Laurentian origin for the North Slope of Alaska: Implications for the tectonic evolution of the Arctic

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ABSTRACT

The composite Arctic Alaska–Chukotka terrane plays a central role in tectonic reconstructions of the Arctic. An exotic, non-Laurentian origin of Arctic Alaska–Chukotka has been proposed based on paleobiogeographic faunal affinities and various geochronological constraints from the southwestern portions of the terrane. Here, we report early Paleozoic trilobite and conodont taxa that support a Laurentian origin for the North Slope subterrane of Arctic Alaska, as well as new Neoproterozoic–Cambrian detrital zircon geochronological data, which are both consistent with a Laurentian origin and profoundly different from those derived from similar-aged strata in the southwestern subterranes of Arctic Alaska–Chukotka. The North Slope subterrane is accordingly interpreted as allochthonous with respect to northwestern Laurentia, but it most likely originated farther east along the Canadian Arctic or Atlantic margins. These data demonstrate that construction of the composite Arctic Alaska–Chukotka terrane resulted from juxtaposition of the exotic southwestern fragments of the terrane against the northern margin of Laurentia during protracted Devonian(?)–Carboniferous tectonism.

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INTRODUCTION

The Amerasian Basin of the Arctic Ocean (Fig. 1) remains the only major ocean basin for which the origin and tectonic history are still largely unknown (e.g., Miller et al., 2010). New and accurate geological data from the modern circum-Arctic margins are critical, not only for understanding the origin of "suspect" terranes embedded in the North American Cordillera and bordering the Arctic Ocean (e.g., Colpron and Nelson, 2011), but also for evaluating kinematic models for the Jurassic–Cretaceous opening of the Amerasian Basin (e.g., Grantz and May, 1983) and the development of its hydrocarbon-rich continental shelves. Currently, the use of potential Proterozoic and Paleozoic piercing points for constraining Mesozoic tectonic reconstructions is limited by a lack of geological constraints and uncertainty surrounding mid-Paleozoic terrane displacements.

The composite Arctic Alaska–Chukotka terrane covers an estimated 3,000,000 km^2 of the Arctic, encompassing the Brooks Range and North Slope of Alaska, the Chukotka Peninsula and Wrangel Island of Arctic Russia, and the adjacent continental shelves of the Beaufort and Chukchi Seas (Fig. 1; Miller et al., 2006; Amato et al., 2009). The identification of the modern continental margin to which the Arctic Alaska–Chukotka terrane restores to prior to the opening of the Amerasian Basin remains a critical question for understanding the tectonic evolution of the Arctic (e.g., Miller et al., 2010). Furthermore, the pre-Mesozoic origin and displacement history of this composite terrane and its relationship to the northwestern margin of Laurentia remain controversial (e.g., Miller et al., 2010; Colpron and Nelson, 2011). Several studies have suggested a Laurentian origin for parts of the Arctic Alaska–Chukotka terrane (e.g., Dutro et al., 1972; Grantz et al., 1991; Moore et al., 1994, 2011; Lane, 2007); however, contrasts in paleobiogeographic affinities of mega- and microfossils and various geochronological constraints suggest an exotic origin for the southwestern subterranes of the Arctic Alaska–Chukotka terrane (Dumoulin et al., 2002; Blodgett et al., 2002; Miller et al., 2006, 2010, 2011; Amato et al., 2009; Colpron and Nelson, 2011). Here, we place new early Paleozoic fossil collections and detrital zircon geochronology in a tectonostratigraphic framework that enables us to reevaluate the origin of the Arctic Alaska–Chukotka terrane and propose a revised model for its role in the Paleozoic tectonic evolution of the Arctic region.

GEOLOGICAL BACKGROUND

A variety of nomenclature systems have been employed to describe the geology of the Arctic Alaska–Chukotka terrane, and a review of these schemes is beyond the scope of this paper (see Dumoulin et al., 2002; Amato et al., 2009; Miller et al., 2010). The geology of the Arctic Alaskan portion of the Arctic Alaska–Chukotka terrane has been divided into six subterranes (Fig. 2A; e.g., Moore et al., 1994), which are partly employed here for consistent descriptive purposes in line with previous publications (e.g., Moore et al., 1994; Dumoulin et al., 2002). We focus on the North Slope subterrane (referred to here as North Slope), grouping the remaining southwestern subterranes of the Arctic Alaska–Chukotka terrane as distinct from the North Slope. We acknowledge that the eastern and western segments of the North Slope may be geologically distinct from each other (e.g., Miller et al., 2011), but no unambiguous suture has been documented at this time.

