by the Stikine terrane. Toward the west, Taku strata are thrust
69 westward over Upper Jurassic-Lower Cretaceous strata of the Gravina belt, which
70 depositionally overlie Paleozoic and upper Mesozoic rocks of the Alexander and
71 Wrangellia terranes (Figs. 1 and 2).

This study examines potential connections between the Taku terrane and adjacent Alexander, Wrangellia, and Yukon-Tanana, and Stikine terranes using U-Pb ages and Hf isotope signatures of detrital zircons. New data from the Taku terrane, presented herein, includes 673 U-Pb ages and 165 Hf isotope analyses from six samples that were collected from the length of SE Alaska (Fig. 1). These data are compared with new data sets from the Wrangellia terrane (Beranek et al. 2014; Ruks 2015; Gehrels and McClelland, written communication, 2015), Alexander terrane (Beranek et al. 2012, 2013a, 2013b; Tochilin et al. 2014; White et al. 2015) and Yukon-Tanana terrane (Pecha et al. 2016).

Geology and U-Pb geochronology of the Taku Terrane

The Taku terrane has been studied in most detail between Juneau and Petersburg by Gehrels et al. (1992) and in the Ketchikan area by Rubin and Saleeby (1991, 1992) and Saleeby (2000). Glacial fjords in these areas provide spectacular exposures of the units, which generally dip moderately eastward such that strata become younger eastward. As described below, with emphasis on protolith features, three distinct stratigraphic components have been characterized (Fig. 3).

The oldest unit in the terrane consists of volcanic-rich metagreywacke layers that are interbedded with metavolcanic rocks of mainly mafic-intermediate composition and, near the base of the sequence, felsic metatuffs. Interlayered marble and metaclastic quartzites occur locally. These rocks are referred to as the Windham Group in the Juneau area (Gehrels et al. 1992) and part of the Alava Sequence in the Ketchikan area (Rubin and Saleeby 1991, 1992; Saleeby 2000). The age of these strata is constrained by the occurrence of mainly 387-369 Ma detrital zircons in a sample of metagreywacke near the

top of the sequence (Gehrels 2002), and by fossils of Permian age in strata of the overlying Gastineau Group (Gehrels et al. 1992). Saleeby (2000) reported Precambrian U-Pb and Pb-Pb ages for a multigrain fraction of detrital zircons from a quartzite layer in the lower part of the unit.

The Windham Group grades upsection into a thick sequence of mafic metavolcanic rocks, marble, and minor metagreywacke, pelitic phyllite and schist, and metaclastic quartzite which are assigned to the Gastineau Group. Pillows and fragmental textures are well preserved in the metavolcanic rocks, and Permian fossils have been reported in the marbles (Buddington and Chapin 1929; Berg et al. 1988; Rubin and Saleeby 1991, 1992; Gehrels et al. 1992; Saleeby 2000). Geochemical analyses of the mafic metavolcanic rocks suggest that they are high-magnesian alkaline to ocean-island basalt in composition (Brew and Ford 1993; Gehrels and Barker, 1993; Stowell et al. 2000).

Rocks of the Gastineau Group are unconformably overlain by Middle and Upper Triassic strata that belong to the Perseverance Group (Fig. 3). This unit consists mainly of metamorphosed black siliceous and carbonaceous shale interlayered with massive and pillowed basalt flows, as well as minor limestone, chert, and conglomerate. Fossils from these strata range from Anisian (Middle Triassic) through Carnian and perhaps Norian (Upper Triassic; Gehrels et al. 1992). Gehrels (2002) reported mainly 364-349 Ma and a few Precambrian ages from a sample of metaconglomerate from the upper Perseverance Group. Geochemical analyses of Perseverance Group metavolcanic rocks suggest that they are tholeiites of within-plate to inter-arc basin affinity (Brew and Ford 1993; Gehrels and Barker, 1993; Stowell et al. 2000).

117 **Sample Descriptions**

118 Following are descriptions of each of the six samples analyzed for this study and
119 the two samples reported by Gehrels (2002). General locations are shown on Figure 1 and
120 specific locations are reported in DR Table 1. Stratigraphic positions of samples are
121 shown on Figure 3 according to the formation names reported by Gehrels et al. (1992).
122 Figure 4 shows representative outcrop views of each sample from our study and from
123 Gehrels (2002). Although rocks of the Taku terrane are moderately to highly deformed
124 and are metamorphosed to greenschist and locally amphibolite facies, protolith features
125 are well-preserved in most strata and are accordingly emphasized below. Samples are
126 described below in interpreted stratigraphic order, from oldest to youngest.

127 ***Windham Group***

128 Sample 12MP31 was collected from the upper part of the Carboniferous(?)–
129 Permian Windham Group from the south shore of the entrance to Windham Bay. The
130 outcrop consists of graded beds that range from black mudstone to coarse sandstone
131 composed of abundant quartz, feldspar, and volcanic-lithic grains (Fig. 4A). Sample Taku
132 1 was collected from near sample 12MP31, and consisted of very similar volcanic-lithic
133 wacke.

