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The tectonic significance of the Early Cretaceous forearc-
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Abstract

A complex array of faulted arc rocks and variably metamorphosed forearc accretionary complex rocks form a mappable arc-forearc boundary in southern Alaska known as the Border Ranges fault (BRF). We use detrital U-Pb zircon dating of metasedimentary rocks within the Knik River terrane in the western Chugach Mountains to show that a belt of Early Cretaceous amphibolite-facies metamorphic rocks along the BRF was formed when older mélange rocks of the Chugach accretionary complex were reworked in a sinistral-oblique thrust reactivation of the BRF during a period of forearc plutonism. The metamorphic subterrane of the Knik River terrane has a maximum depositional age of 156.5 ± 1.5 Ma and a detrital zircon age spectrum that is indistinguishable from the Potter Creek assemblage of the Chugach accretionary complex,

supporting correlation of these units. These ages contrast strongly with new and existing data that show Triassic to Earliest Jurassic detrital zircon ages from metamorphic screens in the plutonic subterrane of the Knik River terrane, a fragmented Early Jurassic plutonic assemblage generally interpreted as the basement of the Peninsular terrane. Based on these findings, we propose new terminology for the Knik River terrane. We propose the terms: (1) “Carpenter Creek metamorphic complex” for the Early Cretaceous “metamorphic subterrane”; (2) “western Chugach trondhjemite suite” for the Early Cretaceous forearc plutons within the belt; (3) “Friday Creek assemblage” for a transitional *mélange* unit that contains blocks of the Carpenter Creek complex in a chert-argillite matrix; and (4) “Knik River metamorphic complex” in reference to metamorphic rocks engulfed by Early Jurassic plutons of the Peninsular terrane that represent the roots of the Talkeetna arc. The correlation of the Carpenter Creek metamorphic complex with the Chugach *mélange* indicates that the trace of the Border Ranges fault lies ~1–5 km north of the map trace shown on geologic maps, although like other segments of the Border Ranges fault, this boundary is blurred by local complexities within the Border Ranges fault system. Ductile deformation of the *mélange* is sufficiently intense that few vestiges of its original *mélange* fabric exist, suggesting the scarcity of rocks described as *mélange* in the cores of many orogens may result from misidentification of rocks that have been intensely overprinted by younger, ductile deformation.

Key Words: Tectonics, Alaska, *mélange*, detrital zircon geochronology, U-Pb dating

44 INTRODUCTION

45 The arc-forearc boundary is one of the most poorly understood tectonic elements of
46 convergent plate margins because of poor exposure. In most margins, the boundary is either
47 underwater or buried by sediment. Where the boundary is exposed, it invariably records a
48 complex overprinting history because the mechanical contrast of rocks along the join leads to
49 repeated reactivation (e.g., Pavlis and Roeske, 2007). Both subduction-erosion processes and
50 strike-slip faulting can reform the contact, juxtaposing rocks originating at different times and
51 positions. Perhaps the most difficult issue, however, is the potential for highly variable thermal
52 conditions during the history of rocks in this setting. During prolonged subduction, the arc-
53 forearc boundary typically would lie in a relatively cold state from the subduction process, but
54 events such as ridge subduction or interruption of a subduction zone by an episode of margin
55 parallel strike-slip faulting could significantly modify the thermal conditions. Similarly,
56 reactivation of the boundary could lead to differential exhumation, burial, or both, across the
57 boundary. Thus, it is not surprising that wherever this boundary is exposed, the inferred geologic
58 history is always complex.

59 The Border Ranges Fault (BRF) of southern Alaska is one of the best exposed arc-forearc
60 boundaries in the world. The BRF separates crystalline basement of a Late Triassic-Jurassic
61 oceanic arc and a forearc accretionary complex that was accreted in the same polarity as the
62 modern subduction zone (MacKevett and Plafker, 1974; Pavlis, 1982). Neogene uplift has
63 exposed the BRF over large areas with spectacular glaciated exposures along the northern flanks
64 of the coastal mountains of southern Alaska (Figure 1). Deeply exhumed rocks are exposed
65 locally with exposures of upper mantle ultramafic tectonites and lower crustal rocks in the arc
66 assemblage (e.g., Burns, 1985; DeBari and Coleman, 1989; Mehl et al., 2003) as well as

67 scattered blueschists in the forearc assemblage (e.g., Roeske, 1986; Sisson and Onstott, 1986;
68 López-Carmona et al., 2011). Although this boundary originated as a subduction megathrust in
69 the Early Mesozoic, the tectonic contact has been extensively reactivated, obscuring much of the
70 pre-Cenozoic history of the contact (e.g., Pavlis and Roeske, 2007). Nonetheless, younger
71 structures locally have isolated remnants of older segments of the structural contact, preserving
72 vestiges of the Mesozoic history. Particularly significant is a segment of the fault system ~75 km
73 northeast of Anchorage (Figure 1) that preserves a record of ductile, Early Cretaceous, sinistral-
74 oblique thrusting along the contact (Pavlis et al., 1988). The combination of high-temperature
75 metamorphism and forearc plutonism associated with this Early Cretaceous event indicates an
76 unusual history compared to the depressed thermal gradients typical of forearc regions and has
77 long been recognized as either a ridge subduction or subduction initiation/rejuvenation event
78 (Pavlis, 1982; Roeske et al., 1989). The area was studied extensively in the 1980's (e.g., Pavlis et
79 al., 1988; Barnett et al., 1994; Pavlis 1996) but, at that time, geochronology was incapable of
80 resolving a number of issues. Applying single-crystal zircon U-Pb geochronology, however, can
81 resolve many questions left unanswered in these older studies.

