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Maurice Colpron and Joanne L. Nelson

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Notes

A Palaeozoic Northwest Passage: incursion of Caledonian, Baltican and Siberian terranes into eastern Panthalassa, and the early evolution of the North American Cordillera

MAURICE COLPRON[1]* & JOANNE L. NELSON[2]

[1]*Yukon Geological Survey, PO Box 2703 (K-10), Whitehorse, Yukon, Canada Y1A 2C6*

[2]*British Columbia Geological Survey, PO Box 9333 Stn Prov Gov't, Victoria, British Columbia, Canada V8W 9N3*

**Corresponding author (e-mail: maurice.colpron@gov.yk.ca)*

Abstract: Palaeozoic to early Mesozoic terranes of the North American Cordillera mostly originated from three distinct regions in Palaeozoic time: the western peri-Laurentian margin, western (Asian) Panthalassa, and the northern Caledonides–Siberia. A review of geological history, fossil and provenance data for the Caledonian–Siberian terranes suggests that they probably occupied an intermediate position between northern Baltica, northeastern Laurentia and Siberia, in proximity to the northern Caledonides, in early Palaeozoic time. Dispersion of these terranes and their westward incursion into eastern Panthalassa are interpreted to result from development of a Caribbean- or Scotia-style subduction system between northern Laurentia and Siberia in mid-Palaeozoic time, termed here the Northwest Passage. Westward propagation of a narrow subduction zone coupled with a global change in plate motion, related to the collision of Gondwana with Laurentia–Baltica, are proposed to have led to initiation of subduction along the western passive margin of Laurentia and development of the peri-Laurentian terranes as a set of rifted continental fragments, superimposed arcs and marginal ocean basin(s) in mid- to late Palaeozoic time. Diachronous orogenic activity from Late Silurian in Arctic Canada, to Early Devonian in north Yukon and adjacent Alaska, Middle Devonian in southeastern British Columbia, and Late Devonian–Early Mississippian in the western USA records progressive development of the Northwest Passage and southward propagation of subduction along western Laurentia.

The North American Cordillera is regarded as one of the type accretionary orogens on Earth, where growth occurred as the result of progressive addition of terranes, crustal elements that preserve a geological record distinct from their neighbours, to the western margin of Laurentia beginning in late Palaeozoic time (Coney *et al.* 1980). The western margin of Laurentia originated during late Neoproterozoic breakup of Rodinia, and passive continental margin deposition prevailed through the early Palaeozoic (Price 1994). In mid-Palaeozoic time, it was converted to an active plate boundary and subduction was initiated, as indicated by first occurrences of arc and back-arc magmatism in Devonian strata of the distal continental margin and the accreted terranes (Rubin *et al.* 1990; Monger & Nokleberg 1996). This convergent margin geodynamic setting, which has prevailed along the western margin of North America up to the present time, provided the environment for generation, dispersion and accretion of the Cordilleran terranes.

Early terrane analysis of the North American Cordillera suggested that allochthonous terranes were of uncertain palaeogeographical origins and that the Cordilleran orogen represented a collage of disparate crustal fragments (Helwig 1974; Coney *et al.* 1980). Since then, detailed mapping coupled with application of analytical tools (Nd, Hf, Sr isotopes; geochemistry; U–Pb geochronology, particularly of detrital zircon suites; palaeomagnetism) and the fossil evidence have greatly improved our knowledge of the geological history and geodynamic affinities of the accreted terranes (Fig. 1). It is now recognized that a group of terranes that generally occupy the core of the orogen (Yukon–Tanana, Quesnellia, Stikinia and related terranes) were generated along the western margin of Laurentia as a series of rifted continental fragments, superimposed arcs and marginal ocean basin(s) in mid-Palaeozoic to early Mesozoic time (Fig. 1; Nelson & Colpron 2007; Nelson *et al.* 2006; Colpron *et al.* 2007). These terranes enclose oceanic rocks with Palaeozoic faunal elements of Tethyan (Asian) affinity that were incorporated during the early Mesozoic development of the Cordilleran orogen (Mihalynuk *et al.* 1994).

In contrast, terranes that generally occupy more outboard positions in the orogen (the Arctic realm of Colpron *et al.* (2007)) have been recognized by

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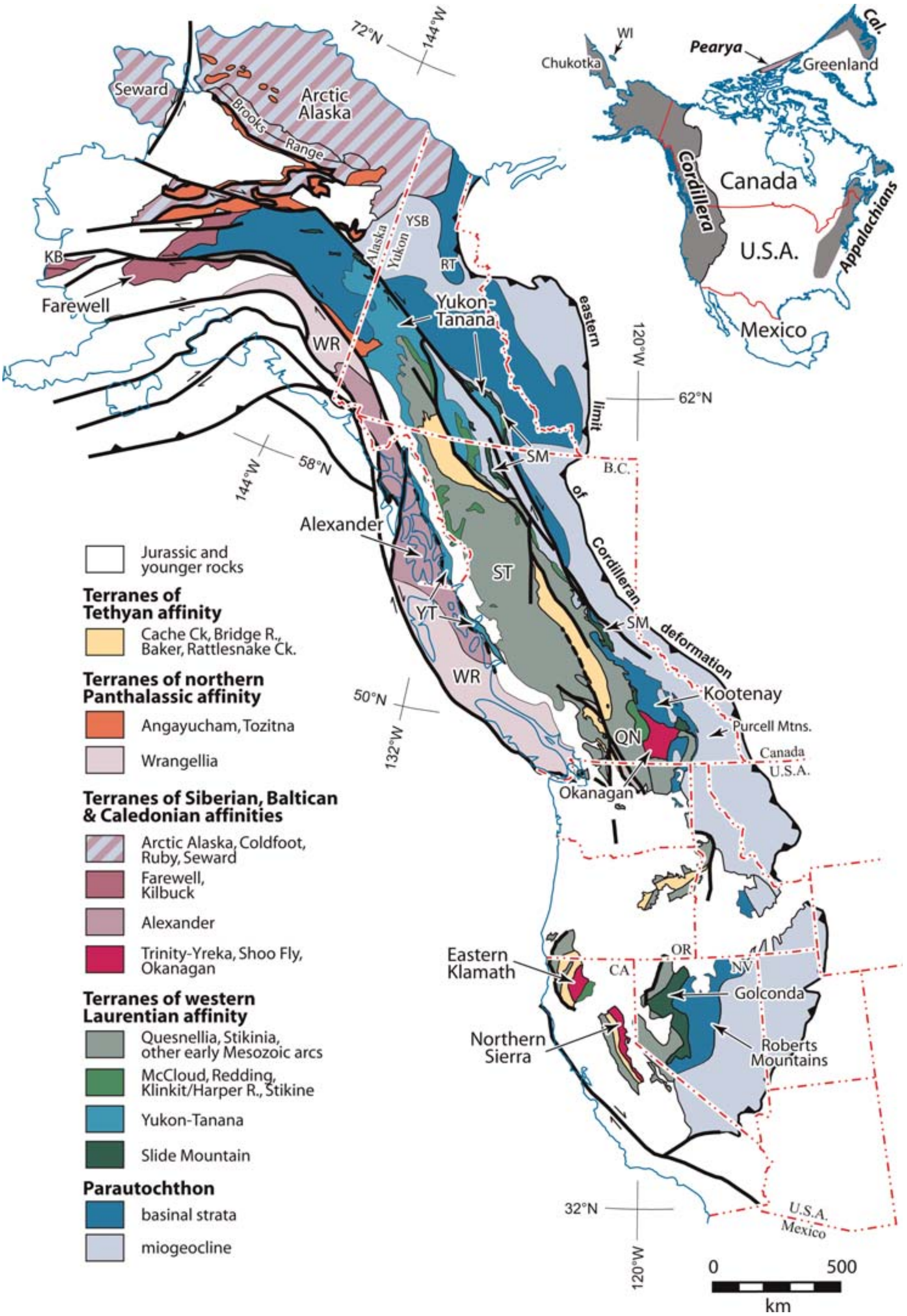

