Detrital zircon geochronology of quartzose metasedimentary rocks from parautochthonous North America, east-central Alaska

Cynthia Dusel-Bacon¹, Christopher S. Holm-Denoma², James V. Jones III³, John N. Aleinikoff³, and James K. Mortensen⁴

¹U.S. GEOLOGICAL SURVEY, GEOLOGY, MINERALS, ENERGY, AND GEOPHYSICS SCIENCE CENTER, 345 MIDDLEFIELD ROAD, MENLO PARK, CALIFORNIA 94025, USA
²U.S. GEOLOGICAL SURVEY, CENTRAL MINERAL AND ENVIRONMENTAL RESOURCES SCIENCE CENTER, DENVER FEDERAL CENTER, DENVER, COLORADO 80225, USA
³U.S. GEOLOGICAL SURVEY, ALASKA SCIENCE CENTER, 4210 UNIVERSITY DRIVE, ANCHORAGE, ALASKA 99509, USA
⁴DEPARTMENT OF EARTH, OCEAN, AND ATMOSPHERIC SCIENCES, UNIVERSITY OF BRITISH COLUMBIA, VANCOUVER, BRITISH COLUMBIA V6T 1Z4, CANADA

ABSTRACT

We report eight new U-Pb detrital zircon ages for quartzose metasedimentary rocks from four lithotectonic units of parautochthonous North America in east-central Alaska: the Healy schist, Keevy Peak Formation, and Sheep Creek Member of the Totatlanika Schist in the northern Alaska Range, and the Butte assemblage in the northwestern Yukon-Tanana Upland. Excepting 1 of 3 samples from the Healy schist, all have dominant detrital zircon populations of 1.9–1.8 Ga and a subordinate population of 2.7–2.6 Ga. Three zircons from Totatlanika Schist yield the youngest age of ca. 780 Ma. The anomalous Healy schist sample has abundant 1.6–0.9 Ga detrital zircon, as well as populations at 2.0–1.8 Ga and 2.7–2.5 Ga that overlap the ages from the rest of our samples; it has a minimum age population of ca. 1007 Ma.

Detrital zircon age populations from all but the anomalous sample are statistically similar to those from (1) other peri-Laurentian units in east-central Alaska; (2) the Snowcap assemblage in Yukon, basement of the allochthonous Yukon-Tanana terrane; (3) Neoproterozoic to Ordovician Laurentian passive margin strata in southern British Columbia, Canada; and (4) Proterozoic Laurentian Sequence C strata of northwestern Canada. Recycling of zircon from the Paleoproterozoic Great Bear magmatic zone in the Wopmay orogen and its Archean precursors could explain both the Precambrian zircon populations and arc trace element signatures of our samples. Zircon from the anomalous Healy schist sample resembles that in Nation River Formation and Adams Argillite in eastern Alaska, suggesting recycling of detritus in those units.

INTRODUCTION

The U-Pb ages of detrital zircon provide an important means to identify the provenance of sedimentary and metasedimentary strata, establish a maximum age constraint for deposition of the strata, determine the sedimentary or recycling pathway to depositional basins, and evaluate possible stratigraphic correlations between units. The detrital zircon age distribution of a sedimentary or metasedimentary unit and/or multiple units within a succession can establish a characteristic pattern that has been described as a fingerprint (Ross and Parrish, 1991), reference (Gehrels et al., 1995; Gehrels and Pecha, 2014), or barcode (Sircombe, 2000; Link et al., 2005). In addition, the concept of detrital zircon lineage has been introduced to describe the source area and recycling history and sediment pathway of zircon populations (Lane and Gehrels, 2014). Complicating the determination of sediment pathways is the fact that detrital zircon grains can be recycled within sedimentary systems while retaining original U-Pb crystallization ages that can be used to identify their ultimate sources (e.g., Rohr et al., 2008; Dickinson et al., 2009; Hadlari et al., 2015).

We report new U-Pb ages, all Precambrian, for detrital zircon from eight samples of quartz-rich metasedimentary rocks from two areas in east-central Alaska that are part of a remote and little studied area of the northern Cordillera: (1) the northern flank of the central Alaska Range, and (2) the western Yukon-Tanana Upland. Unlike most current detrital zircon studies, many of our samples have a relatively small number of analyses per sample (48–89). However, the results represent the first such data reported from a study area that is approximately the size of California and provide important new insights into local and regional lithostratigraphic correlations.

These samples are from an area of metamorphosed pericratonic rocks in east-central Alaska that we, like many others (e.g., Hansen, 1990; Dusel-Bacon et al., 2006, and references therein; Nelson et al., 2006), interpret as the parautochthonous continental margin of North America (blue unit in Fig. 1) that has been offset hundreds of kilometers by the bounding Tinina and Denali dextral strike-slip fault systems. According to this interpretation, the rocks were originally part of the Neoproterozoic to early Paleozoic basin facies of the North American (western Laurentian) miogeocline (Fig. 1). An adjacent area of metamorphosed pericratonic rocks (dark orange unit in Fig. 1) is interpreted as an allochthonous continental margin assemblage that was rifted from the North American miogeocline beginning in Early Mississippian time. Both the parautochthonous and allochthonous pericratonic rocks were originally defined as the Yukon-Tanana terrane by Coney et al. (1980) and referred to for decades as such. However, the Yukon-Tanana terrane was redefined by Colpron et al. (2006a) to exclude the parautochthonous (blue colored) unit; we follow that terminology herein. The allochthonous Yukon-Tanana terrane was rejoined to the continental margin, including the parautochthonous...
North American continental margin, as an intervening ocean basin (Slide Mountain–Seventymile terranes; black unit in Fig. 1) progressively closed along its western margin in Permian to Early Triassic time (e.g., Foster et al., 1994; Dusel-Bacon et al., 2004, 2006; Nelson et al., 2006; Beranek and Mortensen, 2011). The parautochthonous unit and Yukon-Tanana terrane make up the backstop against which outboard allochthonous terranes were accreted (generalized as the outboard white unit in Fig. 1).

Few fossils have been found in east-central Alaska to establish the depositional ages of metasedimentary rocks (discussed in the following and summarized in Table 1). U-Pb zircon geochronology has defined multiple several Paleozoic magmatic episodes in the parautochthonous and allochthonous packages. Late Devonian and Early Mississippian magmatism was widespread in both packages although differing in age ranges and geochemical signatures (e.g., Dusel-Bacon et al., 2004, 2006; Piercey et al., 2006). Pennsylvanian to Permian magmatism occurred only within the Yukon-Tanana terrane, and is attributed to arc magmatism associated with subduction that closed the intervening ocean basin (Piercey et al., 2006; Nelson et al., 2006, and references therein). Triassic and Jurassic
granitoids intrusions are characteristic of the Yukon-Tanana terrane but have not been recognized in the parautochthonous unit. Although the intrusive ages and the deformational and metamorphic episodes affecting these pericratonic rocks have been addressed in a number of studies (summarized in Table 1), our study is one of few to address the provenance of the metasedimentary rocks in the parautochthonous North American assemblages.

Rocks sampled in our detrital zircon study of the parautochthonous North American unit are quartzite and quartz semischist that suggest a mature (recycled) sedimentary provenance, based on the predominance of clastic quartz grains, the relatively minor amount of detrital feldspar grains, and sericite (likely a metamorphosed derivative of feldspar or clay). The tectonic affinity of highly strained and metamorphosed supracrustal rocks is difficult to determine; therefore, in addition to the detrital zircon data, we also present whole-rock major, minor, and trace element analyses of quartz semischist from the Alaska Range and Yukon-Tanana Upland to help evaluate the primary source area from which the sediments were derived.

The primary purposes of our study are to (1) provide a maximum depositional age for the sampled strata based on their minimum detrital zircon age population; (2) help establish a reference for the detrital zircon age distributions for paraautochthonous North American strata in east-central Alaska; (3) determine likely primary crustal sources for detrital zircons in our study; and (4) compare the detrital zircon age distributions of our samples with those of other peri-Laurentian units in east-central Alaska and with passive margin, miogeocline strata in northwestern North America (Fig. 1) in order to determine possible sedimentary transport pathways (lineages) to depositional basins. Of particular interest is evaluating the possibility that detrital zircon signatures can be used to correlate or differentiate the lithologically similar metasedimentary packages in the parautochthonous North America unit and the Yukon-Tanana terrane.

GEOLOGIC SETTING

The Yukon-Tanana Upland and northern Alaska Range of east-central Alaska (Fig. 2) comprise polydeformed pericratonic assemblages of metasedimentary and metavolcanic rocks that formed along the northwestern margin of Laurentia. These rocks were intruded and overlain by Late Devonian–Early Mississippian plutons (now orthogneiss) and bimodal volcanic rocks, respectively, and structurally imbricated with, or overlain by, klippe of oceanic and high-pressure assemblages (Dusel-Bacon et al., 2006, and references therein). Post-tectonic Mesozoic and early Cenozoic igneous rocks intrude and overlie these assemblages (Foster et al., 1994; Dusel-Bacon et al., 2002, 2015). This package of rocks is bounded to the north and south by the right-lateral Tintina and Denali fault systems, respectively (Figs. 2 and 3). The Tintina fault has undergone ~430 km of mostly Eocene displacement (Gabrielse et al. 2006), and the Denali fault ~370 km of mostly post–Early Cretaceous displacement (Lowey, 1998, and references therein). This relatively young strike-slip faulting, combined with the near total lack of fossil control in Alaska, and the complex, polyphase tectonic history of the region, make it difficult to interpret the origin and history of the pre–Late Devonian assemblages.

The northwestern boundary of the metamorphosed rocks of the Yukon-Tanana Upland has been interpreted as a north-directed thrust fault that places a foliated quartzite unit, the metamorphic grade of which increases southeastward to amphibolite facies, against the weakly recrystallized Wickersham grit unit that is dominated by feldspathic quartz wacke (Fig. 2) (Foster et al., 1983; Laird and Foster, 1984). The trace fossil, Oldhamia, was reported to occur in the northern Circle quadrangle (Fig. 2) by Foster et al. (1983), who suggested that it indicated a Cambrian or possibly Hadrynian (Neoproterozoic) age, based on the available paleontological associations of the time (Hofmann and Cecile, 1981). However, subsequent studies have suggested that the Oldhamia trace fossil

---

TABLE 1. SUMMARY OF PERICRATONIC UNITS OF EAST-CENTRAL ALASKA, YUKON, AND NORTHERN BRITISH COLUMBIA

<table>
<thead>
<tr>
<th>Tectonic assemblage</th>
<th>Parautochthonous North America</th>
<th>Yukon-Tanana terrane</th>
</tr>
</thead>
<tbody>
<tr>
<td>Metasedimentary protolith age constraints</td>
<td>Cambrian Oldhamia and Late Ordovician–Middle Devonian</td>
<td>Middle Mississippian to early Permain conodonts, others rocks predates intrusion of Late Devonian or Early Mississippian granitoids</td>
</tr>
<tr>
<td>Paleozoic magmatic episodes and chemical characteristics</td>
<td>ca. 373–356 Ma; bimodal peralcaline rhyolite and OIB; calc-alkaline</td>
<td>Ca. 365–342 Ma, calc-alkaline arc and OIB and MORB backarc; ca. 342–314 Ma (only in Canada), arc-backarc; 314–269 Ma (only in Canada); ca. 263–253, calc-alkaline arc</td>
</tr>
<tr>
<td>Metamorphic episodes</td>
<td>ca. 186–146 Ma tectonic burial beneath Yukon-Tanana terrane</td>
<td>365–250 Ma regional thermal metamorphism; 260–240 Ma</td>
</tr>
<tr>
<td>Eocene and Cenozoic postkinematic magmatism</td>
<td>112–94 Ma; 70–66 Ma</td>
<td>216–208 Ma; 199–181 Ma; 112–94 Ma; 70–66 Ma</td>
</tr>
</tbody>
</table>

Note: MORB—mid-ocean ridge basalt; OIB—ocean island basalt.