134 ***Gastineau Group***

135 Sample 12MP36 was collected from the Permian Gastineau Group along the
136 northeast shore of Gastineau Channel. The outcrop consists of graded beds of coarse-
137 grained calcareous sandstone and siltstone interlayered with thin horizons of andesitic
138 breccia. The sample analyzed consists of coarse-grained calcareous sandstone with

139 visible quartz grains (Fig. 4B).

140 Sample 12MP11 was collected from the east shore of Carroll Inlet. The outcrop
141 consists of marble and quartzite that are interlayered on a several cm scale (Fig. 4C). The
142 sequence is interpreted to belong to the Gastineau Group given that it occurs in
143 association with a thick sequence of mafic to intermediate metavolcanic rocks of the
144 Taku terrane.

145 Sample 12MP32 was collected from the Gastineau Group from the north shore of
146 Windham Bay. The outcrop sampled consists of meter-thick beds of medium- to coarse-
147 grained metagreywacke (Fig. 4D).

148 *Perseverance Group*

149 Sample 12MP02 was collected from the lower part of the Triassic Perseverance
150 Group from the west shore of Thorne Arm (Fig. 1). The sampled outcrop consists of ~15
151 meters of interbedded sandstone and limestone, layered on a several cm scale (Fig. 4E).
152 The sequence contains distinctive carbonaceous concretions that elsewhere have yielded
153 Middle Triassic fossils (Berg et al. 1988).

154 Sample 12MP37 was collected from near the top of the Perseverance Group of
155 Triassic age along the southeast shore of Taku Inlet. The outcrop sampled both for this
156 unit, and for sample Taku 2, consists of schistose metaconglomerate with abundant clasts
157 derived from many different lithologies, including quartzite, marble, mafic volcanic
158 rocks, and granitoids of variable composition (Fig. 4F). The degree of flattening (and
159 moderate elongation) of clasts varies with rock type, with some granitoid clasts
160 remaining undeformed and measuring up to 20 cm in diameter.

Analytical Methods

Zircon separation was performed at the Arizona LaserChron Center using methods outlined by Gehrels et al. (2008), Gehrels (2012, 2014), and Gehrels and Pecha (2014), including crushing/pulverizing, followed by separation with a Wilfley table, Frantz magnetic separator, and heavy liquids (MI). Grains were mounted in a 1" epoxy mount alongside fragments of Sri Lanka-2 (primary standard) and R33 (secondary standard) zircon. Mounts were polished, imaged using cathodoluminescence (CL) and backscatter electron (BSE) methods, and cleaned with a 2% HNO₃ and 1% HCl solution prior to isotopic analysis. CL and BSE images were utilized to select analytical points, avoiding internal structures, zonation, inclusions, and fractures. Additionally, images reveal grain textures, internal zoning patterns, and variations in CL color response that help interpret the significance of U-Pb ages. DR Table 3 presents CL images of zircon crystals that are representative of the grains analyzed from each sample.

U-Pb and Lu-Hf isotopic analyses of zircon grains were conducted by laser ablation multi-collector inductively coupled plasma mass spectrometry (LA-MC-ICPMS). A 30-micron laser spot was used for U-Pb analyses. Hf analyses utilized a 30- or 40-micron spot that was centered over the pre-existing pit excavated for U-Pb analyses (Gehrels and Pecha 2014). Analyses of unknowns are calibrated relative to concurrent analyses (from the same mount) of common zircon standards (R33, Temora2, Mud Tank, 91500, Plesovice, and FC-1) and solutions containing JMC475 and varying concentrations of Yb and Lu. These standard analyses document that our analyses are accurate to within 2-3 epsilon units. Hf analyses were conducted on grains representative of each of the main age groups in each sample. The average uncertainty of each analysis

is 2.2 epsilon units (at 2σ), with larger uncertainty associated with the use of a 30 micron spot needed to analyze the smaller zircon grains.

U-Pb ages are shown on relative age-probability diagrams, which sum the ages and uncertainty distributions of analyses in a sample (or group of samples) into a single curve, and each curve is normalized according to the number of constituent analyses. This produces an age distribution that is representative of the measured ages in a sample or set of samples. A group of overlapping ages is characterized by the range of constituent ages and the peak(s) in age probability.

Hf isotope data are shown on Hf isotope evolution diagrams, with results plotted according to crystallization age and age-corrected epsilon Hf (ϵHf_t) values. For reference, analyses are shown relative to CHUR (from Bouvier et al. 2008), DM (Vervoort and Blichert-Toft 1999), and the evolution of average continental crust (with present-day $^{176}\text{Lu}/^{177}\text{Hf} = 0.0115$; Vervoort and Patchett 1996; Vervoort et al. 1999). Our Hf isotope data are interpreted within the standard framework of juvenile (positive) values indicating magma derived mainly from material extracted from the mantle during or a short time prior to magmatism, versus more evolved (negative) values recording significant incorporation of older crustal materials. Magmatism that changes through time from juvenile to more evolved values is interpreted to result from increased crustal thickening during orogenesis and/or migration of magmatism into progressively older crust (e.g., Kemp et al. 2009).