Fig. 1. Palaeozoic to early Mesozoic terranes of the North American Cordillera. Terranes are grouped according to faunal affinity and/or source region in early Palaeozoic time. Terrane and geological abbreviations: KB, Kilbuck; QN, Quesnellia; RT, Richardson trough; SM, Slide Mountain; ST, Stikinia; YSB, Yukon Stable Block; YT, Yukon–Tanana terrane in the Coast Mountains; WR, Wrangellia. Inset shows location of the Cordilleran orogen in western North America with respect to Chukotka and Wrangel Island (WI), Pearya in the Arctic Islands, the Greenland Caledonides (Cal.) and the Appalachians along the east coast.

a growing consensus as manifesting Palaeozoic and older affinities with northern Baltica (Alexander; Bazard *et al.* 1995; Gehrels *et al.* 1996; Soja & Antoshkina 1997; Antoshkina & Soja 2006; Soja & Krutikov 2008), Siberia (e.g. Farewell; Blodgett *et al.* 2002; Dumoulin *et al.* 2002; Bradley *et al.* 2003, 2007; Fryda & Blodgett 2008), the northern Caledonides (part of Arctic Alaska; Nilsen 1981; Moore *et al.* 1994), or a combination of these end-members and northern Laurentia (e.g. Arctic Alaska, Eastern Klamath, Northern Sierra and others; Dumoulin *et al.* 2002; Wright & Wyld 2006; Lindsley-Griffin *et al.* 2008; Fig. 1). Equally important, shared faunas, igneous and deformational events, and similar detrital zircon populations suggest that all of these terranes developed in some proximity to each other, and therefore constitute elements of a single, albeit complex tectonic system.

Here, we summarize the evidence that constrains the tectonic evolution and probable sites of origin of Palaeozoic–early Mesozoic terranes of the North American Cordillera, with particular emphasis on the convergence of published opinion as to the probable palaeo-Arctic origins of the outboard terranes. We then present a hypothesis that accounts for the incursion of crustal fragments of inferred Siberian, Baltican and Caledonian affinities into eastern Panthalassa, the late Palaeozoic World Ocean (Scotese 2002), and at the same time provides a mechanism for the mid-Palaeozoic initiation of subduction along the western passive margin of Laurentia. Our model calls for the development of a Caribbean- or Scotia-style subduction system along the northern margin of Laurentia in mid-Palaeozoic time. A similar concept was proposed earlier by Wright & Wyld (2006), who suggested that a mid-Palaeozoic Caribbean-style system, which developed between southern Laurentia and Gondwana, allowed south to north migration of the Alexander and parts of the Eastern Klamath and Northern Sierra terranes from Iapetus into Panthalassa. Our review of the geological evidence (below) leads us to conclude that these terranes have much stronger affinities with northern Caledonian, northern Baltican and Siberian source regions than with Appalachian Iapetan terranes. Our model also provides an explanation for the enigmatic mid-Palaeozoic compressional (transpressional) deformational events documented along the northern and western continental margin of Laurentia.

Our discussion is focused on terranes with inferred Caledonian–Baltican–Siberian affinities and their Palaeozoic interactions with northern and western Laurentia. Terranes of Tethyan (western Panthalassan) affinity in Palaeozoic time were introduced to the Cordilleran arena only in the early Mesozoic and will not be considered any further here. Aspects of their evolution have been presented by Mihalynuk *et al.* (1994, 2004) and English & Johnston (2005).

Our review of the tectonic evolution of the North American Cordillera is primarily focused on its pre-Mesozoic history, prior to the Jurassic–Palaeocene orogenesis that led to development of the modern Cordilleran mountain belt (Fig. 1). Recent reviews of the Mesozoic to early Cenozoic evolution of the Cordillera have been presented by Monger & Nokleberg (1996), Monger & Price (2002) and Evenchick *et al.* (2007).

Peri-Laurentian terranes

The inner belt of terranes of the Canadian Cordillera, the pericratonic terranes of Wheeler *et al.* (1991; Kootenay, Yukon–Tanana and others, Fig. 1), have faunal affinities and provenance ties with western Laurentia, but their mid-Palaeozoic to early Mesozoic geological record differs from that of the continental margin (Fig. 2). They probably formed a mid- to late Palaeozoic set of island-arc and rifted crustal fragments that were separated from the Laurentian continental margin by a marginal ocean basin, remnants of which are preserved in the Slide Mountain terrane (Fig. 1; Nelson *et al.* 2006; Colpron *et al.* 2007). Development of these terranes began with the onset of subduction along western Laurentia in mid-Palaeozoic time (Rubin *et al.* 1990). Early indications of this convergent plate setting are recorded in local Middle Devonian shortening of continental margin strata in southeastern British Columbia (Purcell Mountains, Fig. 1; Root 2001) and in the Late Devonian to Early Mississippian Antler orogeny of the southwestern USA (Roberts Mountains allochthons, Fig. 1; Johnson & Pendergast 1981). In contrast, Late Devonian–Early Mississippian continental margin strata in the northern Cordillera record extension and localized alkaline to calc-alkaline bimodal volcanism and a distal influx of detritus from the Ellesmerian orogen to the north (Gordey *et al.* 1987; Smith *et al.* 1993).

The earliest record of arc magmatism in the peri-Laurentian realm occurred in late Middle Devonian time (*c.* 387 Ma) in the Yukon–Tanana terrane of coastal British Columbia and southeastern Alaska (Nelson *et al.* 2006) and the western Kootenay terrane of southern British Columbia (Schiarizza & Preto 1987; Fig. 1). By Late Devonian–earliest Mississippian time, arc magmatism was widespread in Yukon–Tanana and locally significant on the distal Laurentian margin (Nelson *et al.* 2006; Piercey *et al.* 2006).