1See references cited in this paper.
2Dusel-Bacon et al. (2006).
4Staples et al. (2013).
5Wilson et al. (1985).
6Dusel-Bacon et al. (2002).
7Dusel-Bacon et al. (2015, and references therein).
8Dusel-Bacon and Harris (2003).
9Orchard (2006).
10Nelson et al. (2006).
11Piercey et al. (2006).
12Berman et al. (2007).

---

Downloaded from https://pubs.geoscienceworld.org/gsa/lithosphere/article-pdf/9/6/927/3985590/927.pdf by guest
Figure 2. Generalized geologic map of the Yukon-Tanana Upland and northern Alaska Range (north and south of the Tanana River, respectively) showing location of two detrital zircon samples from this study. Adapted from Dusel-Bacon et al. (2015). P—pressure; Qtz—quartz; Ser—sericite; Chl—chlorite; AK—Alaska; BC—British Columbia; YT—Yukon Territory. Abbreviations in unit labels: T—Tertiary (Paleogene–Neogene); K—Late Cretaceous; mK—mid-Cretaceous; eJ—Early Jurassic; IT—Late Triassic; g—granitic rocks; v—felsic volcanic rocks; s—sedimentary rocks; b—basaltic rocks. Unpatterned areas are Neoproterozoic to Cambrian and Devonian sedimentary rocks north of the Tintina fault, and Quaternary surficial deposits elsewhere. Location of Figure 3 is outlined in red. Detrital zircon sample locations from other studies: 1—Jarvis belt quartzite (Dusel-Bacon and Williams, 2009); 2—Wickersham grit near Wickersham dome (Bradley et al., 2007); 3—Fairbanks schist micaceous quartzite near Cleary Summit (J.K. Mortensen and G.M. Ross, 2002, personal commun.).
Detrital zircon geochronology, east-central Alaska

To tatlanika Schist Fm. (Late Devonian–Early Mississippian)
- Sheep Ck Mbr—Quartz-rich semi-schist, metasiltstone, metatuff, quartzite, and marble
- Mystic Ck Mbr—Felsic metavolcanic schist
- Chute Ck Mbr—Mafic metavolcanic schist
- California Ck Mbr—Quartz-K-feldspar-sericite schist and augen gneiss
- Moose Ck Mbr—Quartz-K-feldspar gneiss, felsic schist, and mafic schist

Keevy Peak Fm—Quartz-sericite schist, carbonaceous quartz schist, slate, and stretched-pebble conglomerate (Devonian)
- Healy schist—Quartz-sericite schist, quartzite, chlorite schist, marble, and metagabbro (Devonian and older)
- Carbonaceous schist—Pattern superimposed on units

Intrusive rocks (Tertiary and Cretaceous)
- Green metavolcanic schist and carbonaceous schist
- Rhyolite schist
- Metasedimentary rocks, including marble, quartzite, and calcarenite

Contact

Anticline

Syncline

Thrust fault—Sawteeth on upper plate
Fault—Unclassified type
Right-lateral strike-slip fault—Concealed

Detrital zircon sample number
U-Pb crystallization age (Ma)

VMS deposit
Town
Fossil

Figure 3. Geologic map of the northern Healy quadrangle showing location of detrital zircon samples. Geology is from Wahrhaftig (1968) and Gilbert and Bundtzen (1979). U-Pb ages of igneous rocks are from Dusel-Bacon et al. (2004, 2012), and conodont fossil location is from Csejty et al. (1992). Abbreviations: Mbr—member; Ck—creek; Fm—formation; VMS—volcanogenic massive sulfide.
is Early Cambrian to early-Middle Cambrian in age (Hofmann et al., 1994; MacNaughton et al., 2016). The *Oldhamia*-bearing rocks in the northwestern Circle quadrangle were correlated by Weber et al. (1992) with the Wickersham grit unit mapped in the Livengood quadrangle to the west, whereas the two occurrences of *Oldhamia* north of the northern strand of the Tintina fault are included in the Crazy Mountains terrane of Churkin et al. (1982) (Fig. 2). Dover (1994) interpreted the *Oldhamia*-bearing argillite in the basement of the Crazy Mountains terrane, which he redefined as a belt, to be the upper part of the Wickersham grit unit that crops out to the west. Currently, there are no known exposures of Precambrian rocks in the Yukon-Tanana Upland or in the Alaska Range.

Along the northern flank of the Alaska Range in the northern Healy quadrangle, greenschist facies metasedimentary rocks and associated metavolcanic rocks form range-parallel east-west–trending belts north of the Hines Creek strand of the Denali fault system (Wahrhaftig, 1968, 1970a, 1970b, 1970c; Gilbert, 1977; Gilbert and Bundtzen, 1979) (Figs. 2 and 3). Protoliths consist of felsic and mafic volcanic and shallow-level intrusive rocks interdigitated with siliciclastic and carbonaceous sedimentary rocks deposited in a submarine, basinal setting. Rocks were metamorphosed and deformed in the Mesozoic (Wilson et al., 1985) and were subsequently folded into an anticline and associated syncline (Wahrhaftig, 1968; Gilbert and Bundtzen, 1979). Wahrhaftig (1968) was careful to note, however, that known and suspected thrust faulting among all the metamorphic rock units of the central Alaska Range makes determination of stratigraphic thicknesses and even the stratigraphic sequence uncertain. Quartz-sericite schist, quartzite, chlorite schist, and subordinate carbonaceous schist and marble of the Healy schist (Newberry et al., 1997; Birch Creek Schist of former usage in Wahrhaftig, 1968; Gilbert, 1977; and Gilbert and Bundtzen, 1979) core the regional anticline. A U-Pb zircon age of 370 ± 2 Ma from a felsic metaporphry interpreted to intrude the Healy schist (Dusel-Bacon et al., 2004) establishes a local minimum protolith age for a part of that unit (Fig. 3). Polyphase deformation and folding observed in the outcrops of Healy schist quartzite from which our three detrital zircon samples were collected (Fig. 4) are typical for the unit and illustrate the likely modification of the original stratigraphic relationship among the samples.

Quartz-sericite schist, carbonaceous schist, slate, and minor stretched-pebble conglomerate and felsite make up the Keevy Peak Formation, which crops out north of and stratigraphically above the Healy schist. Felsic schist of probable tuffaceous origin, spatially associated with carbonaceous schist in the Keevy Peak Formation, yielded a U-Pb zircon age of 368 ± 4 Ma (Fig. 3) (Dusel-Bacon et al., 2012); it is not known

**Figure 4.** (A–C) Photographs of Healy schist quartzite from which our samples were collected showing characteristic folding and fabric development within the unit. We interpret the fabrics shown in B to represent two deformation events (D1 and D2). Locations of sample field number (in upper right of photographs) are shown in Figure 3.
whether the felsic schist is in stratigraphic or structural relationship with the quartzite sampled for detrital zircons in our study.

Bimodal metaigneous rocks and associated carbonaceous and siliceous metasedimentary rocks of the Totatlanika Schist overlie the Keevy Peak Formation. Wahrhaftig (1968) divided the Totatlanika Schist into five different members (Fig. 3). Contacts between the members are thought to be mostly of depositional origin, but locally contacts are faults (Wahrhaftig, 1968). The Sheep Creek Member, from which two of our detrital zircon samples were obtained, forms the uppermost member and consists of quartz-feldspar-geysemishist or grit, metasiltstone, metatuff, quartzite, and marble. The Totatlanika Schist members occur in a syncline, with the Sheep Creek Member occupying the core (Fig. 3). No intrusions that crosscut the Sheep Creek Member have been dated. Metaigneous rocks from other members of the Totatlanika Schist have yielded U-Pb zircon crystallization ages of 373 ± 3 Ma and 372 ± 5 Ma (augen orthogneiss in the California Creek Member of the Totatlanika Schist) and 367 ± 4 Ma to 356 ± 3 Ma (metamorphite in the Moose Creek and Mystic Creek Members of the Totatlanika Schist) (Dusel-Bacon et al., 2004, 2012). Most of the metamorphite in the Mystic Creek Member is interpreted to be metavolcanic (Dusel-Bacon et al., 2012). Conodont fossils found in marble at one locality in the Mystic Creek Member of the Totatlanika Schist (Fig. 3) indicate an age of Middle Devonian to Early Mississippian (Csejtey et al., 1992).

Greenschist facies rocks similar to the described units in the Healy quadrangle are present north of the Alaska Range in the Big Delta quadrangle (Fig. 2), part of the Yukon-Tanana Upland. These rocks occur in units referred to (from structurally, and possibly also stratigraphically, lowest to highest) as the Fairbanks-Chena assemblage, the Dan Creek and Blackshell units, and the Butte assemblage. The Fairbanks-Chena assemblage is composed mostly of greenschist and amphibolite facies quartzite, quartz schist, and minor metavolcanic rocks (Fairbanks schist; Robinson et al., 1990; Newberry et al., 1996) and amphibolite facies pelitic schist, quartzite, marble, and amphibolite (Chena River sequence; Robinson et al., 1990; Smith et al., 1994). Protophils of the Fairbanks-Chena assemblage metasedimentary rocks predate the intrusion of metaigneous bodies with Late Devonian to Early Mississippian (369 ± 3–351 ± 2 Ma) U-Pb zircon ages (Aleinkoff and Nokleberg, 1989; Newberry et al., 1998; Dusel-Bacon et al., 2003). The structurally overlying Dan Creek unit (Smith et al., 1994) consists of thinly layered calcphyllite and carbonate. Favorables corals were found in siliceous calcphyllite in the Chena River drainage in the northwestern Big Delta quadrangle and were interpreted to have been derived almost certainly from the Dan Creek unit (W.A. Oliver and F.R. Weber, 1985, written commun., reported in Smith et al., 1994). On this basis, Smith et al. (1994) proposed a depositional age for the Dan Creek unit of between Late Ordovician and Middle Devonian. The Dan Creek unit is overlain by carbonaceous quartzite and phyllite, and subordinate felsic and maﬁc metavolcanic rocks of the Blackshell unit (Smith et al., 1994).