U-Pb Geochronologic and Hf isotopic results from the Taku Terrane

Windham Group

Two samples, 12MP31 and Taku 1, have been analyzed from strata in the upper part of the Windham Group. Both samples yield a single group of ages ranging from 412 to 357 Ma, with an age peak of 376 Ma (Fig. 5; DR Table 1). Hf isotope analyses from sample 12MP31 yield ϵHf_t values that range from +16 to -2 (Fig. 6; DR Table 2).

Gastineau Group

Three samples have been analyzed from the Gastineau Group, one from near the base (sample 12MP36), one interpreted to occur near the middle of the sequence (sample 12MP11), and one from near the top (sample 12MP32) of the group (Fig. 3). Four age groups are apparent, with dominant age ranges from 383 to 353 Ma (peak age of 370 Ma), 299 to 279 Ma (peak age of 290 Ma), 272 to 252 Ma (peak age of 261 Ma), and a minor group from 463 to 426 Ma (peak age of 435 Ma). The Permian ages for the younger two groups, together with the presence of Permian fossils in strata of the Gastineau Group, suggest that much of the volcanism in this part of the section is Early and Late Permian in age (according the Time Scale of Cohen et al. 2013).

Hf isotope analyses from zircons in these samples yield ϵHf_t values that change dramatically through time. As shown on Fig. 6, Silurian grains yield juvenile values of +16 to +10; Devonian grains yield values that range from -1 to -13; and Permian grains belong to two distinct clusters of +10 to +5 for Early Permian grains and -4 to -10 for Late Permian grains.

Perseverance Group

Three samples have been analyzed from the Perseverance Group, one (sample 12MP02) from a sandstone from near the base of the sequence, and two (samples

12MP37 and Taku 2) from a metaconglomerate horizon in the upper part of the unit. These samples yield a single dominant age group ranging from 376 to 344 Ma (peak age of 362 Ma) and three smaller groups with peak ages of 273, 256, and 226 Ma. The ~256 Ma age may record Late Permian magmatism in the underlying Gastineau Group, whereas the ~226 Ma grains were probably derived from intraformational volcanic rocks that are known to be Late Triassic in age (Gehrels et al. 1992).

Hf isotope analyses from zircons in these samples yield ϵHf_t values that also change through time. As shown on Figure 6, grains with >380 Ma ages tend to yield juvenile (+12 to +8) ϵHf_t values, whereas <380 Ma grains range from juvenile (e.g., maximum of +12) to highly negative (e.g., minimum of -18) ϵHf_t values.

Potential ties with Wrangellia, Alexander, Stikine, and Yukon-Tanana terranes

Previous workers have suggested that the Taku terrane has primary stratigraphic connections with the Wrangellia, Alexander, Stikine, or Yukon-Tanana terranes (Figs. 1 and 2). Following is an outline of relevant geologic aspects of the adjacent terranes and a comparison of available geologic, U-Pb geochronologic, and Hf isotopic information.

Potential ties with Wrangellia

Connections with Wrangellia were suggested by Plafker et al. (1989) on the basis of a comparison of Triassic strata that occur in the Wrangellia terrane northwest of Skagway (Fig. 1) with very similar rocks near Skagway that Berg et al. (1978) and Monger and Berg (1987) assigned to the Taku terrane. All subsequent work in this region has supported this correlation, resulting in assignment of the Triassic rocks near Skagway

to Wrangellia rather than the Taku terrane (e.g., Gehrels 2000). Extension of this correlation to the southeast has been highly controversial – Brew and Ford (1993) argue that Triassic strata of the Taku terrane to the south also correlate with Wrangellia, and geochemical studies of Taku basalts to the south in SE Alaska (Brew and Ford 1993; Gehrels and Barker, 1993; Stowell et al. 2000) support this correlation. In contrast, Gehrels (2000, 2002) questioned this correlation given that rocks to the southeast have a very different stratigraphic record than the Wrangellia sequence near Skagway (Gehrels 2000) and detrital zircon ages in Triassic strata to the south suggested connections with the Yukon-Tanana terrane (Gehrels 2002).