The western Kootenay terrane (Eagle Bay assemblage; Schiarizza & Preto 1987; Paradis *et al.* 2006) includes Late Devonian to earliest

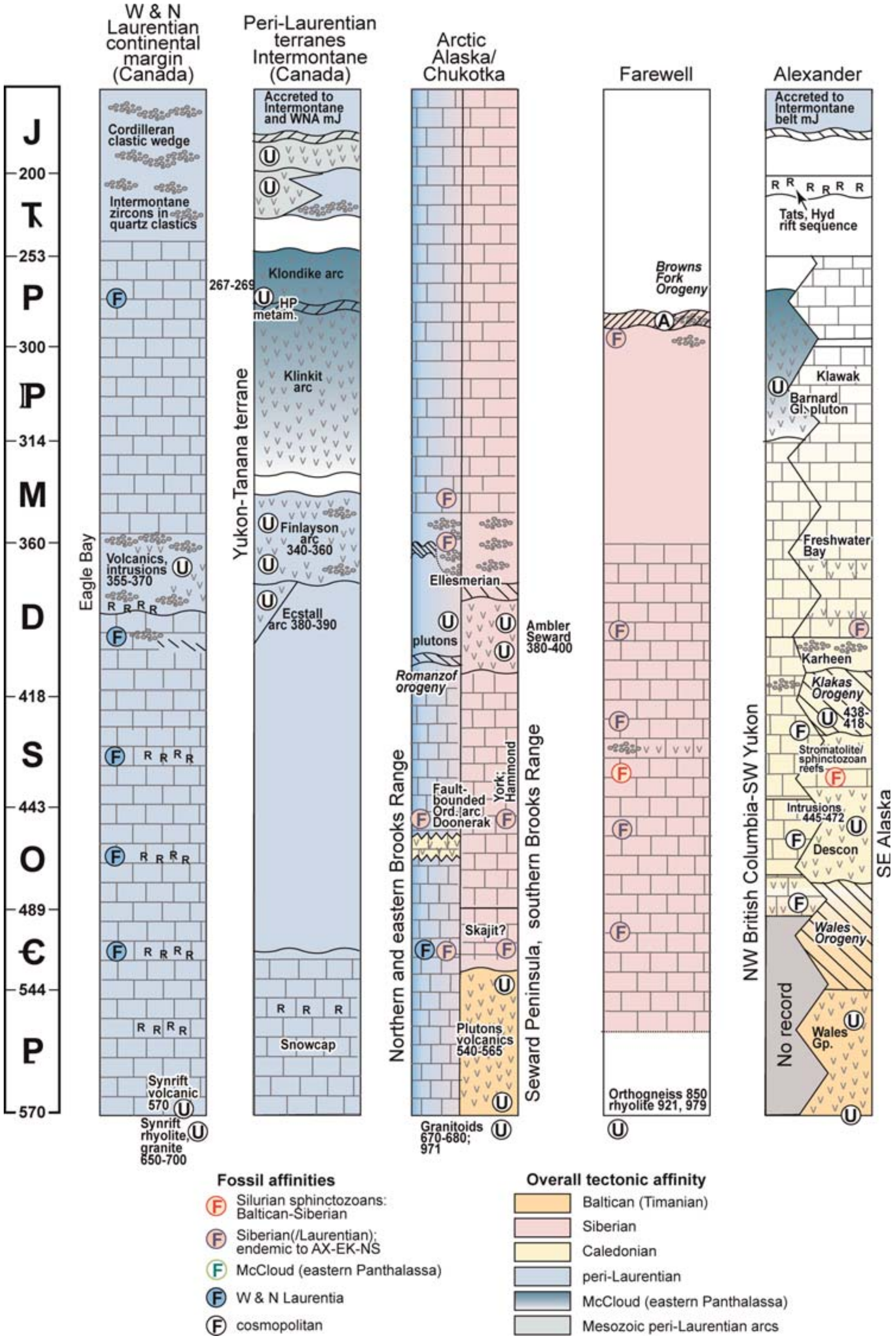

Fig. 2. Composite stratigraphic columns for terranes of peri-Laurentian, Siberian, Baltican and Caledonian affinities in western and northern North America (compiled from sources cited in the text). AMQ, Antelope Mountain Quartzite; AX, Alexander terrane; EK, Eastern Klamath terrane; NS, Northern Sierra terrane.

Mississippian calc-alkaline plutons and coeval bimodal volcanic rocks that intrude and overlie a Neoproterozoic–early Palaeozoic sequence of predominantly clastic metasedimentary rocks and rift-related alkalic to tholeiitic metavolcanic rocks, including an archaeocyathid-bearing marble. This Neoproterozoic–early Palaeozoic sequence is correlated in part with the lower Palaeozoic Lardeau Group east of the Monashee complex (Fig. 3), which conformably overlies Ediacaran