82 In this paper we use detrital zircon U-Pb geochronology to provide new constraints on the
83 nature of this Early Cretaceous forearc plutonic and metamorphic event. We begin with a review
84 of the basic geologic framework developed in the 1980's and show that the ductile thrust system
85 reworked parts of the forearc assemblage. We interpret the high-temperature metamorphism as
86 the product of heat advection related to pluton emplacement, with the ultimate heat source
87 interpreted as an Early Cretaceous ridge subduction event. We also discuss how processes of this
88 type can obscure the original characteristics of the arc-forearc boundary in exhumed arc-trench
89 systems incorporated into collisional orogens.

TECTONIC SETTING

Southern Alaska consists of a series of crustal fragments added to North America during Mesozoic time (Coney et al., 1980). The largest of these fragments is the Wrangellia composite terrane, which comprises a Paleozoic to Mesozoic arc complex that collided with North America during the late Mesozoic (e.g., Plafker et al., 1994; Trop and Ridgway, 2007; Beranek et al., 2014; Israel et al., 2014). An ocean basin was closed along the inboard side of the Wrangellia composite terrane but the details of that basin closure event are controversial (e.g., Umhoefer, 2003; Trop and Ridgway 2007). It is unclear whether this was a large ocean basin or a back-arc basin that formed following an earlier collision, the role of strike-slip during (and following) the closure of the ocean basin, and the paleolatitude of the collision, causing debate of arcs traveling far or existing just offshore (e.g., Beranek et al., 2014; Umhoefer, 2003; Trop and Ridgway, 2007; Cowan et al., 1997; Gehrels et al., 2009; Colpron et al., 2007). Nonetheless, there is widespread agreement that at least parts of the Wrangellia composite terrane were isolated from North America during much of the Mesozoic, particularly the Peninsular terrane of south Alaska, which comprises an oceanic arc with no clear connection to a continent during its Triassic to Middle Jurassic formation (e.g., Roeske et al., 1989; Rioux et al., 2007; Amato et al., 2007). The Late Triassic to Early Jurassic Talkeetna arc of the Peninsular terrane is of great interest because of the unusually complete exposures of a crustal section of this arc system in the northern Chugach Mountains (Figure 1).

The crustal section of the Talkeetna arc is bounded to the south by the BRF (Figure 1). The BRF is defined as the structural contact between the crystalline basement of the Mesozoic arc(s) and a forearc accretionary complex that was emplaced beneath it (Pavlis and Roeske 2007), but

has been defined differently in the past (Plafker et al., 1989). In terrane terminology, the accretionary complex (Figure 1) is generally referred to as the Chugach terrane (Plafker et al., 1977, 1989, 1994), but it is better referred to as the Chugach accretionary complex (Moore et al., 1973; Amato et al., 2013). At regional scale the BRF is easily distinguished as the lithologic boundary between the plutonic roots of the Wrangellia composite terrane and metasedimentary and metavolcanic rocks of the Chugach terrane (e.g., MacKevett and Plafker, 1974). However, at local scales, the contact is a broad zone of deformation known as the Border Ranges fault system (BRFS) with repeated cycles of reactivation and overprinting (Pavlis and Roeske, 2007). The Chugach terrane was emplaced beneath the BRF during subduction of the same polarity as the modern Aleutian trench. Accretion began no later than latest Triassic time (Roeske et al., 1989) and continued, at least intermittently, to the present day (Amato and Pavlis, 2010). The Chugach terrane is divided into two major divisions, or subterrane, based on structural style and lithology: an older *mélange* subterrane and a younger coherently deformed turbidite assemblage, or “flysch” subterrane (e.g., Plafker et al., 1977, 1994). The flysch subterrane comprises the bulk of the Chugach terrane, but is younger than any rocks considered here. We use the simpler, informal term “Chugach *mélange*” for the regional lithotectonic unit that Plafker et al. (1994) referred to as the “*mélange* subterrane of the Chugach terrane.” In the Kenai and Chugach Mountains, the Chugach *mélange* is referred to as the McHugh Complex from the terminology of Clark (1973), but other names are used regionally.