An independent test of possible Taku-Wrangellia connections is enabled by comparison of our data with U-Pb ages and Hf isotope analyses of detrital zircons from upper Paleozoic or lower Mesozoic sandstones that are interpreted to belong to the Wrangellia terrane (Wheeler et al., 1991; Journeay et al., 2000; Nelson et al., 2013) near the north end of Vancouver Island (Wa on inset map of Figure 1). Gehrels and McClelland (written communication, 2015) have analyzed grains from three different samples, most of which yield U-Pb ages of 355-295 Ma and very juvenile ϵHf_t values (DR Tables 1 and 2; Fig. 7, Wrangellia field “A” in lower panel; Wa on inset map of Figure 1). The lack of overlap with Taku strata indicates that primary connections with at least this part of Wrangellia are unlikely. U-Pb ages of Paleozoic igneous rocks on Vancouver Island (Ruks 2015; field “B” on Figure 7; Wb on inset map of Figure 1) and southwestern Yukon (Gardner et al., 1988; Beranek et al. 2014; Israel et al., 2014; most of field “C” on Figure 7; Wc on inset map of Figure 1) are also mostly younger than ages from Taku strata, and evolved isotopic signatures have not been reported in any previous

273 Nd isotopic studies of rocks from Wrangellia (e.g., Samson et al. 1990; Beranek et al.
274 2014; Ruks 2015).

275 Collectively, the available geochronologic and isotopic data appear inconsistent
276 with primary connections between Taku and Wrangellia terranes.

277 **Potential connections with the Alexander terrane**

278 Connections with the Alexander terrane have been proposed by Brew and Ford
279 (1993) and Gehrels and Barker (1993) on the basis of geochemical ties with Wrangellia,
280 and Pennsylvanian plutonic linkages between Wrangellia and the Alexander terrane (e.g.,
281 Gardner et al. 1988; Beranek et al. 2014; Israel et al. 2014).

282 These potential connections can be evaluated by comparison of our data with
283 results from several recent U-Pb/Hf studies of detrital zircons from the Alexander terrane.
284 As shown on Figure 7, arc-type rocks in the southern (SE Alaska) portion of the terrane
285 yield highly juvenile zircons (White et al. 2015), whereas shelf-facies strata in the
286 northern (Saint Elias Mountains) portion of the terrane yield abundant Precambrian
287 zircons and early Paleozoic zircons with intermediate to evolved ϵHf_t values (Beranek et
288 al. 2012, 2013a, b; Tochilin et al. 2014). The mismatch in age and Hf isotope signature
289 suggests that there is little evidence of primary connections between the Alexander and
290 Taku terranes.

291 **Potential connections with the Stikine terrane**

292 Potential connections between the Taku and Stikine terranes were suggested by
293 Rubin and Saleeby (1991) on the basis of similarities in Triassic stratigraphy. In

particular, both terranes contain similar Middle and Upper Triassic volcanic and sedimentary rocks (although with different stratigraphic records), and also have an unconformity separating Triassic strata from underlying rocks. Although Triassic strata were proposed to have originally been continuous, Rubin and Saleeby (1991) did not favor correlations of upper Paleozoic strata in the two terranes given the presence of metaclastic quartzite horizons in Taku strata.

Unfortunately, no age-Hf data are available from Paleozoic or Triassic strata of the Stikine terrane. The available Nd-Sr data suggest, however, that Stikine consists mainly of juvenile igneous rocks and sediments (Samson et al. 1989), which is inconsistent with the negative ϵHf_t values from Taku.

Potential connections with the Yukon-Tanana terrane

Stratigraphic connections between the Taku and adjacent Yukon-Tanana terranes were originally suggested in the Ketchikan area, where a possible depositional contact between the Taku terrane (Alava Sequence) and Yukon-Tanana terrane (Kah Shakes Sequence) is preserved, and metaclastic quartzite horizons occur in both sequences (Rubin and Saleeby 1991; Saleeby 2000). These connections were supported by U-Pb analysis of a multigrain fraction of zircons from a quartzite layer in the lower part of the Taku terrane (Alava Sequence), which yielded Proterozoic U-Pb and Pb-Pb ages (sample T14 of Saleeby 2000). Additional support was provided by U-Pb analyses of the two detrital zircon samples described above (Taku1 and Taku 2; Gehrels 2002), which yielded mid-Paleozoic and Precambrian ages that overlapped with ages reported in previous studies of YTT igneous rocks and detrital grains.

These potential ties can be re-examined in greater detail given the availability of new age-Hf data from the Yukon Tanana terrane (YTT) in SE Alaska (YTTs; Pecha et al. 2016). An important consideration in evaluating potential connections with the Yukon-Tanana terrane is the interpretation of Saleeby (2000) and Pecha et al. (2016) that YTTs originated outboard or along strike of the main mass of Yukon-Tanana terrane in northern British Columbia, Yukon and eastern Alaska (YTTn) and correlative lower Paleozoic strata in east-central Alaska (NAa). The following discussion accordingly compares data from the Taku terrane with U-Pb/Hf data from YTTs and with U-Pb data from YTTn and NAa.

The oldest rocks in YTT consist of pre-Devonian quartzite, marble, and metapelite of the Tracy Arm assemblage in SE Alaska (Berg et al. 1978; Monger and Berg 1987; Rubin et al. 1991; Gehrels et al. 1991, 1992; Saleeby 2000; Gareau and Woodsworth 2000; Pecha et al. 2016) and the Snowcap assemblage to the north (Mortensen 1992; Dusel-Bacon et al. 2004, 2006, 2013; Colpron et al. 2006; Nelson et al., 2006, 2013; Piercey and Colpron 2009). The occurrence of detrital zircons with mainly Archean, Paleoproterozoic, and Mesoproterozoic U-Pb ages (lower panel of Figure 7), and ϵHf_t values that are typical for northwestern Laurentia passive margin strata as well as nearby basement rocks and overlying platformal strata (upper panel of Figure 7; Gehrels and Pecha 2014), supports previous interpretations that these strata accumulated in a passive margin setting along the northern Cordilleran margin.