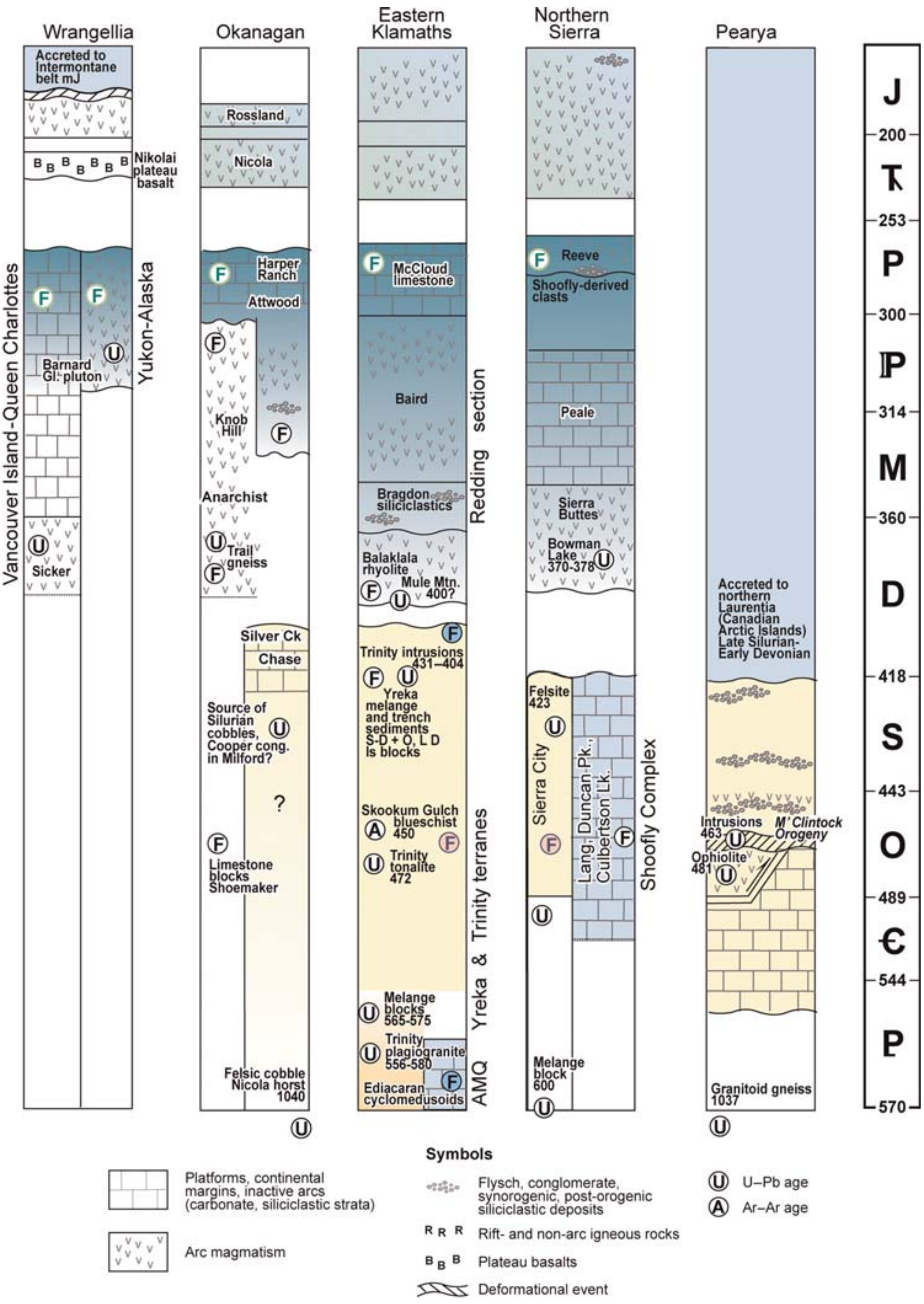

Fig. 2. (*Continued*).

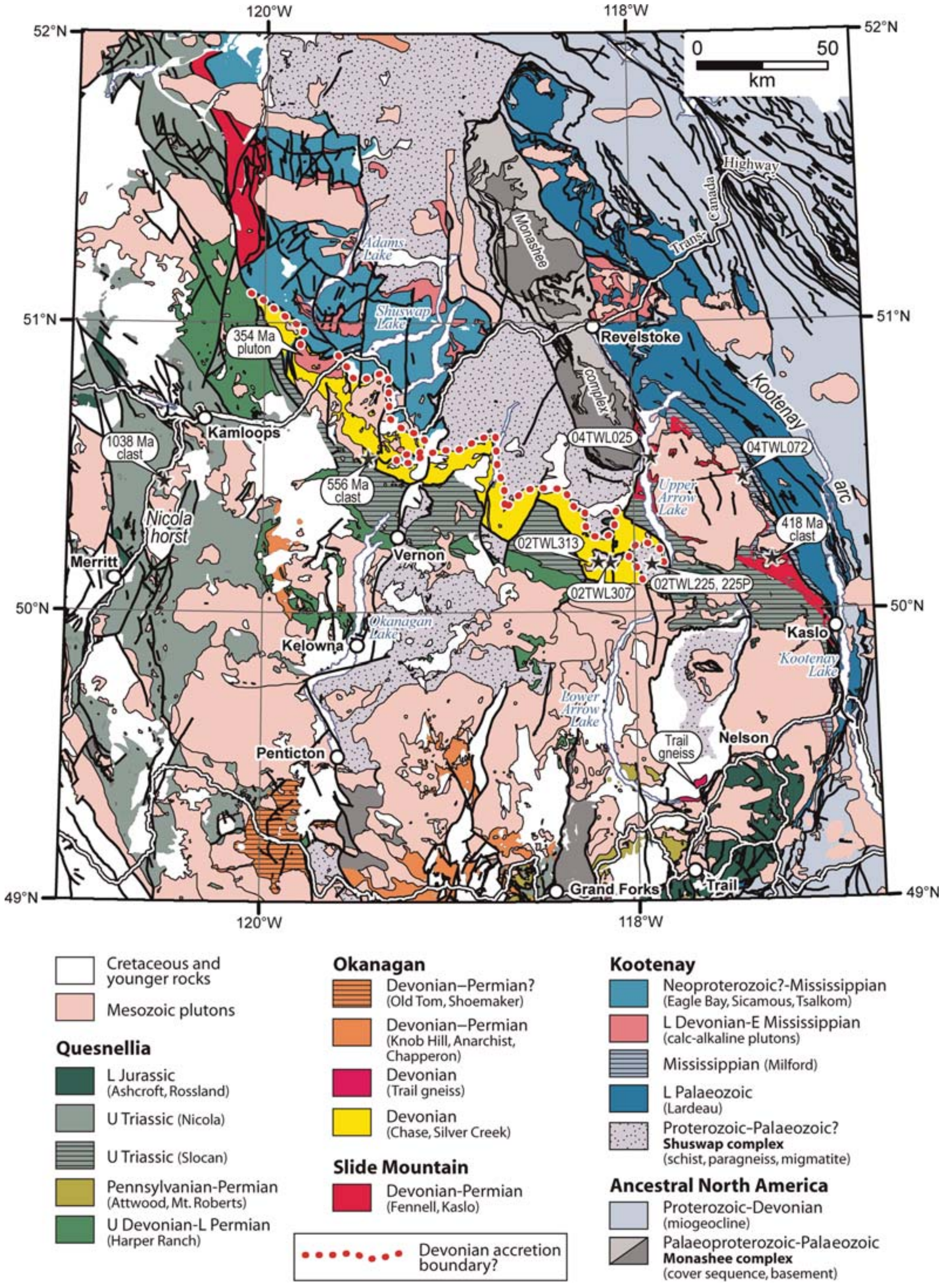

Fig. 3. Geological map of the Okanagan–Kootenay region of southern British Columbia (modified after Massey *et al.* 2005; Thompson *et al.* 2006). Detrital zircon samples reported by Lemieux *et al.* (2007) and other significant features of the Okanagan subterrane and southern Quesnellia are located by stars. Dotted red line shows location of a possible Devonian accretion boundary.

to Lower Cambrian quartzite and marble of the distal Laurentian miogeocline (Logan & Colpron 2006). Limited detrital zircon data from the Lardeau Group and underlying continental margin strata are dominated by *c.* 1.8 Ga grains that suggest a common source (recycling?) in Precambrian domains of Alberta and match the miogeocline reference data for southern British Columbia (Fig. 4c and f; Smith & Gehrels 1991; Gehrels *et al.* 1995). The evolved isotopic composition (εNd_{360} values -6.5 to -6.8) and common inheritance in zircons from calc-alkaline rocks of the Kootenay terrane suggest a continental arc setting (Paradis *et al.* 2006). Depositional ties with the miogeocline in the eastern Kootenay terrane and its occurrence inboard of Devonian–Permian oceanic rocks of the Slide Mountain terrane strongly suggest that the Kootenay terrane is parautochthonous with respect to the Laurentian continental margin.

A similar intepretation is proposed for basinal, clastic metasedimentary rocks and voluminous felsic magmatism of Late Devonian–earliest Mississippian age in east–central Alaska (Fig. 1; Dusel-Bacon *et al.* 2006). Magmatism ended at *c.* 354 Ma along the entire parautochthonous continental margin, presumably as the Slide Mountain ocean widened and the axis of magmatism and the Yukon–Tanana terrane migrated away to the west (Nelson *et al.* 2006; Colpron *et al.* 2007). Parautochthonous rocks of east–central Alaska and the Kootenay terrane therefore preserve the remnant, inboard arc that was isolated behind the Slide Mountain back-arc basin in Mississippian time.