The Butte assemblage structurally overlies the Blackshell unit and consists of quartzofeldsparphathic mylonite schist and gneiss, quartz-feldspar-geysemishist or grit, phyllite, metasandstone, quartzite, marble, and greenstone (Weber et al., 1978; Foster et al., 1994; Dusel-Bacon et al., 2004, 2006; Werdon et al., 2004). U-Pb zircon ages indicate Late Devonian to Early Mississippian crystallization for augen gneiss (364 ± 3 Ma) and metamorphite (372 ± 5 Ma and 353 ± 7 Ma) from the carbonaceous Blackshell unit (Fig. 2) (Dusel-Bacon et al., 2004). The Butte assemblage and Blackshell unit have overlapping crystallization ages for the felsic igneous protoliths and similar whole-rock trace element signatures for both felsic and maﬁc metaigneous rocks, suggesting a geologic link between the two units (Dusel-Bacon et al., 2004).

The lithologic similarities between these described rocks in the Healy and Big Delta quadrangles were noted by many (e.g., Weber et al., 1978; Gilbert and Bundtzen, 1979; Smith et al., 1994; Newberry et al., 1996; Dusel-Bacon et al., 2004). Several studies (e.g., Weber et al., 1978; Smith et al., 1994; Foster et al., 1994) proposed correlation of the carbonaceous Blackshell unit and the overlying Butte assemblage in the Yukon-Tanana Upland with the Keevy Peak Formation and the Totatlanika Schist, respectively, of the Alaska Range. On the basis of similarities in lithologies, U-Pb zircon ages, and whole-rock trace element geochemistry, correlation of the Totatlanika Schist with the Butte assemblage was proposed in Dusel-Bacon et al. (2004); however, they did not support a unique correlation of the Blackshell unit with the Keevy Peak Formation because carbonaceous intervals of substantial thickness are present in almost all members of the Totatlanika Schist as well as in the Keevy Peak Formation (Fig. 3). The Tanana River valley (Fig. 2) that separates the two physiographic areas is known to be a Neogene feature (Wahrhaftig, 1987), and thus geologic continuity of units in the Yukon-Tanana Upland and northern Alaska Range is a reasonable hypothesis.

**ROCK DESCRIPTIONS**

**Detrital Zircon Samples**

All of the successions described here contain abundant siliciclastic rocks. Given the presence of Devonian and Mississippian igneous rocks in these successions, detrital zircon geochronology provides an additional discriminant for testing geologic ties between the units. Because of the near absence of fossils in this region, the minimum age populations of detrital zircon in our samples also can help constrain the maximum depositional age of the sedimentary protoliths. Detrital zircons were separated from six quartzose metasedimentary rocks from the northern flank of the Alaska Range and two from the western Yukon-Tanana Upland. In the Alaska Range, samples are from three geologic units in the northern Healy quadrangle (Fig. 3): Healy schist (n = 3), Keevy Peak Formation (n = 1), and Sheep Creek Member of the Totatlanika Schist (n = 2). In the Yukon-Tanana Upland, samples are from the Butte assemblage in the northern Big Delta quadrangle (n = 2) (Fig. 2). Geologic settings, petrographic descriptions, and location information for each sample are given in Table DR1 in the GSA Data Repository.

Healy schist samples 05ADb34, 05ADb35, and 05ADb36 are all from polydeformed quartzite interlayered with other quartz-rich, greenschist facies metasedimentary rocks that contain variable amounts of white mica. Recumbent isoclinal folding of metamorphic and compositional layering is evident at two of the sample localities (Figs. 4A, 4C); polydeformed quartzite at another locality shows an earlier foliation (S1) that was subsequently folded and later affected by an ~1–10 cm spaced cleavage (S2) that is primarily defined by white mica (Fig. 4B). Photomicrographs of the samples (Figs. 5A–5I) show the foliation to be defined by oriented matrix grains of fine-grained, polygonized quartz and minor sericite that enclose sparse ovoid to rounded clasts of quartz, K-feldspar, and plagioclase.

The single sample (04ADb01) from the Keevy Peak Formation is a homogeneous light gray quartzite, locally containing sparse, dark chert fragments, that is interlayered with conglomerate, slate, and minor phylite. The quartzite is from a stretched-pebble conglomerate lens within

---

1GSA Data Repository Item 2017332, geologic settings, descriptions, and locations of detrital zircon samples; whole-rock analyses of quartz-eye semischist; and analytical methods and results from U-Pb analyses of detrital zircons, is available at http://www.geosociety.org/datarepository/2017, or on request from editing@geosociety.org. The USGS published a raw data release of the tables in this GSA Data Repository Item, which can be found at https://doi.org/10.5066/F76H4FXN.
Figure 5. Photomicrographs of quartzites from the Healy quadrangle that were sampled for detrital zircon. Locations of the sample field number (in upper right of each photomicrograph) are shown in Figure 3. All images were taken in transmitted, cross-polarized light. (A–I) Quartzite from Healy schist showing weakly developed metamorphic fabric defined by oriented matrix grains of finely recrystallized quartz and white mica and, in some photos, by sparse, elongate clasts of K-feldspar (dark gray). (C) An elongate grain of white mica (red interference color) rimmed by black iron oxide of unknown detrital or recrystallized matrix origin. (E) Quartz clasts (gray and black) aligned in the foliation plane. (F) Spaced cleavage (S2) defined by white mica that crosscuts an earlier, less-well-defined fabric (S1). (H) Weakly defined foliation imparted by discontinuous wispy grains of sericite. (I) Dark speckled grain of an iron-bearing alteration product of plagioclase in center of photomicrograph. (J–L) Quartzite from Keevy Peak Formation showing a mixture of both monocrystalline and polycrystalline quartz grains and sparse, elongate, finer grained clasts.
the Keeyo Peak Formation, which underlies the Totatlanika Schist (Wahrhaftig 1970b). In thin section, quartz clasts (~0.5 mm long) occur as both monocrystalline and cryptocrystalline subangular grains (Figs. 5J–5L); one clast is an ~5 mm dark fragment of probable slate (Fig. 5J).

Two samples of quartz semischist (03ADb14 and 98ADb79A) were collected from the Sheep Creek Member of the Totatlanika Schist. Both samples contain oriented, gray-blue quartz grains (~1 mm in diameter) separated by discontinuous micaceous partings; a mylonitic texture is indicated by strained individual quartz grains with fine-grained, comminuted grain boundaries (Figs. 6A–6F). In sample 98ADb79A, in addition to the abundant quartz grains, ~10% of the clasts are K-feldspar and plagioclase, which are enveloped in a matrix of sericite, fine-grained (comminuted) quartz and feldspar, and trace amounts of tourmaline (Fig. 6F).

The two samples of quartz semischist from the Butte assemblage (96ADb25A and 97ADb43A), like the two samples from the Sheep Creek Member, are mylonitic and characterized by quartz eyes, albeit slightly larger in size (2–5 mm in diameter) than those in the Sheep Creek Member (Figs. 6G–6L). K-feldspar clasts are also more common in these two samples than in the Sheep Creek samples. At the locality of sample 96ADb25A, semischist also contains very sparse, elongate shale clasts ~1 × 3 cm long, with the largest shale clast measuring 5 × 20 cm in length. Metasedimentary rocks topographically lower in the outcrop sequence include fine-grained phyllitic rocks, and sands and shales of possible turbiditic origin. At the sample locality of 97ADb43A, quartz semischist is in sharp contact with overlying and underlying finer grained layers in which quartz clasts are ≤1 mm in length. These abrupt grain-size transitions may be sedimentary, but alternatively could be a result of shear strain. Size grading is not obvious, but if present, suggests an upright sequence locally.

**Whole-Rock Geochemistry Samples**

Representative whole-rock samples of quartz semischist from the Sheep Creek Member of the Totatlanika Schist (n = 3) in the Alaska Range and Butte assemblage (n = 3) in the Yukon-Tanana Upland were analyzed for major, minor, and trace element contents (Table DR2). Whole-rock powders from Sheep Creek Member samples are from 98ADb79A, the same sample used for detrital zircon (Fig. 3); 98ADb79B, a slightly coarser grained quartz-eye semischist at the same locality; and 96ADb9A, similar fine-grained semischist, collected ~100 m northeast of locality 98ADb79. Both samples 98ADb79A and 96ADb9A contain <1 mm, oval grains of ~90% quartz, the remainder being plagioclase and K-feldspar.

Whole-rock powders from Butte assemblage samples are 96ADb25A, the same sample analyzed for detrital zircon (Fig. 2); 98ADb69, quartz semischist from ~150 m east of detrital zircon sample 97ADb43A; and 98ADb68B, quartz semischist from ~3 km southeast of sample 97ADb43A. Sample 98ADb69 is a relatively coarse semischist (phyllonite) with eyes (augen) measuring ~0.5 cm in length, and composed of ~75% highly strained quartz, and 25% microcline and sparse quartz-feldspar rock fragments. Sample 98ADb68B is from a layer of relatively massive semischist that underlies a more schistose layer and is associated with calc-phyllite and dolostone in nearby outcrops. In thin section, sample 98ADb68B consists of 1–2 mm monocrystalline, strained quartz eyes in a fine-grained sericite-quartz matrix. Approximately 10% of the eyes are plagioclase and a few are K-feldspar.

All samples were analyzed by wavelength-dispersive X-ray fluorescence and inductively coupled plasma–mass spectrometry (ICP-MS) at the GeoAnalytical Laboratory, Washington State University (see Appendix A in Dusel-Bacon et al., 2013, for a detailed description of analytical procedures).

**RESULTS**

**Detrital Zircon U-Pb Data**

**Methods**

U-Pb detrital zircon data reported here were obtained from three different laboratories using two different analytical methods: laser ablation (LA) ICP-MS for six samples and secondary ion mass spectrometry using sensitive high resolution ion microprobe–reverse geometry (SHRIMP-RG) for two samples. Data determined by LA-ICP-MS for three samples each were generated at the University of British Columbia by J.K. Mortensen and at the U.S. Geological Survey (USGS), Denver, by C. Holm-Denoma; data determined by SHRIMP-RG for two samples were gathered at the Stanford–USGS facility by J.N. Aleinikoff. Descriptions of the analytical methods and results from each of the three laboratories are presented in Tables DR3–DR5. The geological time scale (Okulitch, 2002) used in this paper has the following age brackets for the relevant Precambrian eras: Mesoarchean, 3400 ± 200 to 2900 ±/–100 Ma; Neoarchean, 2900 ±/–100 to 2500 ± 10 Ma; Paleoproterozoic, 2500 ± 10 to 1600 Ma; Mesoproterozoic, 1600 to 1000 ± 50 Ma; Neoproterozoic, 1000 ± 50 to 544 ± 1 Ma.