Although mapped regionally as a single unit, we now know the Chugach *mélange* is comprised of several different assemblages of different ages and lithologies (Amato and Pavlis, 2010; Amato et al., 2013). From oldest to youngest the known components include the following:

- 1) A series of blueschist bodies recognized along or in close proximity to the BRF in south-central Alaska (Roeske, 1986; Sisson and Onstott, 1986; Roeske et al., 1989). These blueschists yield Early Jurassic cooling ages with unknown protolith ages (Sisson and Onstott, 1986; Roeske et al., 1989).
- 2) Detrital zircon studies show that a large part of the Chugach mélange has Late Jurassic maximum depositional ages that Amato and Pavlis (2010) suggested approximated their accretionary age. In the Anchorage area, this unit is lithologically distinct, characterized by mélange matrix of black argillite-chert-green tuff that is a common association in circum-Pacific mélanges (e.g., Cowan, 1985). Amato et al. (2013) proposed the name Potter Creek assemblage for these rocks.
- 3) Day (2014) demonstrated that the Liberty Creek blueschist in the central Chugach Mountains is a distinctly younger blueschist assemblage, with ages no older than 130-140 Ma, but accreted prior to mid-Cretaceous time.
- 4) The youngest unit of the Chugach mélange is the McHugh Creek assemblage of Amato et al. (2013), which is dominated by mid-Cretaceous coarse, clastic rocks with structurally interleaved slabs of metavolcanic rocks. In the Anchorage area, the McHugh Creek assemblage can be routinely distinguished from the Potter Creek assemblage by lithology, although prior to detrital zircon dating, the age distinction in the assemblage was not known (e.g., Clark, 1973; Pavlis, 1982).

Because of overprinting, different segments of the BRF record different histories (Pavlis and Roeske, 2007). Here we focus on a segment of the BRF in the western Chugach Mountains, northeast of Anchorage (Figure 2), where younger structures have partially bypassed Mesozoic structures, preserving a record of the Early Cretaceous history.

GEOLOGY OF THE WESTERN CHUGACH MOUNTAINS

From the Knik River eastward to just east of Coal Creek (Figure 2) the pseudostratigraphy of the Talkeetna arc is well preserved with deeper structural levels from north to south. This segment of the BRFS contains a complex Cretaceous overprint that has been largely lost or is different in other segments of the margin (Pavlis and Roeske, 2007). Four distinctive lithotectonic belts are recognized from south to north 1) the Chugach mélange (McHugh Complex), comprised of the McHugh Creek assemblage (KMm--dark green unit, Figure 2) and a transitional mélange unit that may appear lithologically equivalent to the Potters Creek but likely has a Early Cretaceous depositional age due to being cut by Cretaceous plutons (JKamm--blueish green unit, Figure 2); 2) a belt of metamorphic rocks (KJsch--blue and Jgw/Jum—purple units in Figure 2) that are extensively intruded by a suite of Cretaceous leuco-tonalite to trondhjemite plutons (Klt—red unit, Figure 2); 3) a complexly faulted assemblage that is comprised primarily of intermediate to mafic plutonic rocks (Jg—purplish units, Figure 2) with small, isolated screens of metamorphic rock (Jsch—gray unit, Figure 2) and cut by the Cretaceous plutons; and 4) a major fault zone marked by cataclastic rock up to 1 km wide (TKc—dark green unit, Figure 2) that separates both of these assemblages from rocks just to the north. These northern rocks are clearly part of the Peninsular terrane/Talkeetna arc based on extensive exposures of the Early Jurassic Talkeetna volcanic rocks (Jtk--dark blue unit, Figure 2), and are cut by intermediate plutonic rocks with Early Jurassic intrusive and cooling ages (Jeqd—orange unit, Figure 2) (Pavlis, 1982, 1983; Barnett et al., 1994; Rioux et al., 2007; Hacker et al., 2008). The Talkeetna arc assemblage is also the basement for thick late Mesozoic to Paleogene forearc-basin deposits

exposed just to the north in the Matanuska Valley (Km--green and Tch—tan units, northern part of Figure 2).

Pavlis et al., (1988) used terrane analysis to define the second and third assemblages as the Knik River terrane. However, they interpreted the third assemblage (Jg and Js, figure 2) as the faulted middle crust of the Talkeetna arc and metamorphosed ultramafic bodies (Jm and associated Jgw, Figure 2) as the upper mantle basement of the Talkeetna arc. They further interpreted the deformation as a broad, ductile to brittle thrust system that is Early Cretaceous in age. In this interpretation (Figure 3), the metamorphic rocks (KJs in Figures 2 and 3) represent a ductile, Early Cretaceous sinistral-oblique, thrust system that was invaded by the leucotonalite/trondjemite suite (Klt, Figures 2 and 3) late in the thrusting history (Pavlis et al., 1988). Early Cretaceous cooling ages are limited to this metamorphic assemblage and the Cretaceous plutons (Barnett et al., 1994), but the plutons also cross-cut brittle faults at higher structural levels as well as a mélange that contains blocks of the metamorphic assemblage (JKamm, Figures 2 and 3) at lower structural levels. These observations, together with partial preservation of an inverted metamorphic field gradient within the thrust system, suggest that the metamorphism was intimately related to heat-advection by the syn-tectonic plutons emplaced into an active thrust with disturbed thermal gradients (Pavlis et al., 1988; Pavlis, 1986a; Pavlis, 1996). In this model, the metamorphic peak was achieved during ductile thrusting when the bulk of the plutons were emplaced, but the system cooled below conditions for ductile deformation, incorporating slices of the metamorphic assemblage into the mélange prior to the emplacement of the pluton that cuts the JKamm mélange (Figures 2 and 3). This model predicts that the pluton in upper Carpenter Creek, which cuts the JKamm mélange (Figure 2), is also the youngest pluton in the belt.