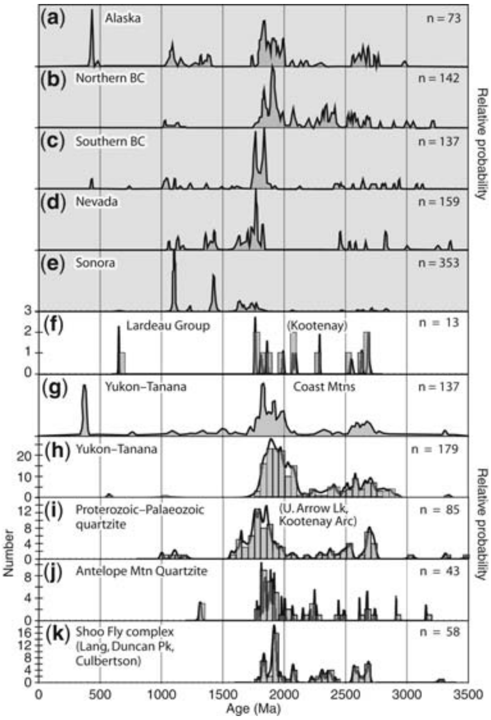

Fig. 4. Detrital zircon data for peri-Laurentian terranes compared with reference data of Gehrels *et al.* (1995) and Gehrels & Ross (1998) for the North American miogeocline (**a**–**e**; after Gehrels 2000); (**f**) Broadview Formation, Lardeau Group (Kootenay terrane), southern British Columbia (after Smith & Gehrels 1991); (**g**) Yukon–Tanana terrane from the Coast Mountains of southeastern Alaska (after Gehrels & Kapp 1998); (**h**) Yukon–Tanana terrane of northern British Columbia and Yukon (composite of three samples; after Devine *et al.* 2006; Nelson & Gehrels 2007; M. Colpron, unpubl. data); (**i**) Proterozoic–lower Palaeozoic schist from Upper Arrow Lake region, southern British Columbia and basal Milford quartzite of the Kootenay Arc region (Fig. 3; composite of samples 02TWL225P, 02TWL307 and 04TWL072 of Lemieux *et al.* 2007); (**j**) Antelope Mountain Quartzite, Eastern Klamath terrane (after Wallin *et al.* 2000); (**k**) Lang, Duncan Peak and Culbertson Lake allochthons of the Shoo Fly Complex, Northern Sierra terrane (after Harding *et al.* 2000). Reference data are shown with shaded background in this and other detrital zircon plots.

The Yukon–Tanana terrane lies outboard (west) of the oceanic Slide Mountain terrane in the northern Cordillera (Fig. 1; Mortensen 1992). It consists of a metasedimentary basement (Snowcap assemblage) overlain by up to three unconformity-bounded Upper Devonian to Permian volcanic arc sequences (Finlayson, Klinkit, Klondike; Fig. 2) that are coeval with oceanic chert, argillite and mafic volcanic rocks of the Slide Mountain back-arc terrane (Colpron *et al.* 2006). The Snowcap assemblage is pre-Late Devonian in age and comprises varying amounts of quartzite, pelite, psammite, marble and calc-silicate, and minor mafic metavolcanic and meta-intrusive rocks (Colpron *et al.* 2006). Its lithological, geochemical and isotopic compositions suggest that the Snowcap assemblage represents a distal portion of the continental margin that was rifted off western Laurentia in mid-Palaeozoic time and subsequently formed the nucleus upon which magmatic arcs of the Finlayson, Klinkit and Klondike assemblages were deposited (Nelson *et al.* 2006; Piercey & Colpron 2006). Detrital zircons from Upper Devonian–Lower Mississippian sandstone of the Yukon–Tanana terrane are dominated by grains of 1.8–2.1 Ga and 2.5–2.7 Ga, with minor populations at *c.* 1.3–1.4 Ga (Fig. 4g and h; Gehrels & Kapp 1998; Devine *et al.* 2006; Nelson & Gehrels 2007) that match well with the miogeoclinal reference for northern British Columbia (Gehrels *et al.* 1995; Gehrels & Ross 1998). Rocks of the Snowcap assemblage appear to have been deformed and metamorphosed prior to deposition of the overlying Upper Devonian to Permian strata. The cause of this deformational event remains enigmatic. Berman *et al.* (2007) interpreted a Late Devonian low-pressure metamorphic and deformational event in the western Yukon–Tanana terrane to be related to arc plutonism above an east-dipping subduction zone.

Arc and back-arc magmatism began in Late Devonian time (*c.* 365 Ma) in most of Yukon–Tanana terrane and was widespread in the terrane by Early Mississippian time (*c.* 355–345 Ma), forming large calc-alkaline plutons intruding the Snowcap basement and extensive, coeval volcanic successions of the Finlayson assemblage (Colpron *et al.* 2006; Piercey *et al.* 2006). Back-arc volcanism occurred in association with basinal, carbonaceous phyllite and syngenetic sulphide deposits that have highly radiogenic Pb isotopic compositions, similar to those of broadly coeval syngenetic sulphide occurrences in basinal continental margin strata to the east; a lead isotopic signature that is unique to the Late Devonian of northwestern Laurentia (Godwin & Sinclair 1982; Mortensen *et al.* 2006; Nelson *et al.* 2006). The wide range of Nd isotopic compositions (εNd values of -5.1 to $+7.0$), widespread felsic magmatism and the ubiquitous Palaeoproterozoic–Archaean inheritance in zircons all suggest a continental arc setting.

By Middle Mississippian time (*c.* 340 Ma), the Yukon–Tanana arc had reached a mature stage, as indicated by the predominance of andesite, basaltic andesite and volcaniclastic rocks, and locally thick carbonate of the Klinkit assemblage (mid-Mississippian to Lower Permian; Colpron *et al.* 2006). Primitive geochemical and isotopic compositions (εNd $= +6.7$ to $+7.4$) indicate limited interaction with evolved crustal material (Simard *et al.* 2003). The Klinkit assemblage is correlated on the basis of stratigraphy and geochemistry with late Palaeozoic sequences of Quesnellia (Simard *et al.* 2003; Nelson & Friedman 2004). These locally include limestone with giant *Parafusulina*, a southern Laurentia endemic fauna that also occurs in the McCloud terranes, which are interpreted as fragments of late Palaeozoic arcs that developed some distance west of the continent (Stevens 1995).