Probability density plots (PDP) of U-Pb ages for all the samples are shown in Figures 7 and 8 and a summary of the youngest concordant analysis and detrital zircon age ranges and age populations is given in Table 2. The 207Pb/206Pb ages were used when grains were older than 1300Ma; a small subset of ages that are younger than 1300 Ma use the 206Pb/238U age. Only ages that are <10% discordant are plotted. A compilation of the U-Pb ages that passed our discordance filter and, therefore, were used for constructing PDPs and kernel density estimates (KDEs) and for calculating statistically significant age populations is provided in Table DR6; uncertainties of individual ages are reported at the 1σ level. For one sample (03ADb14), detrital zircon from the same sample was analyzed by both LA-ICP-MS and SHRIMP methods in separate pucks made from the same concentrate in order to compare the results of the different analytical methods and laboratories. In Figure 8A, all age spectra are normalized so that the areas under the curves are equivalent, regardless of the number of analyses. In Figure 8B, cumulative U-Pb ages are shown.

The minimum age population shown for each sample in Table 2 is the weighted average of the youngest three or more grains that overlap within uncertainty, have an MSWD of 2 or less, and, therefore, define a single population. We used Kolmogorov-Smirnoff (K-S) statistics (Press et al., 1986) on our filtered data set to help assess the similarity of the detrital zircon age populations (e.g., Berry et al., 2001; Dickinson and Gehrels, 2009) among the following samples. The test mathematically compares two age distributions to determine if there is a statistically significant difference between the two and returns the probability (P) that the age distributions were drawn from the same population. The P value must be >0.05 to be >95% confident that two populations are not statistically different. Table 3 shows the results of the K-S test in comparing our samples with each other and with other published samples from throughout the broader region; P values >0.05 are shown in bold and shaded in yellow. Some of our samples have a relatively small number of analyses, and statistical comparisons such as the K-S test and the multidimensional scaling (MDS, see following) rely on the proportions of ages in addition to their presence or absence. Thus, whereas the comparisons might adequately indicate similarity in the age populations that are present, the respective proportions of age populations might not be well constrained.

**Healy Schist**

Two of the three Healy schist detrital zircon samples (05ADb35 and 05ADb36) are similar to each other (Table 3) in that they have...
Figure 6. (A–L) Photomicrographs of quartz semischist from the Healy and Big Delta quadrangles sampled for detrital zircons. Locations of the sample field number (in upper right of photomicrographs) are shown in Figures 2 and 3. All images were taken in transmitted, cross-polarized light, except for H and K, which were taken in transmitted, plane-polarized light. (A–F) Protomylonitic quartz semischist from the Sheep Creek Member of the Totatlanika Schist has oriented, variably strained quartz grains in a matrix of discontinuous wisps of sericite and fine-grained quartz and feldspar. F shows an uncommon microcline-twin K-feldspar clast adjacent to more typical quartz clasts. (G–L) Typical mylonitic textures in quartz-eye semischist from the Butte assemblage. L shows an atypical clast of highly strained quartz.
Figure 7. Probability density plots showing U-Pb ages of detrital zircons from quartzite and quartz semischist from east-central Alaska. Information in upper right of diagram gives number of ages plotted/number of ages determined, analytical method used, and analyst (Mortensen, JKM; Aleinikoff, JNA; Holm-Denoma, CHD). U-Pb data are given in Tables DR3–DR6. Abbreviations: LA-ICP-MS—laser ablation–inductively coupled plasma–mass spectrometry; SHRIMP-RG—sensitive high resolution ion microprobe–reverse geometry. (A–C) Healy schist. (D) Keevy Peak Formation. (E–G) Sheep Creek Member of Totallanika Schist. (H–I) Butte assemblage.
Figure 8. (A) Normalized age probability density plot of detrital zircon ages from east-central Alaska. Samples in A are normalized to each other by number of analyses (given in parentheses after each sample number) so that the area below each curve is equal. Samples are described in Table DR1 and their locations are shown in Figures 2 and 3. U-Pb data are given in Tables DR3–DR6. (B) Cumulative age probability plot.
TABLE 2. SUMMARY OF NEW DETRITAL ZIRCON AGES FOR QUARTZOSE METASEDIMENTARY ROCKS FROM EAST-CENTRAL ALASKA

<table>
<thead>
<tr>
<th>Sample</th>
<th>n&lt;sub&gt;total&lt;/sub&gt;</th>
<th>Age range (Ma)</th>
<th>Youngest concordant analysis (Ma)</th>
<th>Minimum age population (Ma) ± (2σ)</th>
<th>n&lt;sub&gt;range&lt;/sub&gt;</th>
<th>MSWD&lt;sub&gt;range&lt;/sub&gt;</th>
<th>Peak age ranges (Ma)</th>
<th>n&lt;sub&gt;range&lt;/sub&gt;</th>
<th>Peak age ranges (continued) (Ma)</th>
<th>n&lt;sub&gt;range&lt;/sub&gt;</th>
<th>Age peaks (Ma)</th>
<th>n&lt;sub&gt;peak&lt;/sub&gt;</th>
<th>Age peaks (continued) (Ma)</th>
<th>n&lt;sub&gt;peak&lt;/sub&gt;</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>05ADb34 Healy schist</td>
<td>55</td>
<td>2711–890</td>
<td>890 ± 5</td>
<td>1007 ± 12</td>
<td>4 ± 1.8</td>
<td>1000 1014</td>
<td>1420 1536</td>
<td>5 ± 2000</td>
<td>4 ± 8340</td>
<td>8 ± 5000</td>
<td>1009 4 ± 1834</td>
<td>8 ± 5000</td>
<td>1009 4 ± 1834</td>
<td>8 ± 5000</td>
</tr>
<tr>
<td>05ADb35 Healy schist</td>
<td>89</td>
<td>3678–1330</td>
<td>1330 ± 37</td>
<td>1837 ± 27</td>
<td>27 ± 2.1</td>
<td>1780 1999</td>
<td>2410 2431</td>
<td>0 ± 2306</td>
<td>9 ± 2427</td>
<td>3 ± 2380</td>
<td>1837 23 ± 2427</td>
<td>3 ± 2380</td>
<td>1837 23 ± 2427</td>
<td>3 ± 2380</td>
</tr>
<tr>
<td>05ADb36 Healy schist</td>
<td>59</td>
<td>2858–1323</td>
<td>1323 ± 31</td>
<td>1879 ± 23</td>
<td>18 ± 2</td>
<td>1409 1426</td>
<td>2629 2778</td>
<td>12 ± 1903</td>
<td>1 ± 2102</td>
<td>4 ± 907</td>
<td>1879 18 ± 2674</td>
<td>9 ± 907</td>
<td>1879 18 ± 2674</td>
<td>9 ± 907</td>
</tr>
<tr>
<td>04ADb01B Keevy Peak Fm.</td>
<td>48</td>
<td>3622–1436</td>
<td>1436 ± 31</td>
<td>1766 ± 27</td>
<td>6 ± 2</td>
<td>1717 2039</td>
<td>2477 2494</td>
<td>0 ± 2043</td>
<td>0 ± 2178</td>
<td>14 ± 2261</td>
<td>1763 5 ± 1987</td>
<td>8 ± 2261</td>
<td>1763 5 ± 1987</td>
<td>8 ± 2261</td>
</tr>
<tr>
<td>03ADb14 Sheep Creek Mbr. Totat. Schist Fm.</td>
<td>48</td>
<td>2776–1680</td>
<td>1680 ± 21</td>
<td>1782 ± 23</td>
<td>13 ± 1.7</td>
<td>1700 2009</td>
<td>2567 2700</td>
<td>12 ± 2282</td>
<td>5 ± 1843</td>
<td>4 ± 1971</td>
<td>1776 13 ± 2310</td>
<td>4 ± 1971</td>
<td>1776 13 ± 2310</td>
<td>4 ± 1971</td>
</tr>
<tr>
<td>03ADb14 ICP-MS Sheep Creek Mbr. Totat. Schist Fm.</td>
<td>63</td>
<td>2831–787</td>
<td>787 ± 8</td>
<td>1767 ± 22</td>
<td>16 ± 0.7</td>
<td>1701 1999</td>
<td>2625 2691</td>
<td>4 ± 2530</td>
<td>4 ± 1865</td>
<td>24 ± 1937</td>
<td>1765 16 ± 2564</td>
<td>6 ± 1937</td>
<td>1765 16 ± 2564</td>
<td>6 ± 1937</td>
</tr>
<tr>
<td>03ADb14 combined Sheep Creek Mbr. Totat. Schist Fm.</td>
<td>111</td>
<td>2831–787</td>
<td>787 ± 8</td>
<td>1772 ± 21</td>
<td>28 ± 1</td>
<td>1684 2011</td>
<td>2530 2713</td>
<td>20 ± 2273</td>
<td>7 ± 1860</td>
<td>35 ± 1964</td>
<td>1768 28 ± 2573</td>
<td>8 ± 1964</td>
<td>1768 28 ± 2573</td>
<td>8 ± 1964</td>
</tr>
<tr>
<td>98ADb79A Sheep Creek Mbr. Totat. Schist Fm.</td>
<td>128</td>
<td>3182–771</td>
<td>771 ± 14</td>
<td>1765 ± 20</td>
<td>19 ± 1</td>
<td>1711 1905</td>
<td>2410 2711</td>
<td>56 ± 1934</td>
<td>9 ± 1835</td>
<td>21 ± 2081</td>
<td>1765 19 ± 2484</td>
<td>4 ± 2081</td>
<td>1765 19 ± 2484</td>
<td>4 ± 2081</td>
</tr>
<tr>
<td>96ADb25A Butte assemblage</td>
<td>101</td>
<td>3261–1143</td>
<td>1143 ± 7</td>
<td>1759 ± 20</td>
<td>19 ± 1.8</td>
<td>1720 2014</td>
<td>2551 2759</td>
<td>24 ± 2018</td>
<td>5 ± 1762</td>
<td>26 ± 2058</td>
<td>1762 19 ± 2097</td>
<td>4 ± 2058</td>
<td>1762 19 ± 2097</td>
<td>4 ± 2058</td>
</tr>
<tr>
<td>97Adb43A Butte assemblage</td>
<td>83</td>
<td>2967–1499</td>
<td>1499 ± 31</td>
<td>1700 ± 24</td>
<td>3 ± 0.9</td>
<td>1683 1715</td>
<td>2537 2641</td>
<td>14 ± 1719</td>
<td>2 ± 1697</td>
<td>3 ± 2453</td>
<td>1697 3 ± 2578</td>
<td>4 ± 2453</td>
<td>1697 3 ± 2578</td>
<td>4 ± 2453</td>
</tr>
</tbody>
</table>

Note: n<sub>total</sub> refers to total number of grains included in age pick analysis; n<sub>range</sub> refers to the number of grains included in the minimum age population, and MSWD<sub>range</sub> indicates the MSWD (mean square of weighted deviates) of the calculated minimum age. Age range is the total range of ages of all grains included in the age pick analysis. Peak age range represents the range of age-probability contributions (at 2σ) from 3 or more analyses. n<sub>peak</sub> indicates number of ages that contributed to the peak age range. Age peaks represent maxima in the age probability curve comprising 3 analyses or more. n<sub>peak</sub> indicates the number of analyses that contribute age probability to an age peak. Age peak data were calculated using Microsoft Excel macros made available by G. Gehrels at the University of Arizona LaserChron Center (Gehrels, 2010). Abbreviations: Mbr.—Member; Fm.—Formation; Totat.—Totatlianika; Min.—minimum; Max.—maximum; SHRIMP—sensitive high-resolution ion microprobe; ICP-MS inductively coupled plasma–mass spectrometer.
Paleoproterozoic (ca. 1.9–1.8 Ga) and Neoarchean (ca. 2.8–2.6 Ga) major age peaks and age ranges (Figs. 7B, 7C, and 8; Table 2). Sample 05ADb36 zircon has a larger relative percentage of Paleoproterozoic ages; 35 of 59 give ages between ca. 2110 and 1787 Ma (Table DR6). The youngest individual detrital zircon age for samples 05ADb35 and 05ADb36 are ca. 1330 Ma and ca. 1323 Ma, respectively (Table DR3), but their statistically viable minimum age populations are ca. 1837 Ma and 1879 Ma, respectively (Table 2). Sample 05ADb35 yielded the oldest age (3678 ± 10 Ma) for a single zircon in our study.