The Tracy Arm assemblage grades upsection into mafic to felsic metavolcanic rocks with minor quartzite and metapelite which belong to the Endicott Arm assemblage (Gehrels et al. 1992). U-Pb ages of the metavolcanic rocks, and of metamorphosed

plutons that intrude the Tracy Arm and Endicott Arm assemblages, are mainly 440-360 Ma (McClelland et al. 1991; Gehrels et al. 1992; Saleeby 2000; Gareau and Woodsworth 2000; Gehrels 2001; Pecha et al. 2016). Metaclastic strata also yield abundant Precambrian detrital zircons. εHf_t values from the Paleozoic zircons record two distinctive evolutionary trends from juvenile to evolved values, first during Late Ordovician through Early Devonian time, and again from Middle Devonian through Late Devonian time (Fig. 7). These patterns are interpreted to record a progression from incorporation of mainly juvenile crust during crustal thinning to melting of mainly evolved crust during crustal thickening within the YTT magmatic arc (Pecha et al. 2016). The Finlayson assemblage of YTTn is very similar to the Endicott Arm assemblage, except that magmatism to the north began during Late Devonian time and continued into Early Mississippian time (Colpron et al. 2006; Nelson et al. 2006, 2013).

The Endicott Arm assemblage is overlain unconformably by Carboniferous strata of the Port Houghton assemblage in YTTs. The base of the unit is a polymictic metaconglomerate bearing a wide range of metasedimentary, metavolcanic, and metaplutonic clast types. Overlying the metaconglomerate horizons is a thick sequence of metagraywacke and metapelite layers that are interlayered with mafic and felsic metavolcanic rocks. Sandstones in the Port Houghton assemblage yield grains with Silurian-Devonian ages and juvenile εHf_t values that are similar to those in the Endicott Arm assemblage, whereas conglomerates in the sequence yield Early Mississippian grains with highly negative εHf_t values (Fig. 7). Given that the underlying Endicott Arm assemblage does not contain igneous rocks with such young/evolved grains, Pecha et al. (2016) suggest that the conglomerates were shed from Early Mississippian igneous rocks

of the Finlayson assemblage of YTTn (Fig. 7). Conglomerate-bearing strata of the Klinkit assemblage of YTTn are an excellent match for the Port Houghton assemblage (Colpron et al. 2006; Nelson et al. 2006, 2013).

YTTn also contains three younger assemblages that are not recognized in YTTs. Oldest are Middle Mississippian through Lower Permian mafic volcanic and volcanoclastic rocks and limestone that belong to upper portions of the Klinkit Assemblage. These rocks are overlain by Middle and Upper Permian felsic and minor mafic igneous rocks of the Klondike Assemblage, which are interpreted to be largely of crustal derivation (Nelson et al. 2006). Overlying these rocks unconformably are Triassic basinal strata that consist of carbonaceous shale, chert, argillite, limestone, sandstone, polymictic conglomerate, and minor basalt and rhyolite (Nelson et al. 2006; Colpron et al. 2006, Plate 2).

As shown on Figure 7, the available age-Hf data from the Taku terrane and YTTs are remarkably similar, and support the conclusion of Rubin et al. (1991), Saleeby (2000), and Gehrels (2002) that the lower part of the Taku terrane is correlative with the upper part of YTTs, and that younger strata of the Taku terrane accumulated on top of YTTs. With this configuration, the combined YTTs and overlying Taku terrane are interpreted to be very similar to the Yukon-Tanana terrane to the north. This linkage yields the following interpretations for provenance of detrital zircons in the Taku terrane:

(1) Zircon grains in Windham Group strata are interpreted to have been shed mainly from juvenile to intermediate igneous rocks of Middle and Late Devonian age in the Endicott Arm assemblage of YTTs and perhaps Finlayson assemblage of YTTn. Given

the similar lithic components (e.g., fine-grained marine clastic strata and subordinate layers of basalt, felsic tuff, and metaclastic quartzite), it is likely that the lower part of the Windham Group is equivalent to the upper part of the Port Houghton assemblage (as shown on Figure 3). The combined Port Houghton assemblage and Windham Group are very similar to upper Paleozoic strata of the Klinkit assemblage of YTTn.