The youngest arc succession in the Yukon–Tanana terrane, the Middle to Late Permian Klondike assemblage (Colpron *et al.* 2006), is dominated by felsic magmatism (Mortensen 1990; Piercey *et al.* 2006). It is paired with a belt of eclogite and blueschist (U–Pb zircon ages of 267–269 Ma) that lies along the eastern edge of the Yukon–Tanana terrane (Erdmer *et al.* 1998), separating it from the oceanic Slide Mountain terrane. Arc magmatism of the Klondike assemblage is interpreted to record west-dipping subduction of the Slide Mountain back-arc oceanic lithosphere beneath the Yukon–Tanana arc terrane in mid- to Late Permian time (Nelson *et al.* 2006). The cause of this mid-Permian reversal in subduction polarity and the fate of the earlier east-dipping subduction of Panthalassa oceanic lithosphere remain enigmatic. By Triassic time, generally fine-grained siliciclastic rocks that contain metamorphic detritus and zircons derived from the Yukon–Tanana terrane were deposited unconformably on the Yukon–Tanana and Slide Mountain terranes, as well as miogeoclinal strata to the east (Beranek & Mortensen 2007), suggesting that the Slide Mountain ocean had closed. Significant crustal thickening in the Yukon–Tanana terrane is indicated by *c.* 239 Ma amphibolite-facies metamorphism (*c.* 9 kbar and 600 °C) in western Yukon (Berman *et al.* 2007). Subsequent early Mesozoic arc magmatism of Quesnellia and Stikinia was developed in part on top of the Palaeozoic successions of Yukon–Tanana and above renewed east-dipping subduction of Panthalassa oceanic lithosphere beneath western Laurentia (Colpron *et al.* 2007).

In summary, the peri-Laurentian terranes show early linkages to and relationships with the western margin of Laurentia, such as the following:

(1) There are stratigraphic similarities between basement siliciclastic–carbonate–basalt sequences in the Yukon–Tanana terrane and Neoproterozoic–early Palaeozoic units on the autochthonous continental margin.

(2) Detrital zircon populations with marked peaks in the 1.8–2.0 Ga range, and distributions into the Archaean and in some cases minor grains in the range 1.0–1.3 Ga; the latter are considered to represent very distal Grenvillian detritus (Rainbird *et al.* 1997; Fig. 4).

(3) Continental arc magmatism commenced in Middle to Late Devonian time, accompanied by widespread evidence of extension and local compressional tectonics.

(4) There is complete lack of evidence for subduction and/or magmatic arc development in the Neoproterozoic to early Palaeozoic. In addition, Neoproterozoic arc development adjacent to western Laurentia would have been unlikely, as the rifting events responsible for creating an open, ocean-facing margin were not yet complete (e.g. Colpron *et al.* 2002, and references therein). A few Neoproterozoic (700–540 Ma) rift-related igneous bodies have been identified; they may be the source of small detrital zircon populations in this age range that are present in miogeoclinal samples.

Terranes of Siberian, Baltican and Caledonian affinities

The Palaeozoic parts of the outboard terranes of the Cordillera (Arctic realm of Colpron *et al.* 2007) do not share these characteristics. They present tectonic histories, detrital zircon populations and fossil assemblages that differ profoundly from western Laurentia and the peri-Laurentian terranes of the Cordillera. In general, their characteristics are more compatible with an Appalachian–Caledonian origin (Wright & Wyld 2006). Recent studies of these terranes strongly favour linkages with northern elements of the Caledonian orogen in northeastern Laurentia and Baltica as the closest match for some, and Siberia for others. The main lines of evidence include the following:

(1) affinities of early Palaeozoic macro- and microfossils with those in Siberia, and in some cases NE Laurentia–Baltica;

(2) for terranes of inferred Baltican and Caledonian affinities, detrital zircon signatures reflecting a heterogeneous basement with multiple sources between 1.0 and 2.0 Ga, including significant populations in the 1.49–1.61 Ga North American magmatic gap (Van Schmus *et al.* 1993), and only minor Archaean source terranes;

(3) evidence of Grenvillian magmatism, both direct and reflected in robust detrital zircon populations;

(4) Late Neoproterozoic magmatism and arc development (700–540 Ma);

(5) Ordovician–Silurian arc development.

In the following sections, the inferred Siberian, Baltican and Caledonian terranes, now incorporated in the Cordillera, are described in present geographical order from north to south, with a focus on the characteristics that identify their palaeogeographical affinities, and also their early relationships to each other.

Arctic Alaska–Seward–Chukotka

A sinuous, composite pericratonic terrane extends from far northern Yukon, through the Arctic Alaska region (Brooks Range and North Slope); with correlatives in the Seward Peninsula and the Chukotka Peninsula and Wrangel Island of northeastern Russia (Figs 1 and 5). Its pre-Devonian geological record and early Palaeozoic faunal affinities are distinct from those of northern Laurentia (Fig. 2). Comprehensive faunal analysis led Dumoulin *et al.* (2002) to propose that it developed as an isolated crustal fragment originally located between the Siberian and Laurentian cratons. Metamorphosed basement units include orthogneiss and metavolcanic units of *c.* 970 and *c.* 750–540 Ma in the southern Brooks Range (Hammond and Coldfoot subterranes; Amato *et al.* 2006; McClelland *et al.* 2006), *c.* 680–670 Ma and *c.* 560–540 Ma on the Seward Peninsula (Patrick & McClelland 1995; Amato *et al.* 2006), and *c.* 700–630 Ma on Wrangel Island (Cecile *et al.* 1991). Igneous suites of these ages are rare on the northwestern Laurentian margin, except for a few Neoproterozoic (700–570 Ma) rift-related bodies. On the other hand, magmatic ages in the ranges of 980–900 Ma and 700–600 Ma are more common along the eastern margin of Laurentia and in Barentsia (Svalbard), which led Patrick & McClelland (1995) to propose that Arctic Alaska was originally positioned between Siberia, Barentsia and Greenland (NE Laurentia) within Rodinia. However, calc-alkaline magmatism in the *c.* 560–540 Ma range is not known in either Barentsia or Laurentia but is widespread in the late Neoproterozoic Timanide orogen of eastern Baltica (Gee *et al.* 2006). Finally, Moore *et al.* (2007) reported significant populations of non-western Laurentian detrital zircons (e.g. 1.0–1.2 and 1.5–1.7 Ga; 475–600 Ma) in Proterozoic and younger sandstones from all but far eastern Arctic Alaska, which they interpreted as derived from non-Laurentian sources related to the northern Caledonides.

On Wrangel Island, 540 Ma and older igneous rocks are unconformably overlain by a lower Palaeozoic platformal cover sequence (Kos'ko *et al.* 1993; Amato *et al.* 2006). On the Seward Peninsula, Ediacaran and older metamorphic and igneous rocks are presumably overlain by less-metamorphosed strata, including immature sandstone with detrital zircons as young as *c.* 540 Ma, and fossiliferous Lower Ordovician carbonate (Amato *et al.* 2006). In most of Arctic Alaska, the early Palaeozoic was a period of tectonic quiescence, characterized by platformal to basinal deposition. These strata contain both macrofaunal and microfaunal assemblages with Siberian and Siberian–Laurentian affinities (Blodgett *et al.* 2002; Dumoulin *et al.* 2002). Megafossils with Siberian affinities include Middle Cambrian trilobites in the central Brooks Range, Ordovician trilobites from the Seward Peninsula, and Late Ordovician brachiopods and gastropods from the Seward Peninsula and western and eastern Brooks Range. Characteristic Laurentian forms include Early and Late Cambrian trilobites from the eastern Brooks Range and Late Ordovician corals, stromatoporoids and brachiopods from the Seward Peninsula and central Brooks Range. Faunal components with Siberian affinities, including Ordovician conodonts, decrease markedly from west to east across northern Alaska (Dumoulin *et al.* 2002). Lane (2007) pointed out that Proterozoic to Silurian strata in the far eastern part of the terrane show lithological linkages to autochthonous Laurentian elements such as the Richardson trough and Yukon Stable Block (Fig. 1).