Zircon from the other Healy schist sample (05ADb34) differs from that of the other samples from this unit both statistically (Table 3) and visually (Figs. 7 and 8). In this sample, the majority of detrital zircons (30 of 55) yielded Mesoproterozoic and Neoproterozoic ages between ca. 1593 and 890 Ma (Table DR6). Instead of a few pronounced age peaks, this sample has relatively small numbers of grains defining 12 age peaks that range from ca. 1501 to 1009 Ma, 1966 to 1834 Ma, and 2692 to 2587 Ma (Fig. 7A; Table 2). The youngest zircon grain in this sample is ca. 890 Ma (Table DR6), but the statistically viable minimum age population is ca. 1007 Ma (Table 2).-

**Keevy Peak Formation**

Detrital zircon in sample 04ADb01B yielded mostly Proterozoic age peaks that range from ca. 2370 to 1763 Ma, with the largest number of zircon grains forming a ca. 1878 Ma peak (Figs. 7D and 8; Table 2). Detrital zircons yielded a statistically viable minimum age population of ca. 1766 Ma; the youngest zircon grain had an age of ca. 1436 Ma. Seven zircon grains yielded Neoarchean ages (ca. 2900–2566 Ma) and the oldest single grain yielded a Mesoarchean age of 3622 ± 32 Ma (Table DR6).

**Sheep Creek Member of Totallanika Schist**

Detrital zircon data from both types of analyses of sample 03ADb14 and a single analysis of sample 98ADb79A show major Paleoproterozoic (ca. 1.8–1.7 Ga) and late Neoarchean (ca. 2.6–2.5 Ga) age populations (Figs. 7E–7G and 8; Table 2). All three Sheep Creek analyses have statistically viable minimum age populations of ca. 1770 Ma (Table 2). The youngest individual ages are 787.2 ± 7.84 Ma (2.4% discordant) for sample 98ADb79A, but the statistically viable minimum age populations of ca. 1759 Ma and 1700 Ma, respectively (Table 2). Sample 05ADb35 yielded the oldest age (3678 ± 10 Ma) for a single zircon in our study.

Zircon from the other Healy schist sample (05ADb34) differs from that of the other samples from this unit both statistically (Table 3) and visually (Figs. 7 and 8). In this sample, the majority of detrital zircons (30 of 55) yielded Mesoproterozoic and Neoproterozoic ages between ca. 1593 and 890 Ma (Table DR6). Instead of a few pronounced age peaks, this sample has relatively small numbers of grains defining 12 age peaks that range from ca. 1501 to 1009 Ma, 1966 to 1834 Ma, and 2692 to 2587 Ma (Fig. 7A; Table 2). The youngest zircon grain in this sample is ca. 890 Ma (Table DR6), but the statistically viable minimum age population is ca. 1007 Ma (Table 2).

**Keevy Peak Formation**

Detrital zircon in sample 04ADb01B yielded mostly Proterozoic age peaks that range from ca. 2370 to 1763 Ma, with the largest number of zircon grains forming a ca. 1878 Ma peak (Figs. 7D and 8; Table 2). Detrital zircons yielded a statistically viable minimum age population of ca. 1766 Ma; the youngest zircon grain had an age of ca. 1436 Ma. Seven zircon grains yielded Neoarchean ages (ca. 2900–2566 Ma) and the oldest single grain yielded a Mesoarchean age of 3622 ± 32 Ma (Table DR6).

**Butte Assemblage**

The two samples from the Butte assemblage (96ADb25A and 97ADb43A) are statistically similar to each other (Table 3). Both have prominent Paleoproterozoic (ca. 1.8–1.7 Ga) and late Neoarchean (2.7–2.6 Ga) age peaks (Figs. 7H, 7I, and 8; Table 2). They have statistically viable minimum age populations of ca. 1759 Ma and 1700 Ma, respectively.
Whole-Rock Geochemical Data

Semischist samples show a relatively small range in SiO$_2$ contents, from 78.6 to 86.0 wt%. A log plot of SiO$_2$/Al$_2$O$_3$ and K$_2$O/Na$_2$O ratios (Fig. 9A) shows the samples to have higher SiO$_2$/Al$_2$O$_3$ contents than the average composition of upper continental crust (McLennan, 2001), indicating sediment maturity, consistent with their quartz-rich compositions; K$_2$O/Na$_2$O ratios have a wide range that extends beyond the average value for upper continental crust. All semischist samples plot in the lithic arenite field with one plotting on its boundary with the arkose field. However, because deformation and low-grade metamorphism have undoubtedly modified the distribution of whole-rock major and minor element contents of the samples, the significance of these contents is minor compared to those of their trace elements. Many trace elements have been shown to be relatively immobile up to middle amphibolite facies metamorphism and during hydrothermal alteration at low water:rock ratios (e.g., Pearce et al., 1984).

Bhatia and Crook (1986) showed that graywackes can have a large variation in their trace element characteristics and that these variations can be used to discriminate the tectonic setting of sedimentary basins in which the sediments accumulated. The interrelationships between trace elements Th, Sc, La, Yb, and Zr were used, among other trace elements, by Bhatia and Crook (1986) to recognize oceanic island arc, continental island arc, active continental margin, and passive margin settings. On a La-Th-Sc diagram (Fig. 9B), our semischist samples plot in a tight area that straddles the fields for active continental margin plus passive margin (fields C + D) and continental island arc (field B). On a Th-Sc-Zr/10 diagram (Fig. 9C), Bhatia and Crook (1986) were able to clearly discriminate between the active continental margin and passive margin settings; our samples plot just within the passive margin field, adjacent to its boundary with the continental island arc field.

Although the analyzed samples are greenschist facies metasedimentary rocks, based on associated clastic and calcareous rocks and the presence of Proterozoic to Archean detrital zircon, we also plot their trace element ratios on discrimination diagrams designed for felsic- and intermediate-composition igneous rocks (Figs. 9D, 9E). Our purpose in these plots is to test our hypothesis that the metasedimentary rocks were derived from quartz-phyric, felsic volcanic, hypabyssal, or plutonic rocks. In the Ta versus Yb tectonic-discrimination diagram (Fig. 9D), all of the semischist samples plot in the volcanic-arc granite field with completely overlapping ratios for samples from the Sheep Creek Member and the Butte assemblage. In primitive mantle-normalized multielement plots (Fig. 9E), all samples display deep troughs in Nb and Ta relative to adjacent elements, a pattern that is characteristic of arc magmas (e.g., Sun and McDonough, 1989). As with the Ta versus Yb ratios, multielement plots from the two study areas overlap.

Comparison Among Detrital Zircon Ages in Our Study

A comparison of detrital zircon ages from the Alaska Range and western Yukon-Tanana Upland (Figs. 7 and 8; Tables 2 and 3) shows similar patterns and populations for all but one sample. In general, all the samples (except Healy schist sample 05ADb34) have the same detrital zircon age populations, but in slightly different proportions. The most prominent detrital zircon peak age ranges, ca. 2.7–2.6 Ga and 1.9–1.8 Ga, display the largest increases in the cumulative probability of each sample (Fig. 8B). All these samples exhibit a dominant Paleoproterozoic peak ca. 1.80 Ga and a subdued Neoproterozoic peak ca. 2.6 Ga, secondary peaks between those ages, and no individual ages younger than 771 ± 14 Ma. The one exception is sample 05ADb34, in which Mesoproterozoic ages are abundant (Figs. 7A and 8; Table 2). Mesoproterozoic zircons are rare among all samples except for sample 05ADb34. A few Neoproterozoic grains were identified in three samples, but none defined statistically significant populations.

We also applied MDS using the R code of Vermeesch et al. (2016) as another means of assessing the similarity between our samples and other published data (Fig. 10). The MDS plot of the U-Pb data sets uses the K-S effect size as a dissimilarity measure. MDS is a statistical technique that uses pairwise calculated dissimilarities between samples to produce a map of points on which more similar samples cluster closely (Vermeesch, 2013). More dissimilar samples plot father apart. For samples with a small number of analyses, such as those for the Healy schist and Keevy Peak Formation, the K-S and MDS statistical data record similarities in the presence or absence of ages, but comparisons of the proportions of the age groups might not be well constrained. Nevertheless, Figure 10 clearly shows the marked dissimilarity between Healy schist samples 05ADb35 and 05ADb36 that plot on the left side of the diagram and sample 05ADb34 that plots on the right side of the diagram.

The abundance of U-Pb ages between ca. 1.59 Ga and 0.89 Ga in Healy schist sample 05ADb34 implies that the source area of the detrital grains in this quartzite included, in addition to the widespread Paleoproterozoic zircon populations present regionally, additional local Neoproterozoic and late Mesoproterozoic source areas. This source also may have provided the few Mesoproterozoic grains identified in Healy schist samples 05ADb35 and 05ADb36, collected ~3 km south and 17 km northeast of sample 05ADb34, respectively, and 2 Mesoproterozoic grains (ca. 1.43 and 1.70 Ga) present in sample 04ADb01B from the overlying Keevy Peak Formation (Table DR6).

RESEARCH
Figure 9. Selected plots of whole-rock geochemical data from semischist samples from east-central Alaska. (A) SiO$_2$/Al$_2$O$_3$ versus K$_2$O/Na$_2$O plot showing fields from Pettijohn et al. (1987) modified by Creaser et al. (1997): G—graywacke; LA—lithic arenite; A—arkose. Average composition of upper continental crust is from McLennan (2001). (B, C) La-Th-Sc and Th-Sc-Zr/10 diagrams, respectively, which serve as tectonic setting discrimination diagrams for clastic sediments (Bhatia and Crook, 1986). Labeled fields: A—oceanic island arc; B—continental island arc; C—active continental margin; D—passive margin. (D) Ta-Yb tectonic discrimination diagram for granitic rocks (Pearce et al., 1984). WPG—within-plate granite; syn-COLG—syncollisional granite; VAG—volcanic-arc granite; ORG—ocean ridge-type granite. (E) Primitive mantle normalized plot of trace element data from the quartzose metasedimentary rocks. Primitive mantle values are those of Sun and McDonough (1989); compatibility of elements, i.e., the degree to which they favor the solid phase during melting or crystallization, increases to the right. Geochemical data are given in Table DR2.
structure of the Healy schist has been mapped in any detail, we cannot rule out the possibility that the stratum from which sample 05ADb34 was collected is either from a different stratigraphic level, structural sheet, or both, compared to the other Healy schist and Totatlanika Schist samples.