Pre-Mississippian strata of the North Slope comprise three distinct stratigraphic successions (Fig. 2B; Moore et al., 1994): a widely distributed but poorly understood Neoproterozoic(?)–Early Devonian basinal siliciclastic and volcanic sequence in the northeast Brooks Range and adjacent Yukon Territory (Fig. 2B; Moore et al., 1994; Lane, 2007), a Neoproterozoic–Late Ordovician platformal carbonate sequence exposed in the Shublik and Sadlerochit Mountains (Fig. 2B; Macdonald et al., 2009), and a structurally complex sequence of Cambrian–Silurian arc-related volcanic and siliciclastic

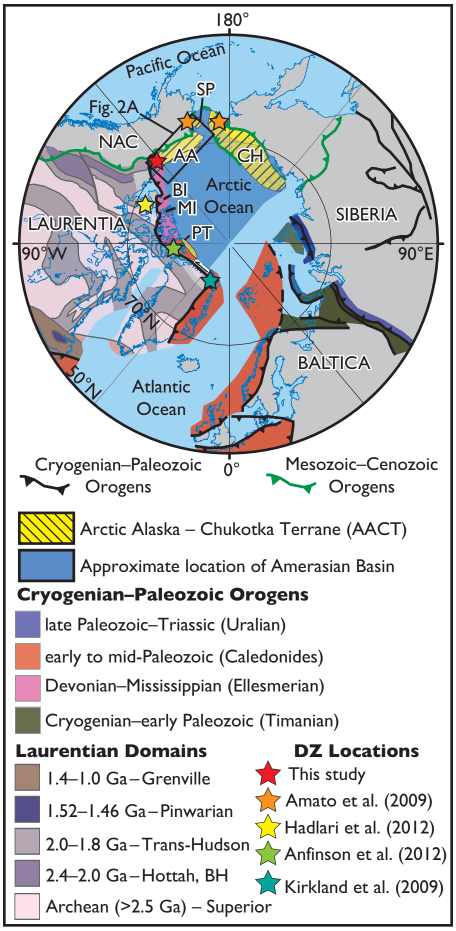

Figure 1. Simplified map of pertinent Proterozoic and Paleozoic orogenic belts, terranes, cratons, basement domains, and locations mapped onto the modern circum-Arctic continental margins and modified from Colpron and Nelson (2011). The Amerasian Basin is crudely outlined by the darker-blue color of the Arctic Ocean. Colored stars denote the locations of various detrital zircon (DZ) collections described in the text. NAC—North American Cordillera; AA—Arctic Alaska terrane; SP—Seward Peninsula; CH—Chukotka; MI—Melville Island; BI—Banks Island; PT—Pearya terrane; BH—Buffalo Head.

rocks exposed in the Doonerak Window of the central Brooks Range (Fig. 2B; Julian and Oldow, 1998). All of these deposits, except perhaps the Doonerak arc complex (Julian and Oldow, 1998), host a pre-Mississippian penetrative cleavage and are intruded by Late Devonian (ca. 375–360 Ma) plutonic and volcanic rocks. They are also overlain with profound angular unconformity by the Late Devonian–Mississippian Endicott Group (Fig. 2B, Endicott Mountains subterrane; Moore et al., 1994), an ~4–6-km-thick fluvial-deltaic, southwestward-prograding (present coordinates) clastic wedge that has been reconstructed as both a rift-related deposit (e.g., Moore et al., 1994) and a foreland basin succession (Nilsen, 1981). In the northeastern Brooks Range and in the subsurface of the North Slope, undeformed Early–Middle Devonian mixed carbonate and siliciclastic rocks rest unconformably on older deformed strata and are themselves tilted and unconformably overlain by the Endicott Group (Fig. 2B; Ulungarat Formation of Anderson, 1991; Moore et al., 1994 and references therein).