Early work on the metamorphic assemblage correlated all of these rocks and assumed they were Early Jurassic or older (Pavlis, 1983). However, as work expanded on the assemblage, it became clear that the southern assemblage was lithologically and geochronologically distinct from the metamorphic screens cut by the Jurassic plutons (Pavlis et al., 1988). Particularly significant was the realization that there were no recognizable Jurassic plutons within the southern metamorphic assemblage (KJsch) other than ultramafic rocks (Jum), the presumed upper mantle basement for the Jurassic Talkeetna arc (Burns, 1985; Mehl et al., 2003; Pavlis et al., 1988). Yet these ultramafic rocks were metamorphosed along with adjacent rocks during the Early Cretaceous (Pavlis, 1983; Pavlis et al., 1988; Barnett et al., 1994). In addition, Barnett et al. (1994) showed that the two metamorphic assemblages recorded distinctly different PT conditions during metamorphism with a low-P/ high-T assemblage in the metamorphic screens to the north (Jsch) and a medium-P, lower- to upper-amphibolites facies assemblage in the Early Cretaceous belt (KJsch). These observations and the general rock associations in the Early Cretaceous belt led to the hypothesis that the metamorphic rocks could represent high-grade equivalents of the Chugach mélange (Pavlis et al., 1988; Pavlis, 1996).

METHODS

U-Pb zircon dating was conducted by crushing and separating samples into grains smaller than 400 micrometers. Zircons were extracted using a density water table followed by magnetic and heavy liquid separation. Separates were mounted and polished for analysis at the Arizona LaserChron Center at the University of Arizona. Samples were analyzed using laser ablation MC-ICPMS following the methods summarized in Gehrels et al., (2008). The maximum depositional ages (MDA) were determined by taking the weighted mean of the zircons that make

up the youngest peak, provided this peak contains a minimum of three grains. Isoplot (Ludwig, 2003) was used for calculating ages and for preparing plots in Figures 4 and 5.

U-Pb ZIRCON DATA

We obtained detrital zircon ages from three metasedimentary rocks and determined the emplacement age of one plutonic rock. The three metamorphic rock samples comprise a sampling of all of the major assemblages within the Knik River terrane (Jsch, KJsch, and a metamorphic block in JKamm, Figure 2). The dated pluton cuts the portion of the McHugh Complex that contains blocks of KJsch (JKamm, Figure 2).

Sample 82PAW-H67 is a trondhjemitic igneous rock that was collected from the pluton that cuts the transitional mélange unit of the McHugh accretionary complex (JKamm, Figures 2 and 3). The weighted mean $^{238}\text{U}/^{206}\text{U}$ age based on 28 zircon analyses is 120.9 ± 1.5 Ma (Figure 4).

The other zircons that we analyzed are from metasedimentary rocks. Sample W79-28A is quartzo-feldspathic schist that contains a typical amphibolite-facies mineral assemblage (biotite + hornblende + garnet + plagioclase + quartz + accessories). It almost certainly represents a meta-graywacke based on composition and presence of detrital zircons of varying ages instead of a unimodal population of igneous zircons (Table 1 and DR1). Detrital zircon ages range from 154 to 195 Ma and yield a maximum age of deposition of ~162Ma from abundant Jurassic zircons and no Precambrian zircons (Table 1, DR1 and Figure 5). Sample 09APaH50-1 is quartzo-feldspathic schist that is lithologically similar to W79-28A but collected from a metamorphic block in the transitional mélange unit (JKamm) that is intruded by the trondhjemitic pluton represented by sample 82PAW-H67. 09APaH50-1 yielded only 14 zircons but the detrital

zircon signature is virtually indistinguishable from W79-28A with both peaks from the age distribution and maximum depositional ages comparable within error.