There are several occurrences of lower Palaeozoic oceanic and arc-related assemblages in the Arctic Alaska terrane (Moore *et al.* 1994). In the Mt. Doonerak fenster, a structural window in the central Brooks Range, a metasedimentary assemblage occupying a high structural level consists of Middle Cambrian limestone containing trilobites of Siberian affinity, along with Ordovician and Silurian basinal strata. A structurally lower volcanic assemblage has a supra-subduction zone geochemical signature and has yielded a K–Ar age of *c.* 470 Ma (Dutro *et al.* 1976). The palaeogeographical and palaeotectonic setting of the Ordovician arc rocks is uncertain. They were probably incorporated into the Arctic Alaska terrane in Devonian time, as the Palaeozoic rocks in the Mt. Doonerak fenster are unconformably overlain by Lower Mississippian clastic rocks of the Endicott Group, which blankets the terrane as a whole. Lower Palaeozoic rocks of oceanic character are also recognized in the Romanzof Mountains in the eastern Brooks Range in a disrupted assemblage that may structurally overlie miogeoclinal facies (Moore *et al.* 1994). The deformed oceanic rocks are truncated by an angular unconformity, which is overlain by Middle Devonian chert-rich sandstone. The presence of these oceanic assemblages, along with the Proterozoic to Cambrian magmatic suites in the southern Brooks Range and strong Siberian faunal affinities in the western Brooks Range all support the concept of Moore *et al.* (1994) that much of the Arctic Alaska terrane evolved apart from western Laurentia in the early Palaeozoic, prior to Devonian time.

The Romanzof orogeny is a late Early to earliest Middle Devonian (*c.* 400 Ma) event that caused shortening in the eastern Arctic Alaska terrane, in the Romanzof and British–Barn Mountains near the Alaska–Yukon border (Fig. 5; Lane 2007). Thrust fault displacement was to the NE and east, and deformation was followed by widespread Late Devonian granitic plutonism (375–362 Ma). The lack of Early to Middle Devonian deformation further to the south and the southward progradation of Early Devonian turbidites suggest that the responsible collision took place in what is now the Beaufort Sea (Fig. 5). Lane (2007) hypothesized that it involved accretion to northern Laurentia of a single continent-scale terrane, which included Pearya in the Arctic Islands, a fragment that was accreted in Late Silurian time (Fig. 5). Moore *et al.* (2007) also considered that Devonian deformation in Arctic Alaska represents a northern element of the Caledonian deformational system that probably once linked up with Caledonian structures in the Canadian Arctic Islands and adjacent continental margin region. A tectonic highland persisted north of present-day Arctic Alaska from Early Mississippian to Triassic time, based on successive onlaps and northward-coarsening of siliciclastic strata (Moore *et al.* 1994). Ediacaran–Cambrian (600–500 Ma) and Ordovician (490–445 Ma) zircons in northerly derived Triassic units in the eastern Arctic Alaska terrane and the autochthonous Sverdrup Basin of Arctic Canada (Miller *et al.* 2006) may have sourced this now-submerged terrane.

A two-fold belt of mid-Devonian plutonic and volcanic bodies occurs along the southern fringe of the Arctic Alaska terrane (Fig. 5). The more

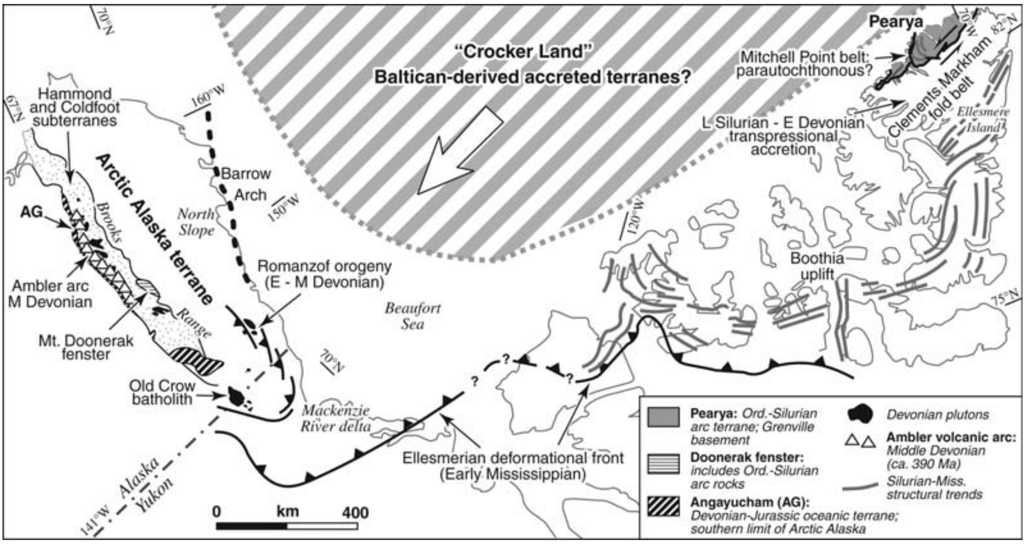

Fig. 5. Distribution of the main mid-Palaeozoic tectonic elements of northern Canada and adjacent Alaska (after Moore *et al.* 1994; Lane 2007).

northerly Hammond terrane lacks volcanic rocks, but is intruded by an east–west-trending belt of I-type and crustally derived granitoids with discordant U–Pb zircon ages between 366 and 402 Ma (Moore *et al.* 1994). The Ambler sequence in the Coldfoot subterrane to the south (Fig. 5) is a Middle Devonian (378–386 Ma, U–Pb zircon; McClelland *et al.* 2006) pericratonic arc, intruded by comagmatic plutons. Arc polarity was probably southward above a north-dipping (in present-day coordinates) subduction zone that consumed oceanic lithosphere now represented by the Angayucham ophiolitic terrane (Figs 1 and 5). Limited detrital zircon data from a quartzite in the Coldfoot subterrane yielded primarily Late Devonian grains (360–370 Ma) with scattered Proterozoic and Archaean grains at *c.* 1.3, 1.8–2.0, 2.3.–2.5 and 2.8 Ga (Fig. 6b; Moore *et al.* 1997*a*). Ambler arc activity commenced about 5–10 Ma after the Romanzof orogeny had finished. Initiation of this arc along the present southern margin of the Arctic Alaska crustal fragment could have represented a subduction polarity reversal following Romanzof terrane collision along its present NE (Fig. 5).

In the Mackenzie Delta region of northern Yukon, the Early Mississippian Ellesmerian orogeny is expressed as a southerly to southeasterly vergent fold and thrust belt that apparently terminates near the eastern limit of rocks assigned to the Arctic Alaska terrane, and east of rocks affected by the older Romanzof orogeny (Fig. 5; Lane 2007). The opposing vergences, differing ages and distinct geographical distribution of Ellesmerian and Romanzof structures suggests that they represent two discrete tectonic events formed as a result of mid-Palaeozoic terrane interactions in the Arctic region (Lane 2007).