The southwestern subterranes of the Arctic Alaska–Chukotka terrane (Fig. 2) include variably metamorphosed Neoproterozoic(?)–Silurian carbonate and siliciclastic strata that overlie Neoproterozoic–Cambrian metasedimentary and crystalline basement (Fig. 2B; Miller et al., 2010, and references therein). They are both locally intruded by Devonian (ca. 402–366 Ma) granitoids (Amato et al., 2009, and references therein) and unconformably overlain by the Endicott Group. These subterranes have been variably interpreted as remnants of a large early Paleozoic carbonate platform that existed between Laurentia and Siberia based on faunal assemblages (Dumoulin et al., 2002) and as semicoherent fragments of the continental margin of Baltica based on detrital zircon provenance studies (Miller et al., 2011).

The Late Devonian–Mississippian Ellesmerian orogeny (sensu stricto) involved deposition of a southwestward-prograding (present coordinates) clastic wedge across much of northern Laurentia, and it has been attributed to collision with a continental source terrane of uncertain origin (e.g., Embry, 1988; Beranek et al., 2010; Anfinson et al., 2012). The Ellesmerian activity was preceded by Ordovician–Silurian accretion of arcs and continental fragments of the Pearya terrane (Fig. 1; Trettin, 1991; McClelland et al., 2012) and localized deformation of the pre–Middle Devonian Romanzof orogeny on the North Slope (Lane, 2007). These events indicate that Paleozoic orogenesis in Arctic Canada and Alaska involved a complex and protracted tectonic history that overlapped in time with the ca. 490–390 Ma multiphase Caledonian orogeny of northeastern Laurentia (Trettin, 1991; McKerrow et al., 2000; McClelland et al., 2012).

NEW INSIGHTS FROM THE NORTH SLOPE SUBTERRANE

Stratigraphy and Faunal Affinities

The Katakturuk Dolomite and overlying Nanook Limestone of the Shublik and Sadlerochit Mountains (Fig. 2A) comprise an ~3.5-km-thick succession of Neoproterozoic–Late Ordovician platformal carbonate that rests conformably on mixed siliciclastics, carbonate, and <800 Ma basalt (Fig. 2B; Macdonald et al., 2009, and references therein). In the Shublik Mountains, these deposits are tilted and unconformably overlain by the Early Devonian Mount Copleston Limestone, which is also tilted and unconformably overlain by the Endicott Group (Fig. 2B; Blodgett et al., 1988).

Recent biogeographic summaries (e.g., Blodgett et al., 2002) link the North Slope with the southwestern subterranes of the Arctic Alaska–Chukotka terrane and Siberia on the basis of Ordovician brachiopod and gastropod genera in the Nanook Limestone that, although common in Siberia, also occur in Laurentia (Blodgett et al., 1988). Our expanded collections confirm the presence of uniquely Laurentian species within the Lower Ordovician portion of the Nanook Limestone, including the conodont *Clavohamulus densus* and the trilobite *Plethopeltis armatus* (Figs. 3A–3D and 3G); neither species has been reported from unequivocally non-Laurentian strata. *Plethopeltis armatus* (Figs. 3A–3D), originally reported from the Nanook on only two exfoliated cranidia (Blodgett et al., 1986), is now represented by more than 25 specimens that conform in all respects to a significantly narrowed morphologic concept provided for that species by Ludvigsen et al. (1989). With that narrowed definition, the established distribution of *P. armatus* (aside from the Nanook) is limited to the outer-shelf and toe-of-slope facies of the central and northern Appalachians (Rasetti, 1959; Ludvigsen et al., 1989), although documentation of coeval faunas in adjacent areas of northern Laurentia (e.g., Arctic Canada) is currently inadequate. New collections from slightly higher in the Nanook also contain the uniquely Laurentian trilobite genus *Paraplethopeltis* (Figs. 3E and 3F), which occurs at the base of the Stairsian Stage (Lower Ordovician) throughout western North America (Taylor et al., 2012) and Greenland (Fortey and Peel, 1989). Furthermore, scrutiny of material identified by Blodgett et al. (1986) as "cf. *Hystricurus? sainsburyi* Ross" has revealed that the Nanook species is neither conspecific or congeneric with *H? sainsburyi*, a species described from the Seward Peninsula of Alaska (Ross, 1965). Thus, the updated faunal data from the Nanook Limestone, along with a previous report of Laurentian taxa in basinal clastics of the nearby British Mountains (Fig. 2; Dutro et al., 1972), contradict a Siberian origin and instead suggest that the North Slope is autochthonous with respect to northeastern (present coordinates) Laurentia.