Sample C80-36A is quartzo-feldspathic gneiss collected from a metamorphic screen intruded by Jurassic plutonic rocks (Jsch, Figure 2). This sample also yielded an age distribution consistent with a clastic protolith and produced a maximum depositional age of ~194 Ma (Figure 5, Table 1). This is significantly older than the maximum depositional age of the other two samples, consistent with its structural position within the plutonic subterrane where metamorphic rocks are screens within an Early Jurassic plutonic suite. Due to this association, the youngest ages may not be characteristic of the original sediment because the gneiss may contain younger plutonic material. The sample also shows a peak at 194 Ma and a broad peak between ~210-220 Ma, which is different from either 09APaH50-1 or W79-28A. However, C80-36a is similar to a sample analyzed by Amato et al. (2007) from a similar structural position immediately to the west (Figure 5). Like the Amato et al. (2007) sample, C80-36a is striking in the absence of pre-Mesozoic zircons with an entirely Triassic to earliest Jurassic source.

DISCUSSION

Correlation of Units in the western Chugach Mountains and revised terminology

Comparing samples W79-28A and 09APaH50-1 to two similar Potter Creek assemblage samples (Figure 5) shows a general pattern that is strikingly similar aside from small shifts in peaks, all within the range of samples from the Potter Creek assemblage (Figure 5) (Amato et al., 2013). This observation provides strong support for the interpretation that the rocks that Pavlis et al. (1988) referred to as the “metamorphic subterrane of the Knik River terrane” are a metamorphosed equivalent of the Potter Creek assemblage. Thus, we conclude that Early

Cretaceous metamorphism reworked an existing subduction complex, the Potter Creek assemblage, along the Border Ranges Fault system to generate this “metamorphic subterrane of the Knik River terrane”. Based on these observations, we suggest a revised terminology for rock assemblages in this region.

We suggest the formal term “Carpenter Creek metamorphic complex” for the belt of metamorphosed rocks with a demonstrable Early Cretaceous metamorphism at higher grade than the sub-greenschist facies conditions typical of the Potter Creek assemblage of the McHugh Complex. This unit is a formal equivalent of the informal “metamorphic subterrane of the Knik River terrane” defined by Pavlis et al. (1988). The name arises from a proposed type area for the complex in upper Carpenter Creek (Appendix 1). For detailed descriptions of the rocks see Pavlis (1983, 1986b). By this definition, the Carpenter Creek metamorphic complex includes metasedimentary and metavolcanic rocks (KJsch, Figures 2 and 3) that we infer are metamorphosed Potter Creek assemblage but could include other rocks. We include metamorphosed ultramafic bodies (Jum with associated Jgw, Figure 2) that have long been referred to as the Wolverine ultramafic complex (Clark, 1972) as a part of the Carpenter Creek metamorphic complex because these rocks share the Early Cretaceous metamorphism of adjacent foliated metamorphic rocks. Using modern lithostratigraphic terminology (<http://ngmdb.usgs.gov/Info/NACSN/Code2/code2.html#Article3>), we suggest that the term Wolverine complex be abandoned and replaced by the term Wolverine ultramafic-mafic suite, which is in line with the inclusion of these rocks in the Carpenter Creek metamorphic complex.

Following Karl et al. (2015), we revive the term “Knik River metamorphic complex” for the pre-earliest Jurassic metamorphic rocks (Jsch, Figure 2 and 3) that are invaded by Early Jurassic plutons of the Talkeetna arc. In our study area, these rocks show a very distinctive detrital zircon

signature (Figure 5) devoid of older sources and dominated by Triassic ages. The source of these zircons is unclear because these ages predate the inferred latest Triassic inception of the Talkeetna arc (e.g., Roeske et al., 1989; Rioux et al., 2007). Triassic rocks are known from the Peninsular terrane west and north of the Cook Inlet forearc basin and roof pendants in the Jurassic batholiths have also yielded similar Triassic zircons, as well as even older zircons (Amato et al., 2007). Nonetheless, there is no obvious source for these zircons on the Peninsular terrane, suggesting the source has been removed by either younger strike-slip, subduction erosion, or both. These older detrital zircon data raise an as yet unresolved paleogeographic questions on their source that needs evaluation through further study.

Similarly we propose the name “western Chugach trondhjemite suite” for the family of leucotonalite to trondhjemite, Early Cretaceous plutons in the western Chugach Mountains. These rocks are not included with the Carpenter Creek metamorphic complex because they invade rocks outside the Carpenter Creek complex and are lithologically distinctive (Pavlis et al., 1988; Barnett et al., 1994).

Finally, the similarity in detrital zircon patterns between samples W79-28A and 09APaH50-1 is significant because 09APaH50-1 is from a fault-bounded slice of metasedimentary rocks within the lower grade *mélange* along the BRFS (unit JKamm, Figure 2). Pavlis et al., (1988) interpreted these metamorphic blocks as slices of the Knik River metamorphic subterrane (Carpenter Creek metamorphic complex) emplaced into the *mélange* during thrusting after the ductile thrust system had cooled to brittle-deformation conditions. These data support that conclusion, but because this *mélange* is also cut by leuco-tonalite/trondhjemite plutons of the western Chugach trondhjemite suite (Figure 2), this result raises questions about the protolith age for this *mélange* unit (JKamm, Figures 2 and 3). In line with other subdivisions of the Chugach

mélange, we informally refer to this unit (JKamm) as the Friday Creek mélange assemblage after extensive exposure in the headwaters of Friday Creek (Figure 2)