(2) Zircon grains from the Gastineau Group are interpreted to have been shed from four different sources, including: (A) juvenile igneous rocks of Silurian-Early Devonian age in the Endicott Arm assemblage of YTTs; (B) highly negative Late Devonian to Early Mississippian igneous rocks in the Finlayson assemblage of YTTn; (C) Lower Permian volcanic rocks of juvenile to intermediate Hf isotopic composition that occur in the lower Gastineau Group of YTTs and/or upper Klinkit assemblage of YTTn; and (D) Upper Permian volcanic rocks of evolved Hf isotopic composition that occur in the upper Gastineau Group and/or the Klondike assemblage.

(3) Zircon grains in the Perseverance Group are interpreted to have been shed (with likely recycling) in part from the Tracy Arm and Endicott Arm assemblages of YTTs and/or the Snowcap and Finlayson assemblages of YTTn. Most grains, however, were shed from latest Devonian to Early Mississippian igneous rocks with highly negative ϵHf_t values, which appear to also have been the source of conglomerates in the Port Houghton assemblage (Fig. 7). Given that the Endicott Arm assemblage is not a viable source for zircons with this young age and evolved Hf isotope signature, it is likely that conglomerates in both the Perseverance Group and the Port Houghton assemblage were shed mainly from the Finlayson assemblage of YTTn. Strata of the Perseverance Group are interpreted to have been lateral equivalents of similar Triassic strata in the upper part

of YTTn (Colpron et al. 2006; Nelson et al. 2006) which belong to a clastic wedge and overlap assemblage that records accretion of YTT along the northern Cordilleran margin (Beranek and Mortensen 2011).

Summary and Conclusions

Our new U-Pb ages and Hf isotope signatures from detrital zircons in the Taku terrane of SE Alaska yield important new information about the provenance of clastic strata, the petrogenesis of igneous rocks in source terranes, and the nature of primary connections with the Yukon-Tanana terrane in SE Alaska and to the north.

U-Pb ages of detrital zircons from the Taku terrane are mainly Silurian through Early Mississippian in age, with subordinate groups of Precambrian, Early Permian, and Late Permian age (Fig. 5). Hf isotope signatures of the dated grains are highly variable, with ϵHf_t values that range from +15 to -20 (Fig. 5). Mid-Paleozoic grains record an important change from juvenile to evolved ϵHf_t values (Fig. 6), which is interpreted to record increasing incorporation of older continental material during magmatism primarily due to crustal thickening. A similar progression is recorded during Permian time, with juvenile to intermediate values during Early Permian time and more negative values during Late Permian time (Fig. 6).

Stratigraphic relations described by previous workers (Rubin and Saleeby 1991; Gehrels et al. 1992; Saleeby 2000), combined with the relationships described above, provide strong evidence for primary connections between the Taku terrane and the adjacent Yukon-Tanana terrane (YTTs). The strongest isotopic evidence arises from the similarity of ϵHf_t patterns in mid-Paleozoic zircon grains from the two terranes. As

shown in Figure 7, both terranes display a progression from juvenile to more evolved values from Silurian to Early Mississippian time, but the larger data set from Yukon-Tanana (from Pecha et al. 2016) allows this progression to be divided into two separate “pull-downs” from juvenile to more evolved values. The first pull-down is exhibited in Late Ordovician-Early Devonian igneous rocks of the Endicott Arm assemblage, and the second pull-down is recorded in the progression from juvenile values in Devonian igneous rocks of the Endicott Arm assemblage to evolved ϵHf_t values in Early Mississippian grains from conglomerates of the Port Houghton assemblage (Fig. 7).

These strong similarities, combined with the available stratigraphic information, suggest that the Taku terrane is stratigraphically linked to the Yukon-Tanana terrane in SE Alaska. As suggested originally by Rubin and Saleeby (1991), the lower part of the Windham Group is interpreted to correlate with the upper part of the Port Houghton assemblage, and overlying Permian and Triassic strata of the Taku terrane are interpreted to have accumulated on these Carboniferous and older strata. This combined history is very similar to that recorded in the Yukon-Tanana terrane of northern British Columbia, Yukon, and eastern Alaska (YTTn; Colpron et al. 2006; Nelson et al. 2006, 2013), where rocks of the Taku terrane are an excellent match with the upper Paleozoic Klinkit and Klondike assemblages and overlying Triassic strata. These correlations support the conclusion of Saleeby (2000) and Pecha et al. (2016) that rocks of the Taku and Yukon-Tanana terranes in SE Alaska (YTTs) may have formed adjacent to, either outboard or along strike of, rocks of the Yukon-Tanana terrane to the north (YTTn).

Interpreted connections between the Taku terrane, YTTs, and YTTn are summarized on Figure 8, based largely on relations described herein for the Taku terrane,

452 Pecha et al. (2016) for YTTs, and Colpron et al. (2006) and Nelson et al. (2006, 2013) for
453 YTTn. Significant aspects of each time slice are as follows, beginning with accumulation
454 of rocks of the Endicott Arm/Finlayson assemblages that underlie strata of the Taku
455 terrane.

- 456 • Middle and Late Devonian time (Fig. 8A): Juvenile magmatism in an extensional
457 environment, recorded in the Endicott Arm (YTTs) and Finlayson (YTTn) assemblages.
458 This marks the final phase of magmatism recorded in the Endicott Arm assemblage, and
459 initial rifting of YTT from the Cordilleran margin.