Detrital Zircon Geochronology

New detrital zircon laser ablation–inductively coupled plasma–mass spectrometry (LA-ICP-MS) U-Pb ages from pre-Mississippian

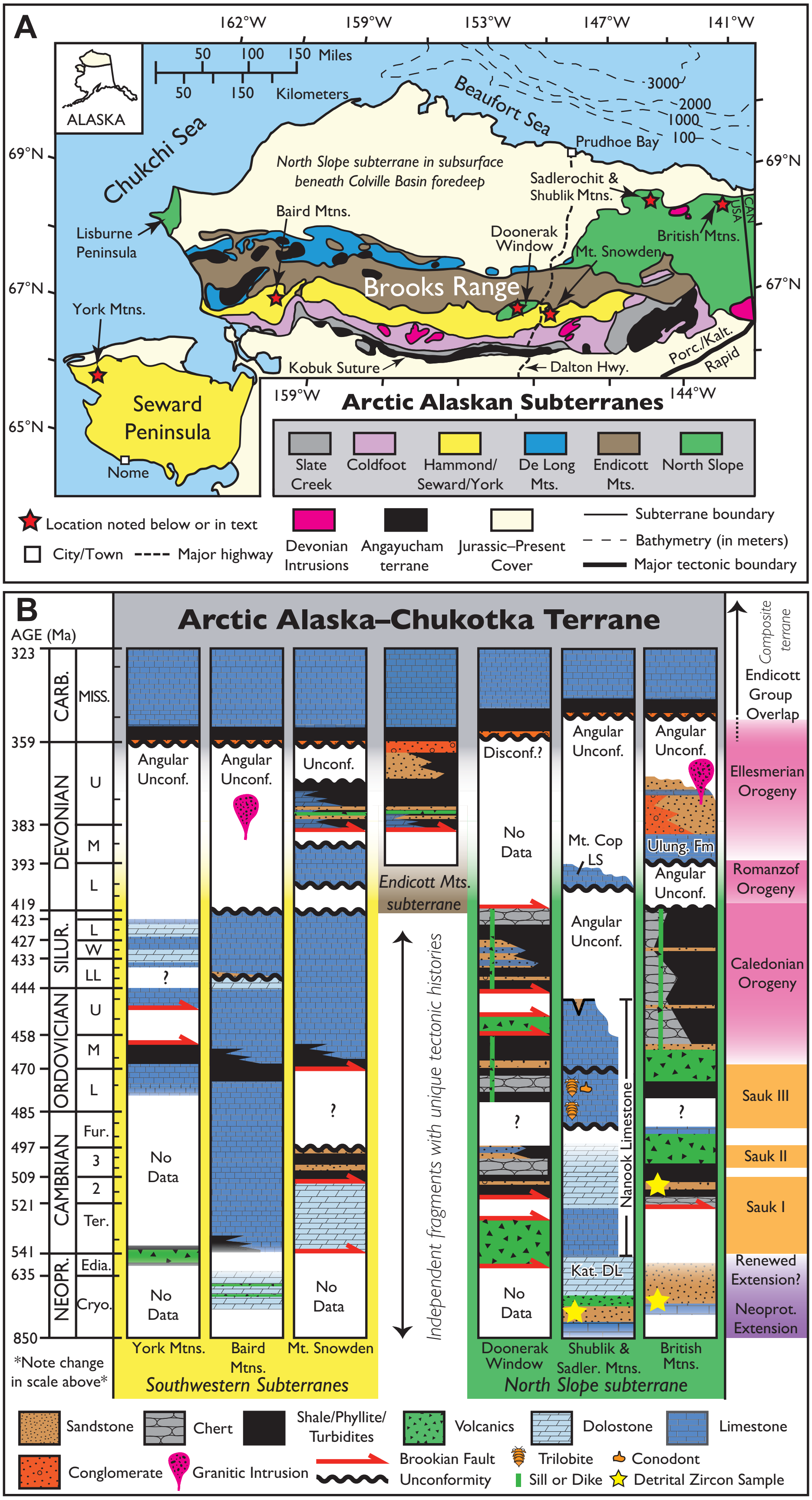

Figure 2. (A) Simplified subterrane map of northern Alaska modified after Moore et al. (1994). Putative sutures (e.g., Grantz et al., 1991) are likely delineated by approximate subterrane boundaries, but the individual subterranes could also host internal sutures as discussed in the text. The Porcupine-Kaltag-Rapid fault array is abbreviated. (B) Generalized stratigraphic columns of representative localities from the North Slope, Endicott Mountains, and southwestern subterranes of the Arctic Alaska–Chukotka terrane after Moore et al. (1994), Dumoulin et al. (2002), Amato et al. (2009), and Miller et al. (2010, 2011). The fading of colors is meant to indicate uncertainties in age constraints and/or the loss of subterrane independence via Arctic Alaska–Chukotka terrane amalgamation during northeastern Laurentian Devonian(?)–Mississippian orogenesis. Kat. DL—Katakturuk Dolomite; Mt. Cop LS—Mount Copleston Limestone; Ulung. Fm—Ulungarat Formation.

strata of the North Slope can also be linked to Laurentia (Figs. 4 and 5). Eight samples (Fig. 4; GSA Data Repository[1]) were collected from sandstone underlying the <800 Ma basalt of the Shublik and Sadlerochit Mountains (Macdonald et al., 2009) and Cryogenian(?)–Cambrian sandstone in the British Mountains (Fig. 2). The ages of these strata are constrained by trace and body fossils (Lane, 2007) and overlying volcanic rocks interbedded with Upper Cambrian trilobite fauna (Dutro et al., 1972). The new samples yield zircon U-Pb age populations ranging from ca. 760 Ma to 3420 Ma, with prominent peaks at 1000–1200 Ma, 1400–1500 Ma, 1800–2000 