Our new data for sample 82PaW-H67 (Figure 4) provides the third U-Pb age estimate for the pluton that cuts the Friday Creek mélange assemblage from two distinct samples of the pluton, further confirming the ~121 Ma age estimate of Amato and Pavlis (2010). The best age estimate for this pluton probably remains the SHRIMP (sensitive high-resolution ion microprobe) analyses reported in Amato et al. (2013) of 125 ± 2 Ma. In any case, these U-Pb ages support a conclusion that this pluton was the youngest within the belt because hornblende $^{40}\text{Ar}/^{39}\text{Ar}$ cooling ages from other plutons are within error, or older, than these dates (Barnett et al., 1994). More importantly, however, the new ages reported here create uncertainties on how the Friday Creek mélange assemblage correlates to other units. Specifically, the minimum age for the Friday Creek mélange assemblage provided by the plutons is older than any known rocks from the McHugh Creek assemblage of the Chugach accretionary complex (Amato et al., 2013). Yet, the Friday Creek mélange assemblage contains blocks of Carpenter Creek metamorphic complex that is presumably Potter Creek assemblage that was metamorphosed to amphibolite facies, cooled to temperatures below the brittle-ductile transition, and emplaced in the Friday Creek mélange, all prior to the emplacement of the pluton.

The question is then raised of what materials comprise the mélange matrix of this assemblage. The question is important because Amato et al. (2013) noted a gap in detrital zircon ages between the Late Jurassic Potter Creek assemblage and the mid-Cretaceous McHugh Creek assemblage, and these rocks may span part of that time interval, carrying further records of that event. Field observations of this mélange matrix indicate mesoscopic lithologic similarities to the Potter Creek assemblage with the characteristic chert-argillite association. However, that

correlation is not possible if the Potter Creek assemblage is a single tectonic unit that was accreted in the Late Jurassic because rocks with the same detrital signature, but different metamorphic grade, are mixed within the assemblage. One possibility is a younger matrix, possibly equivalent to the Liberty Creek schist, which Day (2014) has shown has a maximum depositional age of ~135 Ma. This hypothesis is allowable because the rocks are lithologically similar other than metamorphic grade. Alternatively, radiolarian fossil ages as young as Valanginian were reported at a single locality within the Potter Creek assemblage near Anchorage (Karl et al., 1979) allowing parts of the Potter Creek to be as young as ~135 Ma. Nonetheless, even if parts, or all, of the Potter Creek assemblage were accreted after ~135 Ma, the Friday Creek mélange assemblage poses a problem of the mixing of seemingly equivalent rock assemblages that achieved different peak metamorphic grades. One possibility is that the Friday Creek mélange assemblage could be lower-grade Potter Creek assemblage, brought in from structurally higher levels during evolution of the Early Cretaceous thrust. If this were the case, the Potter Creek assemblage would have to have been a more extensive accretionary complex at the time to juxtapose the different structural levels seen today. In any case, much more work needs to be done on these rocks before these questions can be answered.

Implications for the Border Ranges Fault System

The entire region between the Matanuska Valley on the north and Friday Creek to the south (Figure 2) comprise different elements of the Border Ranges fault system as defined by Pavlis and Roeske (2007). That is, faults and ductile shear zones within this broad zone represent accumulated slip from different periods of motion along the boundary. Therefore, the Border Ranges fault system includes the broad band of Early Cretaceous ductile and brittle deformation

recorded by structures in the Carpenter Creek metamorphic complex and the Friday Creek mélange assemblage. Moreover, it was affected by younger strike-slip deformation that overprints these assemblages. As a regional structural contact separating distinct terranes, however, the original placement of the BRF (e.g., Clark, 1972; Pavlis, 1986b; Burns et al., 1991) requires modification.

Based on the evidence that the Carpenter Creek metamorphic complex is metamorphosed Potter Creek assemblage, we note that the appropriate location for the BRF as a regional terrane boundary lies well north of the original mapped boundary (Clark, 1972 and later works). Specifically, the primary lithologic break occurs at the northern limit of the Carpenter Creek metamorphic complex (Figure 2 and 3). Yet, at smaller scale, this definition raises issues, much as other segments of the BRF, because of the composite nature of the boundary.