- 460 • Early to mid-Mississippian time (Fig. 8B): Magmatism continued throughout
461 YTT, with εHf_t values that record a transition to evolved magmatism that is interpreted as
462 a response to crustal thickening. This phase is recorded in conglomeratic strata of the Port
463 Houghton (YTTs) and Klinkit (YTTn) assemblages, which are interpreted to have been
464 shed from widespread Late Devonian-Early Mississippian igneous rocks of YTTn. The
465 Slide Mountain ocean basin was opening in a back-arc position during this time.

- 466 • Middle Mississippian to Early Permian time (Fig. 8C): Juvenile magmatism and
467 basinal sedimentation within the Port Houghton assemblage (YTTs) and the overlying
468 (and partly correlative) Windham Group (Taku terrane). Correlative rocks to the north
469 (YTTn) belong to the Klinkit assemblage.

- 470 • Middle to Late Permian time (Fig. 8D): Evolved magmatism within the Gastineau
471 Group (Taku terrane) and the Klondike assemblage (YTTn) as YTT/Taku approached the
472 Cordilleran margin.

- 473 • Triassic-Early Jurassic time (Fig. 8E): Accumulation of Triassic basinal strata in
474 the Perseverance Group (Taku terrane) and over much of YTTn. Conglomerates in the

sequence may record collision of YTT/Taku with the Cordilleran margin. Triassic basalt flows of extensional origin age are common in the Taku terrane, but not in YTT to the north.

- Late Jurassic-Early Cretaceous (Fig. 8F): Taku/YTTs is interpreted to have moved ~1000 km southward along a sinistral Late Jurassic-Early Cretaceous shear zone, leaving YTTs outboard of the Stikine terrane (Monger et al. 1994; Gehrels et al. 2009; Pecha et al. 2016). This sinistral emplacement model is offered as an alternative to the view that YTTs formed along the western margin of the Stikine terrane and was rotated counter-clockwise to its present position outboard of the Cache Creek terrane (Mihalynuk et al. 1994; Nelson et al. 2013).

- Mid-Cretaceous time (100 Ma; Fig. 8G): Terranes along the western flank of the batholith were imbricated along west-vergent thrust faults during this time (Rubin et al. 1990; Rubin and Saleeby 1991, 1992; McClelland et al. 1991, 1992; Gehrels et al. 1992; Saleeby 2000; Gehrels 2001). This imbrication resulted in the present geometry of an inverted panel of YTTs overlying an upright panel of Taku terrane, which overlies an upright panel of the Gravina belt (Fig. 8G). Plutons of the Coast Mountains batholith were emplaced into this thrust belt.

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- 697

Figure Captions

Figure 1. Sketch map showing location of samples analyzed from the Taku terrane in southeastern Alaska and coastal British Columbia. Geologic relations are adapted from Wheeler and McFeely (1991) and Gehrels and Berg (1992). Inset diagram adapted from Silberling et al. (1992) and Colpron et al. (2006), with YTTs = YTT in SE Alaska; YTTn = YTT in eastern Alaska, Yukon, and northern British Columbia; NAa = peri-cratonic strata in east-central Alaska. AK = Alaska, YK = Yukon, BC = British Columbia, US = continental United States. Wa = Wrangellia strata in southwestern BC that provide U-Pb/Hf data (Gehrels and McClelland, written communication, 2015); Wb = volcanic and clastic strata of Wrangellia on southern Vancouver Island that have been analyzed for U-Pb ages by Ruks (2015); Wc = plutonic rocks of northern Wrangellia that have been analyzed for U-Pb ages by Beranek et al. (2014) and Israel et al. (2014).

Figure 2. Schematic columns summarizing ages of assemblages in the Taku, Wrangellia, Alexander, Yukon-Tanana, and Stikine terranes. Adapted from Gehrels (2002). Vertical dark lines represent mid-Cretaceous thrust faults that bound the Taku terrane. Wavy horizontal lines represent unconformities. Groups within Taku and assemblages within YTTs are from Gehrels et al. (1992); assemblages within YTTn are from Colpron et al. (2006) and Nelson et al. (2006).

Figure 3. Schematic columns showing stratigraphy and interpreted sample positions for strata of the Taku terrane (adapted from Gehrels et al. 1992). Samples with “12MP” in the label are from this study; data for samples Taku 1 and Taku 2 were reported by Gehrels (2002).