Ma, and 2700–2800 Ma, and they lack zircons of the Laurentian magmatic gap (Fig. 4; Grove et al., 2008, and references therein). These populations are similar to common age distributions from coeval strata and older basement preserved along the northern margin of Laurentia (Figs. 1 and 4; Kirkland et al., 2009; Hadlari et al., 2012; Anfinson et al., 2012). The occurrence of a small number of Neoproterozoic (ca. 760–980 Ma) detrital zircons in sandstone from the Sadlerochit Mountains led some workers to suggest a potential exotic origin for the platform sequence of the North Slope (Macdonald et al., 2009; Moore et al., 2011). However, zircons of this age recently reported from autochthonous Laurentian strata of similar age (Hadlari et al., 2012; Rainbird, 2012) call into the question the claim that this population is unambiguously exotic.

[1]GSA Data Repository Item 2013251, a summary of analytical procedures, detailed sample descriptions, and U-Pb data tables, histograms, and concordia plots, is available at www.geosociety.org/pubs/ft2013.htm, or on request from editing@geosociety.org, Documents Secretary, GSA, P.O. Box 9140, Boulder, CO 80301-9140, USA.

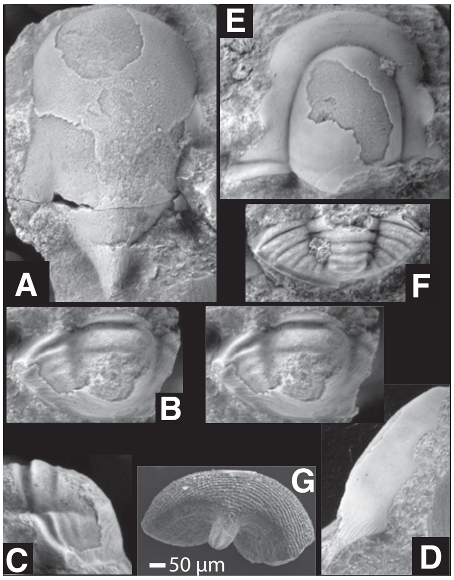

Figure 3. Laurentian fossils from the Cambrian–Ordovician Nanook Limestone, Shublik Mountains, North Slope subterrane, Arctic Alaska. All views are dorsal, except C and G. (A–D) *Plethopeltis armatus*, Upper Cambrian (Furongian) trilobite: (A) cranidium, USNM 553718, X3.2; (B–C) pygidium, USNM 553719; dorsal stereopair and lateral view, X5.4; (D) librigena, USNM 553720, X3.3. (E–F) *Paraplethopeltis* sp., Lower Ordovician (Tremadocian) trilobite: (E) cranidium, USNM 553721, X3.5; (F) pygidium, USNM 553722, X4.7. (G) *Clavohamulus densus*, Tremadocian conodont, USNM 553723.