Particularly significant are the details of the contact relationships of the Wolverine ultramafic-mafic suite within the Carpenter Creek metamorphic complex. These ultramafic bodies typically have been correlated to Peninsular terrane upper mantle, (e.g., Burns 1985; Pavlis et al., 1988; Mehl et al., 2003) but their presence within the Carpenter Creek metamorphic complex calls this correlation into question. If they are equivalent to other ultramafic bodies of the Border Ranges mafic-ultramafic assemblage, they are slabs of Peninsular terrane mantle within the Chugach terrane (Carpenter Creek metamorphic complex). In this case, the BRF as a lithologic break is blurred with structural contacts bounding all of the ultramafic bodies as individual segments of the BRF *sensu-stricto*. Alternatively, it is possible that the Wolverine mafic-ultramafic suite is not Peninsular terrane mantle. Instead, their incorporation into a mélange derived from oceanic rocks suggests they could be oceanic mantle incorporated into the Chugach mélange, then reworked during Cretaceous metamorphism. Admittedly, other ultramafic bodies of the Border

Ranges mafic-ultramafic assemblage lie within, or atop, the Chugach mélange (e.g., Bradley et al., 1999; Kusky et al., 2007) and other lithologic similarities have been noted between the Wolverine suite and the regional assemblage (e.g., Burns, 1985). Nonetheless, the distinctive metamorphic history of the Wolverine ultramafic-mafic suite and its structural association necessitates further work to distinguish which alternative is more likely.

Finally, our re-interpretation of the Carpenter Creek metamorphic complex as metamorphosed Potter Creek assemblage resolves an enigmatic observation made by Pavlis (1983) on the structural style of some of these rocks. Pavlis (1983) described a "metamorphosed mélange" assemblage that separated the ultramafic bodies from the adjacent, highly faulted plutonic rocks. We suggest that this metamorphosed mélange is simply a part of the metamorphosed Potter Creek assemblage that escaped Cretaceous ductile deformation, but did not escape the thermal overprinting related to mid-Cretaceous plutonism.

Implications for recognition of accretionary complexes in collisional orogens

It has always been difficult to recognize subduction zone assemblages when they are incorporated into the interior of a collisional orogen. This problem arises in part from geometry. In a collision, the hanging wall of the subduction zone will experience the most exhumation, which tends to destroy evidence of its existence through erosion across the suture zone (e.g., Dewey, 1977). Nonetheless, with increasing evidence of deep subduction of sediment (Hacker et al., 2011) and sediment subduction along plate margins (e.g., Clift and Vannucchi, 2004), it is less clear that these subduction assemblages would be removed by exhumation during a collision.

409 We suggest that our data from the Carpenter Creek metamorphic complex provides one
410 explanation that may help resolve this issue. The detrital zircon data presented here indicates that
411 this metamorphic complex formed as a *mélange*, the Potter Creek assemblage, derived from
412 pelagic to hemi-pelagic rocks and accreted in an oceanic arc. In its typical low-grade exposures,
413 the Potter Creek assemblage has a classic structural style similar to *mélanges* throughout the
414 Pacific rim (e.g., type I and II *mélanges* in the classification of Cowan, 1985). However, in the
415 Carpenter Creek metamorphic complex, this assemblage is now amphibolite-facies schists in
416 which ductile deformation has obscured the original *mélange* fabric (Pavlis, 1983a). Ductile
417 finite-strain magnitudes are unknown in the Carpenter Creek metamorphic complex, but they are
418 characterized by an intense continuous cleavage with an oblique mineral and stretching lineation
419 (Pavlis et al., 1988; Pavlis, 1983a). The narrow belt along the northern edge of the complex
420 (Figure 2) escaped the ductile overprint and preserved *mélange* fabrics (Pavlis, 1983a), but
421 original lithologic variations inherited from the *mélange* have been completely transposed into
422 foliation in all other parts of the belt. Thus, without the insight from the narrow, preserved
423 *mélange* belt and the detrital zircon data reported here, it would be impossible to recognize this
424 assemblage as rocks that originated as a *mélange*. Moreover, given the presence of large
425 granitoid bodies, most geologists would infer an origin within an arc terrane, making a forearc
426 setting an unlikely interpretation were these rocks found in the interior of a collisional orogen.

427 This issue is not unique to this locality. The southern Alaskan margin experienced a similar
428 event in the Paleogene when the forearc was heated to high temperatures and granitoids were
429 emplaced throughout the forearc creating the Sanak-Baranof belt (Bradley et al., 2003) as well as
430 an elongate band of high-grade metamorphism within the forearc called the Chugach
431 metamorphic complex (Hudson and Plafker, 1982; Sisson et al., 1989). The Chugach

metamorphic complex is approximately the size of the state of Massachusetts, yet it is doubtful even a feature of this scale would be recognized as a forearc assemblage if it were caught up in a collision zone. For a narrow belt of metamorphism and plutonism, such as the Carpenter Creek metamorphic complex, proper recognition of its origin would be even less likely. Thus, it seems likely that forearc metamorphic assemblages of this type are typically misidentified as accreted arcs.