Spectra of all three detrital zircon populations of Sheep Creek Member semischist (Figs. 7E–7G and 8A) have a prominent double peak between ca. 1.85 and 1.77 Ga as well as a subsidiary peak ca. 2.60 Ga. The differences between the combined analysis for Sheep Creek sample 03ADb14 and that of sample 98ADb79A, discussed here, are illustrated in the multidimensional scaling plot (Fig. 10). There, the combined analysis of sample 03ADb14 plots in a lower cluster on the diagram than the higher cluster formed by sample 98ADb79A, two Healy schist samples, and the Keevy Peak sample. Because the Sheep Creek Member of the Totatlanika Schist was mapped as the core of a syncline (e.g., Gilbert and Bundtzen, 1979), and because published U-Pb zircon ages indicate that the underlying members of the Totatlanika Schist include abundant Late Devonian and Early Mississippian felsic and intermediate-composition metaigneous rocks (Fig. 3) (Dusel-Bacon et al., 2004), the absence of Devonian or Mississippian zircons in the detrital zircon populations of the Sheep Creek samples is surprising. However, given the evidence for polyphase deformation and thrust faulting in the region, the original stratigraphic relationship of the Sheep Creek protoliths to those of the adjacent rocks is uncertain, and therefore the proposed syncline may be described more accurately as a synform. Previously published SHRIMP U-Pb ages of inherited zircon cores of ca. 2681–761 Ma for metaigneous rocks from the Totatlanika Schist and ca. 2673–895 Ma for a metaigneous rock that intrudes the Healy schist (Supplementary Data Table S2 of Dusel-Bacon and Williams, 2009) indicate a similar provenance for the source of the incorporated crustal material in the Devonian and Mississippian magmas and for the detrital zircons in the quartzose metasedimentary rocks of our study.

The detrital zircon patterns of the two semischist samples from the Butte assemblage have a major age cluster ca. 1.9–1.7 Ga and minor populations between ca. 2.6 and 2.5 Ga, similar to each other and to the detrital zircon pattern of semischist from the Sheep Creek Member of the Totatlanika Schist (Figs. 7 and 8; Table 2). On the MDS plot (Fig. 10), the two Butte assemblage samples plot very close to Sheep Creek sample 03ADb14. K-S statistics (Table 3) also indicate a close similarity between Butte assemblage and Sheep Creek samples. We conclude that...
the similarity in detrital zircon populations, in addition to the previously mentioned textural and geochemical similarities between the Sheep Creek Member of the Totatlanika Schist and the Butte assemblage, supports continuity of the geology (i.e., correlation of these units) across the Tanana River valley and derivation from common source areas. Detrital zircon populations from Sheep Creek and Butte assemblage also have P values >0.05 when compared with zircons from the Keevy Peak sample and Healy schist sample 05ADb36 (Table 3), suggesting that all the zircons in these units were likely derived from the same population.

**Comparison of Our Detrital Zircon Ages with Those from Other Areas**

We compare individual and composite detrital zircon samples from our study with those from previously published studies of three samples of siliciclastic metasedimentary rocks in east-central Alaska and from two samples from the allochthonous Yukon-Tanana terrane in the Yukon by means of K-S statistics (Table 3), the MDS plot (Fig. 10), and normalized KDE plots (Fig. 11). These detrital zircon samples are from: (1) quartzite from the Jarvis belt (Dashkysky et al., 2003) of the central Alaska Range (locality 1 in Fig. 2). The Jarvis belt is made up of green-schist facies semischist, phyllite, and marble of unknown protolith age, and Late Devonian and Early Mississippian felsic metaigneous rocks that were correlated (in Dusel-Bacon et al., 2006) with the Totatlanika Schist and the Butte assemblage; (2) grit of the Talkeetna quadrangle (Bradley et al., 2007) (locality 1 in Fig. 12), interpreted by Silberling et al. (1994) to be part of the Yukon-Tanana terrane; (3) grit from the Wickersham unit (Bradley et al., 2007) northwest of Fairbanks (locality 2 in Fig. 2); and (4) quartzite from pre–Late Devonian age metasedimentary rocks of the Snowcap assemblage in western Yukon (Piercey and Colpron, 2009) (locality 2 in Fig. 12). The Snowcap assemblage is interpreted to be the basement of the allochthonous Yukon-Tanana terrane, which is the rifted fragment of the western continental margin of Laurentia (Nelson et al., 2006; Colpron et al., 2006a, 2006b).

All of these detrital zircon samples have comparable major age populations ca. 2.8–2.6 and 2.1–1.8 Ga. They all lack ages in the range of ca. 1.6–1.0 Ga that only have been found in Healy schist sample 05ADb34 (Fig. 11). The MDS plot shows the spatial grouping of the Jarvis, Talkeetna, Wickersham, and Snowcap samples with all of our samples except the anomalous Healy schist sample. The K-S statistical comparison of detrital zircon age populations from our study with those from the other areas in east-central Alaska and Yukon (Table 3) also shows the dissimilarity of Healy schist sample 05ADb34 with all the samples from other studies. Zircon age populations from the other two samples of Healy schist, Keevy Peak, and Butte assemblage sample 96ADb25A are statistically similar to the age populations from all four comparative studies (Table 3). Sheep Creek sample 03ADb14 is statistically similar to Jarvis, Talkeetna, and Wickersham samples; Sheep Creek sample 98ADb79A only has statistical similarity with the Jarvis sample (Table 3). The similarity between the detrital zircon age populations in many of our samples, which we interpret as part of parautochthonous North America, with those in the Snowcap quartzite supports the generally accepted notion that the two areas were once adjacent prior to rifting during Devonian and Early Mississippian time and were developed in the same continental margin settings (e.g., Dusel-Bacon et al., 2006; Nelson et al., 2006).

Detrital zircons from Early Mississippian to late Paleozoic strata in the allochthonous Yukon-Tanana terrane from central Yukon to southern British Columbia have Archean, Paleoproterozoic, and minor Mesoproterozoic populations that resemble those from our Alaskan study, but unlike our samples, they also include Phanerozoic populations with Devonian and Early Mississippian ages (Gleeson et al., 2000; Colpron et al., 2006b; Murphy et al., 2006; Nelson and Gehrels, 2007; Holm-Denoma and Jones, 2016). Figure 11 shows detrital zircon plots from two Mississippian samples from the Yukon-Tanana terrane, a grit sample from the upper Swift River Group (locality 3 in Fig. 12; Nelson and Gehrels, 2007) and a clastic rock from the Wolverine Lake group in the displaced sliver of the terrane northeast of the Tintina fault (Fig. 1) in the Finlayson Lake area in southern Yukon (locality 4 in Fig. 12; Murphy et al., 2006). The mid-Paleozoic detrital zircon ages in these samples are roughly coeval with the oldest arc- and rift-related magmatism in the Yukon-Tanana terrane (e.g., Piercey et al., 2006; Nelson and Gehrels, 2007). The range of Precambrian detrital zircon ages indicates a shared Laurentian miogeoclinal provenance for the parautochthonous North American rocks of east-central Alaska and the Snowcap assemblage prior to rifting of the allochthonous Yukon-Tanana-Tanana terrane in Devonian to Mississippian time.

**Constraints on the Depositional Ages and Provenance of Our Samples**

The depositional ages of our samples from the metasedimentary strata of parautochthonous North America in east-central Alaska are poorly constrained. The youngest detrital zircon age populations from our study (Table 2) establish maximum depositional ages of ca. 1007 Ma for the anomalous Healy schist sample (05ADb34) and ca. 1879–1765 for the other samples in the Alaska Range, and ca. 1700 Ma for the Butte assemblage of the western Yukon-Tanana Upland. Although the 3 ca. 780 Ma U-Pb zircon ages from 2 samples of the Sheep Creek Member of the Totatlanika Schist in the Alaska Range (Table DR6) are too few to constitute a statistically viable minimum age population (Table 2), they nonetheless have significant implications in indicating both a Neoproterozoic maximum depositional age for at least that unit, and a potential source from a major magmatic event in western Laurentia. Precise U-Pb dating of baddeleyite from mafic igneous rocks extending from near the Arctic Ocean to Wyoming and Montana yielded 16 statistically indistinguishable ages that have a composite age of 779.4 ± 0.8 Ma (Harlan et al., 2003). Harlan et al. (2003) named the widespread and synchronous magmatic event that produced the ca. 780 Ma dikes and sills the Gunbarrel magmatic event; they showed that this event extended for >2400 km along the western margin of the Neoproterozoic Laurentian craton and suggested that it may have accompanied initial breakup of the supercontinent Rodinia and development of the proto-Pacific Ocean. Thus, the ca. 780 Ma geologically significant age in 2 of our samples is consistent with the clear Laurentian signature of our detrital zircons based on the older and statistically viable age populations and ranges discussed in the following.

A minimum depositional age for the metasedimentary rocks of our study is indicated by Late Devonian U-Pb zircon crystallization ages of crosscutting metagneous bodies and overlying metavolcanic rocks (Dusel-Bacon et al., 2006, and references therein). This minimum depositional age is supported by the Middle Devonian to Early Mississippian conodonts at one locality in the Mystic Creek Member of the Totatlanika Schist (Csejtey et al., 1992), and coral bracketed between Late Ordovician and Middle Devonian age found in float in the northwestern Big Delta quadrangle (Smith et al., 1994).

U-Pb detrital zircon ages from our study compare favorably with those from Devonian and older passive margin strata from western North America (Fig. 13). Especially relevant to our study are detrital zircon age references for passive margin strata from eastern Alaska and British Columbia (Gehrels and Pecha, 2014). The detrital zircon reference patterns for two passive margin miogeoclinal samples in eastern Alaska, one from the lower Cambrian Adams Argillite and another from the upper Devonian
Figure 11. Normalized kernel density estimate plots of detrital zircon ages from our study compared with those from other areas of parautochthonous North America (PNA) basement in east-central Alaska and the allochthonous Yukon-Tanana terrane (YTT) in the Canadian Cordillera. Units and sample numbers for plots are shown on left; number of grains is plotted on right. Composite plots shown in bold. The portion of the upper Swift River Group spectrum for ages younger than 600 Ma has been multiplied by 10× in order to better illustrate the presence of the mid-Paleozoic age population. References for data from other samples from the parautochthonous North American and Yukon-Tanana terrane are given in the text.
Nation River Formation (locality 5 in Fig. 12), both have dominant detrital zircon age populations of 2.0–1.8 Ga that are also common to our samples from eastern Alaska (Fig. 13) (Gehrels and Pecha, 2014). However, the Nation River Formation also contains zircon grains of Ordovician to Early Devonian (0.47–0.40 Ga) and Mesoproterozoic (1.6–1.0 Ga) age that are absent from all but one (05ADb34) of our samples. Results of the K-S test (Table 3) and MDS plot (Fig. 10) indicate that only the anomalous Healy schist sample is significantly similar to the samples from the Nation River Formation and Adams Argillite; all other samples showed no similarity to these strata, indicating that they were derived from one or more different sources.