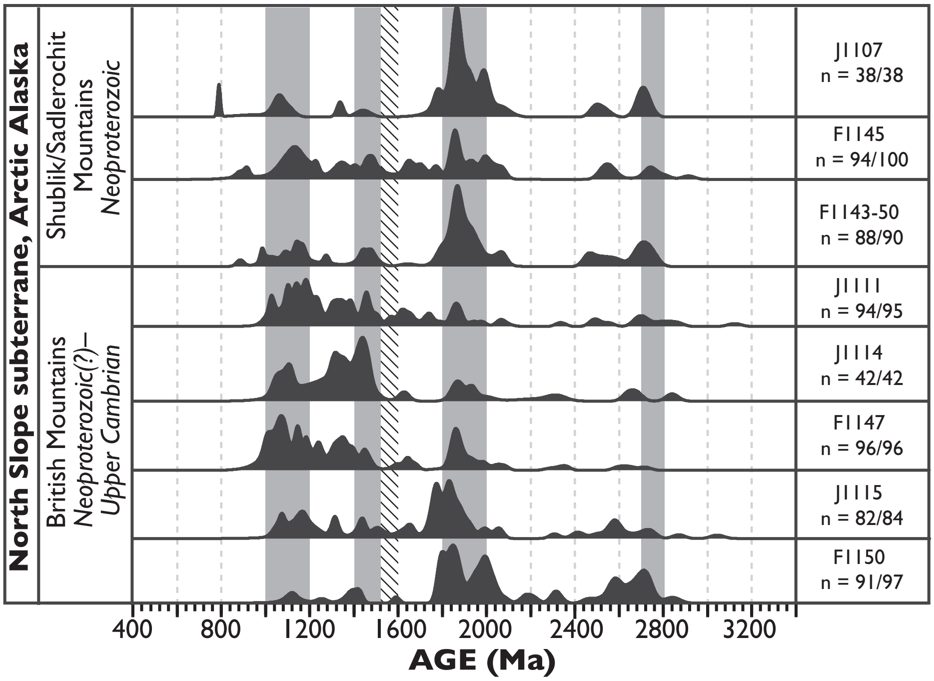

Figure 4. Detrital zircon laser ablation–inductively coupled plasma–mass spectrometry (LA-ICP-MS) U-Pb relative age probability distributions from Neoproterozoic–Cambrian strata of the Shublik, Sadlerochit, and British Mountains of the North Slope subterrane. Detailed sample descriptions and age constraints are described in the GSA Data Repository (see text footnote 1). The gray bars highlight characteristic age populations of Laurentian basement (Fig. 1) and coeval strata of northern Laurentia, including Mesoproterozoic (1000–1200 Ma; 1400–1500 Ma), Paleoproterozoic (1800–2000 Ma), and Neoarchean (2600–2700 Ma) populations. The hatched bar represents the ca. 1490–1520 Ma Laurentian magmatic gap after Grove et al. (2008, and references therein).

DISCUSSION

In sharp contrast to data presented here from the North Slope, the Neoproterozoic–Paleozoic basement and overlying sedimentary deposits of the southwestern subterranes of the Arctic Alaska–Chukotka terrane do not share affinities with Laurentia (Fig. 2B; Amato et al., 2009; Miller et al., 2010). These strata host exotic faunal assemblages, including conodonts and trilobites with Siberian affinity (Blodgett et al., 2002; Dumoulin et al., 2002, and references therein), and their pre-Mississippian stratigraphic architecture is also markedly different. For example, a pronounced mid-Ordovician transgression and thick accumulations of Silurian carbonate are characteristic components of the southwestern subterranes (Fig. 2B; Dumoulin et al., 2002). In contrast, on most Laurentian platforms, the mid-Ordovician is marked by a profound hiatus (i.e., Sauk-Tippecanoe unconformity; Taylor et al., 2012). The Nanook Limestone not only records a coeval disconformity, but it also completely lacks Silurian strata (Fig. 2B; Blodgett et al., 1988).