CONCLUSION

Detrital zircon data indicate that the belt of rocks formerly referred to as the “metamorphic subterrane of the Knik River terrane” (Pavlis et al., 1988) is a high-grade metamorphic equivalent of the Potter Creek assemblage, the older part of the McHugh Complex (aka Chugach *mélange* at regional scale). We propose the name Carpenter Creek metamorphic complex for these Early Cretaceous metamorphosed rocks as well as the terms western Chugach trondhjemite suite for the Early Cretaceous plutons that provide relative chronologies in this region. We further propose the term Friday Creek *mélange* assemblage for a transitional *mélange* unit that contains blocks of the Carpenter Creek metamorphic complex, but is intruded by the western Chugach trondhjemite suite. Older metamorphic screens outside of the Carpenter Creek metamorphic complex (unit Jsch, Figure 2) are cut by Jurassic plutons and yield a distinctly different detrital zircon signature (Figure 5) dominated by a Triassic source of unknown origin. These detrital ages indicate that the trace of the BRF on regional maps should be relocated to the northern edge of the Carpenter Creek metamorphic assemblage. However, the presence of ultramafic bodies in the Cretaceous metamorphic assemblage raises questions on their origin as mantle basement to the Talkeetna arc since these rocks could be oceanic mantle incorporated in the Potter Creek assemblage prior to, or during, Cretaceous deformation. *Mélanges* are common

in circum-Pacific orogens but typically are not described in the cores of ancient orogens. The structural style of the Carpenter Creek metamorphic complex and plutonic association provides one explanation for this discrepancy as a unit that originated as a *mélange* and subsequently had its original fabric obliterated by ductile deformation during ridge subduction.

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KEY WORDS

Tectonics, Alaska, *mélange*, detrital zircon geochronology, U-Pb dating

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Figure Captions

Figure 1. Map of southern Alaska showing the location of the study relative to regional tectonic features. BRF is the Border Ranges fault. Figure is made from GIS files in Colpron and Nelson (2011).

Figure 2. Geological map of the western Chugach Mountains and Matanuska Valley between the Knik River and just east of Coal Creek. Map is modified from USGS digital database for Anchorage Quadrangle (Geological Survey (US) and Wilson 1998) with modifications primarily correcting known digitizing errors from the original mapping by (Pavlis 1982; Pavlis 1983a; Pavlis 1986b; and Burns and others 1991), and redefinition of units by (Amato et al., 2013), and this study. Note sample locations described in the text and the line of section shown in Figure 3.

Figure 3. Composite cross-section across the study area showing major structural features and known cross-cutting relationships among units. Offset in section is shown to restore the approximate right-lateral slip on the Tertiary Carpenter Creek fault. Section drawn using Move software from Midland Valley Ltd. with elevations extracted from U. S. Geological Survey DEM.

649 Figure 4. Tera-Wasserburg Concordia plot for sample 82PAW-H67. Despite variations in
650 analytical precision, all analyses were concordant and yield a Concordia age of 120.9 ± 1.5 Ma
651 (2s). Error ellipses are shown at the 2σ level.

652

653 Figure 5. Relative probability density plots for the detrital zircons in the three samples from the
654 Knik River terrane compared to representative samples from the Potter Creek assemblage
655 (above) and another roof pendant in the plutonic subterrane of the Knik River terrane (Talkeetna
656 arc basement). Note the similarity in patterns between the two groups indicating the correlation
657 of the Knik River metamorphic assemblage with Potter Creek assemblage and the similarity of
658 the two roof pendants.

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661 Table 1: Summary of Maximum Depositional Age estimates

662	<u>Sample</u>	<u>Youngest Peak</u>	<u>Isoplot Age</u>	<u>Youngest zircon</u>
663			<u>Extractor Max Depo Age</u>	
664	W79-28a	162 Ma	163 ± 2 Ma	154 ± 11 Ma
665	C80-36a	194 Ma	194 ± 1 Ma	185 ± 5 Ma
666	09APa50-1	157 Ma	156 ± 4 Ma	152 ± 11 Ma
667				

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EXPLANATION

Qaf; Q_g, etc.: Quaternary surficial deposits

PENINSULAR TERRANE

Tfv: Tertiary intrusive rock

Forearc Basin Strata

Tch

Km

angular unconf.

Jeqd: Jurassic intrusive rocks

Jtk: Talkeetna Fm (Jurassic arc strata)

Peninsular Terrane Basement assemblage (formerly Knik River plutonic subterrane)

Klt: Early Cretaceous leucotonalite and trondhjemite

TKc: cataclastic rocks (major fault zones)

Jg: intermediate and mafic intrusive rocks

Jsch: pre-earliest Jurassic metamorphic rocks undivided

CHUGACH TERRANE

Carpenter Creek metamorphic Complex (formerly Knik River metamorphic subterrane)

Klt: Early Cretaceous leucotonalite and trondhjemite

Jgw: layered gabbro in metamorphosed ultramafics

Jum: metamorphosed ultramafic rocks undivided

KJsch: foliated amphibolite facies metamorphic rocks

low-grade assemblage

JKamm: Friday Creek assemblage (transitional unit)

KMm: McHugh Creek assemblage

Kvs: Valdez Group

Figure 4: Tera-Wasserburg concordia plot for sample 82PAW-H67. Despite variations in analytical precision, all analyses were concordant and yield a Concordia age of 120.9 ± 1.5 Ma (2s). All data point error ellipses are shown at the 2s level.