Figure 4. Photographs of sampled lithologies. A: Coarse-grained metagreywacke of the

upper Windham Group. Samples 12MP31 and Taku 1 were collected from coarse-grained sandstone horizons within these graded beds. B: Quartz-rich metagraywacke horizon in the lower part of the Gastineau Group. Sample 12MP36 was collected from this horizon. C: Interlayered marble (recessive layers) and metaclastic quartzite (resistant layers) interpreted to belong to the Gastineau Group. Sample 12MP11 was collected from the quartzite layers. D: Metagraywacke in the upper part of the Gastineau Group, collected as sample 12MP32. E: Interlayered sandstone and carbonaceous shale of the lower Perseverance Group at sample locality 12MP02. F: Metaconglomerate in the upper portion of the Perseverance Group. Clasts include metaplutonic rocks of felsic to intermediate composition, felsic and mafic metavolcanic rocks, marble, orthoquartzite, and coarse- to fine-grained metasedimentary rocks. Clasts are highly flattened and moderately elongated, with original diameters up to 20 cm. The matrix is metasandstone. Samples 12MP37 and Taku 2 were both collected from this metaconglomerate horizon, and included both clasts and matrix.

Figure 5. Normalized age-distribution diagrams for detrital zircon grains from the Taku terrane. The number of constituent analyses is shown for each sample. Ages shown are the local maxima in age probability.

Figure 6. U-Pb and Lu-Hf isotopic data from samples of the Taku terrane. Lower panel shows U-Pb age distributions from Figure 5; upper panel shows ϵHf_t values. The average uncertainty of analyses reported herein is 2.2 epsilon units (at 2-sigma). DM = depleted mantle (Vervoort and Blichert-Toft, 1999), CHUR = chondritic uniform reservoir (Bouvier et al., 2008), average crustal evolution assumes present-day $^{176}\text{Lu}/^{177}\text{Hf} = 0.0115$ (Vervoort and Patchett, 1996; Vervoort et al., 1999). Note that >500 Ma portions

of age-distribution curves have 10x vertical exaggeration.

Figure 7. U-Pb and Lu-Hf isotopic data from samples of the Taku terrane (from Figure 6) and the Wrangellia, Alexander, and Yukon-Tanana terranes. Data from Wrangellia include (A) U-Pb and Hf data from detrital zircons in upper Paleozoic-lower Mesozoic strata of Wrangellia (Wheeler et al. 1991; Journeay et al., 2000; Nelson et al. 2013) near the north end of Vancouver Island (Gehrels and McClelland, written communication, 2015), (B) U-Pb ages from upper Paleozoic igneous rocks of southern Wrangellia (Ruks 2015); (C) U-Pb ages from igneous rocks near the north end of Wrangellia (Gardner et al. 1988; Beranek et al. 2014; Israel et al. 2014). U-Pb and Hf data from the Alexander terrane are from the northern portion of the terrane (SEM = Saint Elias Mountains; Beranek et al. 2012, 2013a, 2013b) and the southern portion of the terrane (SE AK = SE Alaska; White et al. 2015). A bar showing the timing of mid-Paleozoic magmatism of the northern Stikine terrane is from Plate 2 of Colpron et al. (2006) and from Gunning et al. (2006). Data for YTTs are from Pecha et al. (2016). U-Pb data shown for YTTn/NAa include all available detrital and igneous ages (light purple shading; from compilation of Pecha et al. 2016), igneous ages in YTTn (medium purple shading; from Figure 4 of Nelson et al. 2006), and igneous ages in NAa (dark purple shading; from Figure 4 of Nelson et al. 2006). Note that >650 Ma portions of age-distribution curves have 10x vertical exaggeration.

Figure 8. Schematic model showing interpreted history of the Yukon-Tanana and Taku terranes, based on relations described herein and by Colpron et al. (2006), Nelson et al. (2006, 2013), and Pecha et al. (2016). The Yukon-Tanana terrane is divided into YTTs (SE Alaska) and YTTn (eastern Alaska, Yukon, northern British Columbia), with

correlative lower Paleozoic rocks in east-central Alaska shown as NAa (from Figure 1 of Colpron et al. 2006). YTTs consists of the Tracy Arm, Endicott Arm, and Port Houghton assemblages. YTTn includes the Snowcap, Finlayson, Klinkit, and Klondike assemblages and overlying Triassic strata. The Taku terrane consists of the Windham, Gastineau, and Perseverance groups. The Gravina belt consists of the Seymour Canal, Douglas Island, and Treadwell formations (Gehrels et al. 1992; Gehrels 2000; Yokelson et al. 2015). Volcano symbols with black tops represent juvenile magmatism; symbols with gray tops represent evolved magmatism. Double arrows represent relative plate motions (from Engebretson et al. 1985). See text for explanation.

DR Table 1 (Table and plots with Taku terrane U-Pb data)

DR Table 2 (Table and plots with Taku terrane Hf data)

DR Table 3 (Images of petrography, zircon grains, and CL response of representative grains from each sample).

Figure 1 (map)

Figure 2 (Terrane Columns)

Figure 3 (Strat Columns b&w)

Figure 3 (Strat Columns)

Figure 4 (photos)

Figure 4 (photos)

Figure 5 (Taku U-Pb plot)

Figure 6 (Taku Hf plot)

Figure 7 (Taku-WR-AX-YTT U-Pb & Hf)

Figure 8
(Tectonic Model)