The new geochronological data presented here from the North Slope also differ greatly from those in previous studies of the southwestern subterranes (Fig. 5; Amato et al., 2009; Miller et al., 2010; Moore et al., 2011). The Paleozoic platformal deposits of the southwestern subterranes overlie basement that is intruded by Neoproterozoic (ca. 750 ± 6 Ma and 970 Ma) metagranites in the Hammond subterrane and localized plutons ranging from ca. 540 Ma to 870 Ma on the Seward and Chukotka Peninsulas (Patrick and McClelland, 1995; Amato et al., 2009). Consequently, many workers have suggested an exotic origin for the western segment of the Arctic Alaska–Chukotka terrane, noting the lack of magmatism of this age in northwestern Laurentia (e.g., Patrick and McClelland, 1995; Amato et al., 2009; Miller et al., 2010, 2011). In contrast, exposed basement of the North Slope consists of <800 Ma basalts (Macdonald et al., 2009), which compare favorably with the ca. 780 Ma Gunbarrel and ca. 720 Ma Franklin large igneous provinces of northern Laurentia that extend from Yukon to Ellesmere Island (Harlan et al., 2003; Denyszyn et al., 2009). Moreover, the provenance of Late Neoproterozoic–Ordovician(?) strata of the southwestern subterranes is clearly distinct from that of the North Slope, including overwhelming late Neoproterozoic–Ordovician detrital zircon age populations that lack classic 1800–2100 Ma and 2600–2800 Ma Laurentian signatures (Fig. 5; Amato et al., 2009).

These discrepancies can be explained by the independent evolution of the North Slope and southwestern subterranes and their juxtaposition sometime prior to deposition of the overlapping Late Devonian–Mississippian Endicott Group (Fig. 2B). We emphasize that this does not imply that the North Slope was fixed relative to the northwestern margin of Laurentia throughout the Neoproterozoic and Paleozoic (sensu Lane, 2007). We suggest instead that the North Slope is a continental fragment that originated from northeastern Laurentia and that the southwestern subterranes of the Arctic Alaska–Chukotka terrane evolved as a single or multiple crustal fragment(s) outboard of Laurentia (e.g., Dumoulin et al., 2002; Miller et al., 2010; Moore et al., 2011). Based on geochronological and stratigraphic arguments, other workers (Miller et al., 2010, 2011; Moore et al., 2011) have suggested that the southwestern portion of the Arctic Alaska–Chukotka terrane evolved as a part of Baltica and is currently separated from the eastern segment by an undocu-