Detrital zircons from pre-Devonian passive miogeoclinal strata from northern British Columbia, i.e., the lower Cambrian Atan Group and lower or middle Ordovician Monkman Formation (locality 6 in Fig. 12), contain dominant populations of 2.1–1.8 Ga and subordinate populations between ca. 2.7 and 2.3 Ga (Fig. 13) (Gehrels and Pecha, 2014). These Paleoproterozoic to Neoarchean age populations also are present in our samples from east-central Alaska (Figs. 7 and 8). In addition, the Ordovician Monkman Formation contains several grains with much younger ages of ca. 1.1–1.0 Ga (Gehrels and Pecha, 2014) that overlap a major age cluster present in Healy schist sample 05ADb34. Absent from the detrital zircon pattern of pre-Devonian strata from northern British Columbia are the ca. 1.6–0.9 Ga ages in Healy schist sample 05ADb34. In spite of having some shared age populations, the results of the K-S test (Table 3) and MDS plot (Fig. 10) indicate that our samples are not significantly similar to the miogeoclinal strata from northern British Columbia.

Neoproterozoic to upper Ordovician passive margin strata from southern British Columbia (locality 7 in Fig. 12) have dominant and subordinate detrital zircon age populations (Gehrels and Pecha, 2014) that overlap with the populations of our samples (Fig. 13). Dominant...
<table>
<thead>
<tr>
<th>Layer</th>
<th>Age (Ma)</th>
<th>Count</th>
</tr>
</thead>
<tbody>
<tr>
<td>Healy schist</td>
<td></td>
<td>55</td>
</tr>
<tr>
<td>Healy schist composite</td>
<td></td>
<td>148</td>
</tr>
<tr>
<td>Keevy Peak Fm.</td>
<td></td>
<td>48</td>
</tr>
<tr>
<td>Sheep Creek Member composite</td>
<td></td>
<td>239</td>
</tr>
<tr>
<td>Butte assemblage composite</td>
<td></td>
<td>184</td>
</tr>
<tr>
<td>Composite of all samples but 05ADb34</td>
<td></td>
<td>619</td>
</tr>
<tr>
<td>Nation River Fm. (Upper Devonian)</td>
<td></td>
<td>198</td>
</tr>
<tr>
<td>Adams Argillite (Lower Cambrian)</td>
<td></td>
<td>187</td>
</tr>
<tr>
<td>Monkman Fm. (Lower or Middle Ordovician)</td>
<td></td>
<td>194</td>
</tr>
<tr>
<td>Atan Fm. (Lower Cambrian)</td>
<td></td>
<td>201</td>
</tr>
<tr>
<td>Mt Wilson Fm. (Middle or Upper Ordovician)</td>
<td></td>
<td>193</td>
</tr>
<tr>
<td>Hamill Gp. (Lower Cambrian)</td>
<td></td>
<td>196</td>
</tr>
<tr>
<td>Horsethief Creek Gp. (Neoproterozoic)</td>
<td></td>
<td>195</td>
</tr>
<tr>
<td>Composite of all samples but 05ADb34</td>
<td></td>
<td>302</td>
</tr>
<tr>
<td>Composite of all samples but 05ADb34</td>
<td></td>
<td>102</td>
</tr>
</tbody>
</table>

Figure 13. Normalized kernel density estimate plots of detrital zircon ages from our parautochthonous North American (PNA) samples compared with reference plots for samples from the northwestern North American passive margin strata and detrital zircon lineages from northwestern Laurentia. See text for explanation of lineages. Fm.—formation; Gp.—group.
populations from the Neoproterozoic Horsethief Creek and lower Cambrian Hamill Groups are primarily ca. 1.9–1.7 Ga, with subordinate populations of ca. 3.0–2.5 Ga. Zircon from the Ordovician Mount Wilson Formation has a slightly older dominant population of ca. 2.0–1.8 Ga, in addition to subordinate populations of ca. 2.1–2.0 Ga, 2.8–2.5 Ga, and 1.0 Ga (Gehrels and Pecha, 2014). The K-S test shows the most similarity between zircon from our samples and that from southern British Columbia strata, particularly the Horsethief Creek Group and Mount Wilson Formation (Table 3). This similarity is also illustrated in the MDS plot (Fig. 10) in which the left grouping of our samples is connected by relatively shorter straight lines to the Neoproterozoic Horsethief Creek Group and the Ordovician Mount Wilson Formation. However, there are numerous samples that are not similar to the detrital zircon characteristics of these strata (Table 3).

Viewed together, the detrital zircon ages from our study and those determined for passive margin strata of Neoproterozoic to Ordovician age from northern and southern British Columbia overlap for several age groupings, particularly the dominant 1.9–1.7 Ga populations and the subdominant 2.7–2.6 Ga populations. Statistical analysis of our data, discussed here, indicates that, exclusive of Healy schist sample 05ADb34, our samples show the greatest similarity with Neoproterozoic to Ordovician strata in southern British Columbia. This suggests either a common source for the strata in both areas, or a recycling of Neoproterozoic to Ordovician strata in southern British Columbia as the source for our samples. The large time gap between the youngest detrital zircons and the likely lower Paleozoic depositional age of the strata in our study is consistent with their originating in a passive margin environment (Beranek et al., 2016, and references therein).

Paleogeography and Provenance Implications

Provenance of Alaska Range and Upland Samples Exclusive of Sample 05ADb34

As stated herein, with the exception of Healy schist sample 05ADb34, detrital zircon ages from our east-central Alaska samples most closely resemble those from Neoproterozoic through Middle Ordovician miogeoclinal strata in British Columbia, Canada. In Neoproterozoic time, much of the craton was covered by 1.2–1.0 Ga Mesoproterozoic sedimentary detritus of the Grenville clastic wedge that was deposited by a pancontinental river system originating in the Grenville orogen (Young et al., 1979; Rainbird et al., 1992, 1997, 2012) (Fig. 12). Neoproterozoic strata in southern British Columbia show little sign of detritus from Grenville-age rocks. Instead, strata in southern British Columbia have dominantly Paleoproterozoic (1.9–1.8 Ga) and Neorarchean (2.9–2.5 Ga) detrital zircons (Fig. 13). This age range suggests derivation mainly from the nearby Canadian shield or Wyoming province (Gehrels and Pecha, 2014). The Wopmay orogen, which represents accretion of Proterozoic crust along the west flank of the Archean Slave Province (Ross, 1991, 2002) ca. 1.88 Ga (Hildebrand et al., 1987) (Fig. 12), is a likely source of detrital zircon for British Columbia. Recycling of zircons from the Paleoproterozoic continental arc of the Great Bear magmatic zone in the Wopmay orogen and its Archean precursors (Hildebrand et al., 1987; Ootes et al., 2017) could explain both the arc signature and the Precambrian detrital zircon populations of our samples, assuming that the zircon was transported from the same area.

The paleogeography of Laurentia in Cambrian time consisted of passive-margin sequences fringing the craton and a prominent transcontinental arch in its interior (Sloss, 1988). Cambrian strata from northern and southern British Columbia also have zircon detrital ages older than 1.8 Ga (Fig. 13), suggesting continuation of detritus sourced from the northwestern Canadian shield and the Wopmay orogen (Gehrels and Pecha, 2014). In the Ordovician, sea level was generally high, and Ordovician passive margin strata covered much of Laurentia (Sloss, 1988; Haq and Schutter, 2008). Strata along the length of the Cordilleran margin are dominated by grains older than 1.8 Ga (Gehrels et al., 1995; Gehrels and Pecha, 2014). The Peace River Arch region, a large cratonic uplift in northeastern British Columbia and northwestern Alberta (Fig. 12), was one of the few high-standing basement regions during shallow-marine deposition from Cambrian (and perhaps Neoproterozoic) through Devonian time (Douglas et al., 1970). The Peace River Arch was a likely source for Ordovician strata along the Cordilleran margin because, during that time frame, it not only exposed rocks in the common 1.9–1.8 Ga age range recorded in most detrital zircon populations in the northern Cordillera, but it also exposed rocks in the uncommon 2.1–2.0 Ga age range present in some detrital zircon samples (Gehrels et al., 1995; Gehrels and Ross, 1998; Gehrels and Pecha, 2014). Given the similarity between the detrital zircon age populations in our study, except sample 05ADb34, with the Archean and Paleoproterozoic basement ages in the Peace River Arch region, we also suggest that region to be a likely primary source area for sedimentary detritus in our samples. This source region was proposed in Dusel-Bacon and Williams (2009) for detrital zircons from quartzite from the Jarvis belt (Fig. 11), also part of the parautochthonous North American basement, in the eastern Alaska Range, and for inherited zircon from augen gneiss in the eastern Yukon-Tanana Upland.

Other source areas are also possible, however, given the presence of additional Archean and Paleoproterozoic basement provinces in the western Canadian shield outside of the Peace River Arch area (Fig. 12) that are of the same ages as our detrital zircon populations. In northwestern Canada, Neoproterozoic (ca. 0.8–0.6 Ga) supracrustal rocks of the Windermere Supergroup and correlative strata, referred to as Sequence C by Young et al. (1979), have a detrital zircon distribution characterized by only zircon whose source area is thought to be the Laurentian craton. In northwestern Canada, this Laurentian signature consists of dominant populations of 2.2–1.8 Ga, secondary populations of 2.8–2.5 Ga, and a subsidiary population of 2.4–2.2 Ga (Leslie, 2009; Hadlari et al., 2012). Detrital zircon age populations from Neoproterozoic and Cambrian age sandstones from northwestern Canada that have comparable zircon populations are proposed to have been derived from a recycling of detritus from these supracrustal rocks, and have been described as having a Sequence C or Laurentian cratonal source (Leslie, 2009; Hadlari et al., 2012) and as exhibiting a lineage C depositional pathway (Fig. 11) (Lane and Gehrels, 2014; Lane et al., 2016). The similarity of detrital zircon ages from our east-central Alaska samples, except Healy schist sample 05ADb34, to those from the lineage C composite shown in probability density plots (Fig. 13), the MDS plot (Fig. 10), and the K-S test (Table 3) suggests a dominant Laurentian cratonal source and a lineage C depositional pathway for our samples as well.

An even greater distribution of the northwestern Laurentian provenance and lineage C depositional pathway is indicated by the predominance of ca. 1.8 Ga Paleoproterozoic detrital zircons farther west in the Talkeetna grit (locality 1 in Fig. 12) and to the south where detrital zircon yields populations of ca. 2.0–1.6, 1.2–0.9, and 2.7–2.5 Ga in rocks of the pre-Devonian Tracy Arm assemblage that are included in a southeast Alaska suberrane of the Yukon-Tanana terrane (Fig. 1) (Pecha et al., 2016).