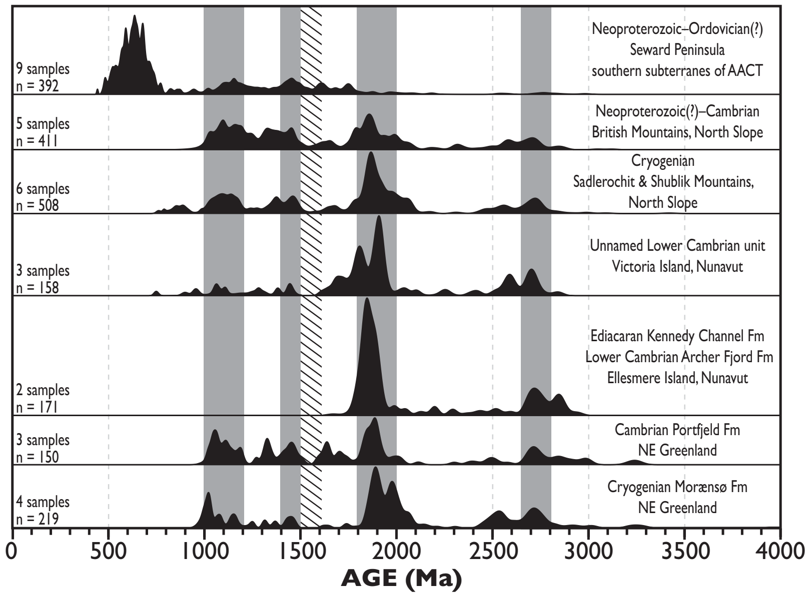

Figure 5. Detrital zircon U-Pb relative age probability distributions from Neoproterozoic–Cambrian strata of the North Slope subterrane and various localities along the northern margin of Laurentia (data from Seward Peninsula—Amato et al., 2009; Greenland—Kirkland et al., 2009; Ellesmere Island—Anfinson et al., 2012; Victoria Island—Hadlari et al., 2012). The different shaded bars highlight the same characteristic age populations as noted in Figure 4. The construction of this figure is outlined in the GSA Data Repository (see text footnote 1). AACT—Arctic Alaska–Chukotka terrane.

mented Caledonian suture. One putative suture between the North Slope and the southwestern subterranes is most likely marked by the prominent low-amplitude magnetic anomalies and a change in the aeromagnetic and gravity fabrics near the southern margin of the North Slope (Fig. 2A; Grantz et al., 1991); however, given the structural complexity and limited understanding of the Brooks Range basement (e.g., Moore et al., 1994), it is more likely that multiple sutures exist in the Brooks Range, indicating a protracted history of Caledonian terrane amalgamation between Baltica and Laurentia that extended through the Canadian Arctic. Importantly, Devonian–Mississippian juxtaposition of the southwestern subterranes with the North Slope along the Canadian Arctic margin provides the previously enigmatic source of exotic Neoproterozoic–Cambrian detritus in the Ellesmerian clastic wedge (e.g., Beranek et al., 2010; Anfinson et al., 2012) and potentially supports the foreland basin model of Nilsen (1981) for the Endicott Mountains subterrane of Arctic Alaska as an extension of this collisional basin.

Many studies use the data of Lane (2007) to provide an Early–Middle Devonian tie point between the Arctic Alaska–Chukotka terrane and the northwestern margin of Laurentia (e.g., Beranek et al., 2010; Colpron and Nelson, 2011). This conclusion hinges on the interpretation that no significant strike-slip displacement has occurred along the Kaltag-Porcupine-Rapid fault array (Fig. 2A; Lane, 2007). In contrast, Oldow et al. (1987) considered this fault system to be a major tectonic boundary separating autochthonous Laurentia from parautochthonous and allochthonous crust. Restoration of the North Slope to a position adjacent to Banks and Melville Islands (Fig. 1) in the Devonian is consistent with the detrital zircon data and faunal assemblages described herein, and it rectifies geological inconsistencies with Late Devonian strata in northern Yukon (e.g., Endicott Group proximal fluvial-deltaic deposits juxtaposed against coeval basin-floor fan deposits in northern Yukon) and aligns similar deformation ages, structural styles, and Late Devonian granitoid intrusions with patterns observed in Arctic Canada (Oldow et al., 1987; Trettin, 1991).

We suggest that the Doonerak arc complex, which hosts trilobites of apparent Siberian affinity (Dutro et al., 1984) but is currently included with the North Slope, evolved independently from the North Slope parautochthon and instead developed in a similar tectonic setting with the Pearya terrane outboard of the Franklinian Basin. In this scenario, juxtaposition of these arc terranes and subsequent oblique docking of the southwestern subterranes of the Arctic Alaska–Chukotka terrane with the Canadian Arctic margin of Laurentia were at least partly responsible for the protracted Devonian(?)–Mississippian Romanzof and Ellesmerian tectonism in northern Laurentia.

CONCLUSIONS

A lack of field-based observations and data from modern circum-Arctic margins has perpetuated controversy regarding the Mesozoic opening of the Amerasian Basin and the Paleozoic tectonic evolution of "suspect" terranes bordering the Arctic region. Here, we present coupled detrital zircon and paleontological data that better constrain the origin and travels of the Arctic Alaska–Chukotka terrane and demonstrate that it is composed of multiple continental fragments that were juxtaposed against northern Laurentia during the Devonian(?)–Mississippian. Subsequent establishment of the timing and kinematics of these mid-Paleozoic orogenic events within Arctic Alaska, Pearya, and on the Canadian Arctic margin of autochthonous Laurentia will provide key tie points for subsequent reconstructions of the Mesozoic opening of the Amerasian Basin of the Arctic Ocean.

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