Provenance of Healy Schist Sample 05ADb34

The detrital zircon age distribution from Healy schist sample 05ADb34 differs markedly from zircon ages in our other samples. In addition to a major Paleoproterozoic cluster at 2.0–1.8 Ga and a minor Neorarchean component at 2.7–2.5 Ga that are common to our other samples, it also...
has Mesoproterozoic and Neoproterozoic populations of ca. 1.6–0.9 Ga that are rare to absent in our other samples (Figs. 7 and 8; Table 2), but are present to a minor, albeit statistically insignificant (Table 3), degree regionally in the following samples. (1) Detrital zircons of ca. 1.1–0.9 Ga age also occur in two of the Sheep Creek Member samples, one of the Butte assemblage samples, and as a minor component in Wickersham girt (Fig. 11; Bradley et al., 2007); (2) detrital populations between 1.6 and 0.9 Ga also occur in the Fairbanks schist from the northwestern Yukon-Tanana Upland (Holm-Denoma and Jones, 2016); and (3) small numbers of ca. 1.4 and 1.1 Ga inherited zircon cores are present in two of four Devonian to Mississippian peraluminous augen gneiss samples from the Tanacross quadrangle in the eastern Yukon-Tanana Upland (Dusel-Bacon and Williams, 2009). This similarity of these younger zircon age populations may suggest either a shared source component for all the above-mentioned areas, or possibly a recycling of the detrital grains from the Wickersham girt and Fairbanks schist into sedimentary strata from which sample 05ADb34 was collected. The incorporation of ca. 1.4 and 1.1 Ga zircon cores in peraluminous augen gneiss suggests a more widespread presence of this crustal component than is evidenced from detrital zircon studies in east-central Alaska.

A more distant northern Cordillera source area whose detritus may have been recycled to provide the ca. 1.6–0.9 Ga detrital zircons abundant in sample 05ADb34 is the upper Devonian Nation River Formation and the lower Cambrian Adams Argillite from eastern Alaska (Lane and Gehrels, 2014; Gehrels and Pecha, 2014) (Figs. 12 and 13; Table 3). The Adams Argillite was deposited on the western margin of a platform promontory, the Yukon stable block. This block was part of the subsiding rifted margin of Laurentia in early Paleozoic time that was flanked to the east and south by coeval deeper water facies of the Richardson trough and Selwyn Basin, respectively (Morrow, 1999; Gehrels et al., 1999). Poorly understood Proterozoic successions underlie the Yukon stable block (Lane and Gehrels, 2014). Our samples from the Yukon-Tanana Upland and Alaska Range may have been derived from a block analogous to, or even part of, the Yukon stable block. An argument in support of this source area is the fact that restoration of right-lateral displacement on the Tintina fault would bring sample 05ADb34 in closer proximity with the Nation River and Adams Argillite sample sites.

Other possible sources are the (1) Neoproterozoic and Cambrian Neruoapkuk Formation in northwestern Yukon and northeastern Alaska, which contains a subsidiary 1.6–1.0 Ga detrital zircon population in addition to the dominant population from the Laurentian craton source area (lineage C; Lane et al., 2016); (2) Proterozoic to Early Cambrian lower Backbone Ranges formation in the central Mackenzie Mountains, Northwest Territories, that has a few ca. 1.2–1.1 Ga detrital zircons among others that indicate a lineage C recycling history (Leslie, 2009); and (3) Neoproterozoic (0.98–0.78 Ga) strata of the Mackenzie Mountains and Shaler supergroup in northwestern Canada, part of the teeton stratigraphic Sequence B of Young et al. (1979) (Leslie, 2009). Neoproterozoic and Cambrian sandstones in northwestern Laurentia with detrital zircon patterns that include a dominant ca. 1.6–1.0 Ga population and other populations that match the signature of Sequence B strata are referred to as having lineage B detrital zircon distribution (Leslie, 2009; Lane and Gehrels, 2014; Lane et al., 2016). Thus, the minor 1.2–1.0 Ga zircon populations, and possibly the few grains at 1.4 Ga in a few of our detrital zircon samples and in inherited igneous zircon cores, may indicate that the depositional basins in which our samples formed included a minor contribution from a lineage B source in addition to the dominant lineage C source (Fig. 13). A similar hybrid of lineages C and B sources is indicated by the large proportion of 1.7–1.0 Ga zircons present in the southeast Alaska subterrane of the Yukon-Tanana terrane (Pecha et al., 2016). However, neither lineage B nor lineage C is statistically similar to Healy schist sample 05ADb34 (Table 3).

**Possible In Situ Source for Precambrian Zircons Beneath Eastern Alaska?**

Although supporting data are scarce, an alternative, more local source for the detrital zircon populations is possible. As mentioned here in discussing the geologic setting of the parautochthonous rocks of the Yukon-Tanana Upland, the oldest fossil in the region identified to date is the *Oldhamia* trace fossil of Early Cambrian to early-Middle Cambrian age from the Wickersham girt unit that is interpreted to structurally underlie the northwestern boundary of parautochthonous North America rocks (Figs. 1 and 2). In addition, because zircon cores of Archean to Neoproterozoic age occur in Devonian and Mississippian metageneous rocks throughout the Yukon-Tanana Upland and Alaska Range, it is reasonable to assume that the inherited zircon cores in the igneous rocks are from detrital zircons in the sedimentary and metasedimentary passive margin strata and/or a basement with Precambrian zircon through which the mid-Paleozoic magmas passed. Given that detrital zircon populations of the Wickersham girt sample overlap those from our study, Neoproterozoic to Ordovician strata may underlie the Yukon-Tanana Upland and eastern Alaska Range and be an extension of, or correlative with, the Wickersham girt.

Based on seismic reflection profiling acquired as part of the Lithoprobe Slave-Northern Cordillera Lithospheric Evolution (SNORCLE) transect, Cook et al. (2004) suggested that ancient North American rocks that project beneath exposed Neoproterozoic and Paleozoic rocks in the eastern part of the Cordillera may extend beneath accreted terranes in the west. Hadlari et al. (2015), building on the seismic reflection data of Cook et al. (2004), proposed that the Paleoproterozoic Fort Simpson Basin, a basin that formed at ca. 1.8 Ga and was filled by continental slope and terrace deposits before 1.6 Ga, extends westward across the Tintina fault beneath the Yukon-Tanana terrane (in their definition, including both the allochthonous Yukon-Tanana terrane and parautochthonous North American rocks). Although highly speculative, given the absence of exposed rock of Proterozoic age, the presence of inherited Proterozoic and Archean zircon cores in igneous zircon from orthogneisses throughout the region makes the possibility of Proterozoic passive margin strata, or even basement, beneath east-central Alaska worthy of further investigation.

Regardless of constraints on the age of the unexposed basement in east-central Alaska, the Precambrian detrital zircon populations in the metasedimentary rocks of our study require either recycling and sedimentary transport from passive margin sequences of northwestern Laurentia or more proximal and, as yet undiscovered or unidentified, basement high of this age that have either been completely removed by erosion or are not yet recognized.

**CONCLUSIONS**

1. The similarity in composition, texture, geochemistry, and detrital zircon geochronology of semischists from the Alaska Range (Sheep Creek Member of the Totallatanka Schist) and Yukon-Tanana Upland (Butte assemblage) suggests continuity of these units across the Tanana River valley and/or derivation from common source areas. Whole-rock trace element signatures of semischist samples imply a sedimentary source terrane dominated by detritus from either a continental margin arc or continental crust derived from such an arc, possibly from the Great Bear magmatic zone.

2. Detrital zircon age spectra from all our samples, except one anomalous Healy schist sample, have a major Paleoproterozoic (ca. 1.8 Ga) and a subdominant Neoarchean (ca. 2.6 Ga) peak, and secondary peaks between
those ages; Neoproterozoic and Mesoproterozoic grains are uncommon or absent. The zircon populations of these samples match those from Neoproterozoic to Ordovician American passive margin strata from British Columbia and may indicate either a recycling of sediments from those strata or possibly their extensions beneath east-central Alaska. The Peace River Arch region exposes rocks in the 2.1–1.8 Ga age range and is a likely source terrane for the Neoproterozoic to Ordovician passive margin sediments. Thus, our study indicates a northwestern Laurentian provenance and lineage C depositional pathway for the quartzose metasedimentary rocks of parautochthonous North American.

3. The anomalous Healy schist sample has subordinate detrital zircon populations of Paleoproterozoic and Neorarchean ages present in other samples from our study, but in addition, has a dominant population of Mesoproterozoic to Neoproterozoic zircon (ca. 1.6–0.9 Ga). The combination of these ages is similar to that in the Nation River Formation and Adams Argillite in eastern Alaska, suggesting either recycling from those units or contributions from a primary or recycled Laurentian cratonic source (lineage C) combined with a contribution from Neoproterozoic strata of the Mackenzie Mountains and Shaler Supergroup in northwestern Canada (lineage B).

4. The similarity between detrital zircon age populations of all but our anomalous sample with quartzite from the Snowcap assemblage, interpreted as basement to the allochthonous Yukon-Tanana terrane, supports, but does not prove (given the far-traveled history of some zircon), the interpretation that the two areas were once adjacent prior to rifting during Devonian and Early Mississippian time. Neoproterozoic minimum detrital zircon age populations in parautochthonous North American rocks contrast with the mid-Paleozoic minimum detrital zircon age populations in the two areas of the Yukon-Tanana terrane dated thus far, and may provide a valuable means of determining the tectonic affinity of pericratonic rocks in other areas of the northern Cordiller.

5. No Precambrian strata, basement, or magmatic rocks have been identified in the Yukon-Tanana Upland, or in the Alaska Range. Thus, a primary source to supply Precambrian detrital zircon in east-central Alaska must either be outside the immediate area (possibly the Yukon stable block) or beneath it as unexposed North American continental margin strata or basement. The overlap between Precambrian ages of inherited zircon cores from mid-Paleozoic metagranite rocks in east-central Alaska and those of zircon from metasedimentary rocks of our study suggests that western North American passive margin strata of Neoproterozoic to early Paleozoic age may underlie east-central Alaska.

ACKNOWLEDGMENTS
We thank Charlie Bacon for his invaluable contributions in field work and sample collection. JoAnne Nelson provided helpful comments on an earlier version of this manuscript. We acknowledge Renee Pillers for mineral separations and imaging of zircons analyzed at the SHRIMP-RG jointly operated by the U.S. Geological Survey and Stanford University. Joe Woodren provided three zircon mounts that were analyzed by Holm-Denoma. Reviews by George Gehrels and Jim Crowley helped improve the manuscript. This study was funded by the Mineral Resources Program of the U.S. Geological Survey. Any use of trade, firm, or product names is for descriptive purposes only and does not imply endorsement by the U.S. Government.

REFERENCES CITED
Detrital zircon geochronology, east-central Alaska


Sirome, R.N., 2000, Reading the bumpy barcode: Quantification and interpretation of detrital geochronology data with provenance study samples from modern beach sands and Archean metasedimentary rocks: Geological Society of America Abstracts with Programs, v. 32, no. 6, p. 68.


MANUSCRIPT RECEIVED 17 APRIL 2017
REVISED MANUSCRIPT RECEIVED 7 JULY 2017
MANUSCRIPT ACCEPTED 6 AUGUST 2017

Printed in the USA