A sub-Mississippian unconformity is present throughout much of Arctic Alaska, overlain by northward-transgressive and coarsening quartz- and chert-rich marine and non-marine clastic rocks of the Endicott Group (Moore *et al.* 1994). Prominent redbeds in this sequence more closely resemble the thick synorogenic and postorogenic Devonian redbeds of the Franklinian, Caledonian, and Appalachian orogens rather than the abundant Upper Devonian and Lower Mississippian flysch of the adjacent Cordilleran orogen to the south (Nilsen 1981). The tectonic environment in northwestern Arctic Alaska at this time was one of mild extension characterized by several broad-scale uplifts and basins developed on a south-facing continental margin. An exception to this setting is shown by the Nuka Formation, which lies within the highest allochthon emplaced during the north-vergent Jurassic–Cretaceous Brookian orogeny, and which therefore restores south of all other elements of Arctic Alaska, including the Hammond and Coldfoot terranes. The Nuka Formation is a coarse, Mississippian–Pennsylvanian(?) arkose with subangular potassium feldspar grains indicative of a local granitic source, and 2.0–2.1 Ga detrital zircons (Moore *et al.* 1994, 1997*b*). It indicates the presence of a Palaeoproterozoic basement block to the south (present coordinates), similar in age to basement rocks of the Kilbuck terrane (2.07–2.04 Ga; Box *et al.* 1990; Fig. 1).

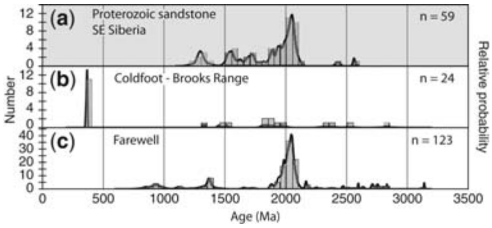

Fig. 6. Detrital zircon data for terranes of Siberian affinities compared with data from Proterozoic sandstone of the eastern Siberian platform (**a**) after Khudoley *et al.* 2001); (**b**) Marion Schist of the Coldfoot terrane, Brooks Range, Alaska (Moore *et al.* 1997); (**c**) Farewell terrane quartzites, central Alaska (composite of three samples; data from Bradley *et al.* 2007).

Farewell terrane

The Farewell terrane, subdivided into the Nixon Fork, Dillinger, and parts of the Mystic terrane, comprises Proterozoic basement overlain by Palaeozoic shelf and slope strata and a Permian clastic wedge (Fig. 2; Bradley *et al.* 2003). The oldest rocks in the Farewell terrane include *c.* 1200 Ma metasedimentary rocks, 980–920 Ma rhyolites and *c.* 850 Ma orthogneiss (Bradley *et al.* 2003, 2007; McClelland *et al.* 2006). Detrital zircons show a prominent peak at *c.* 2050 Ma, and minor peaks at *c.* 1375 and 950 Ma, which correspond to basement ages cited above (Fig. 6c; Bradley *et al.* 2007). Parallels for the 2050 Ma peak can be found in the Nuka Formation in the Brooks Range (Moore *et al.* 2007), in the Kilbuck terrane of western Alaska (Box *et al.* 1990) and in Proterozoic sandstones from the southeastern Siberian platform (Fig. 6a; Box *et al.* 1990; Khudoley *et al.* 2001; Bradley *et al.* 2007). The 980 Ma rhyolite is coeval with an igneous body in the southern Brooks Range (McClelland *et al.* 2006). Detrital grains with ages between 2030 and 890 Ma are reported from Seward Peninsula (Amato 2004), a limited dataset that nevertheless suggests similarities to the Farewell terrane.

The overlying carbonate and siliciclastic strata were deposited on an Ediacaran to Devonian continental platform and slope like that of Arctic Alaska–Chukotka; minor Silurian tuffs suggest nearby arc activity (Fig. 2; Bradley *et al.* 2007). Dumoulin *et al.* (2002) pointed out that the overall pattern of lithofacies correlates closely with that in Arctic Alaska, both consisting of Ediacaran ooid-rich dolostones, Middle Cambrian outer shelf deposits, and Ordovician to Devonian platform and basin facies. Early Palaeozoic faunas, similar to those of Arctic Alaska, show the influence of both Siberian and Laurentian provinces (Blodgett *et al.* 2002; Dumoulin *et al.* 2002). Middle Cambrian trilobites are of Siberian aspect, like those in the central Brooks Range. Identical species of Ordovician brachiopods (*Tsherkidium*) and gastropods are found in both terranes; Ordovician conodont faunas with mixed Siberian–Laurentian affinities characterize both as well (Dumoulin *et al.* 2002).

Silurian stromatolite–sphinctozoan reefs in the Farewell terrane resemble those in the Ural Mountains, as well as those in the Alexander terrane (Soja & Antoshkina 1997; Antoshkina & Soja 2006). Combined with the other faunal evidence, these data favour an early Palaeozoic palaeogeography in which the Farewell and Arctic Alaska crustal fragments were proximal to each other, in a position between Laurentia and Siberia.

The Early Permian (*c.* 285 Ma) Browns Fork orogeny is a distinctive event of deformation, metamorphism and deposition of a clastic wedge in the Farewell terrane. It has no correlatives in the nearby Arctic Alaska–Chukotka terrane. Instead, Bradley *et al.* (2003) have linked this event to Uralian orogenesis related to Permian collision between Baltica, Siberia and Taimyr. This constraint, along with the evidence that Arctic Alaska was interacting with the northwestern margin of Laurentia in Devonian time, suggests that at this time Farewell and Arctic Alaska had separated, with Farewell remaining linked to eastern Siberia and the Uralian orogen until the end of the Palaeozoic.

Alexander terrane

The Alexander terrane occupies a broad belt in the western Cordillera, in close spatial association with Wrangellia (Fig. 1). Together they make up the Insular superterrane. The geology of the Alexander terrane is best known from the detailed work that has been done on Prince of Wales and nearby islands in southeastern Alaska (Gehrels & Saleeby 1987; Gehrels 1990; Gehrels *et al.* 1996). The remaining parts, at least 1000 km long, is mainly described in publications and maps released by the Canadian and US geological surveys; modern high-resolution geochronology, geochemistry and isotopic work is very sparse. Alexander is probably a composite terrane. Stratigraphic successions in various parts of it indicate widely differing, coeval tectonic environments, ranging from the well-known succession of Neoproterozoic to lower Palaeozoic arc-related rocks preserved in southeastern Alaska (Gehrels & Saleeby 1987; Gehrels 1990; Gehrels *et al.* 1996) to a thick Proterozoic–lower Palaeozoic continental platform sequence in the northern part of the terrane near the Tatshenshini River in northwestern British Columbia (Fig. 2; Mihalynuk *et al.* 1993).

The oldest known rocks in the southern Alexander terrane belong to the Ediacaran, arc-related Wales Group (U–Pb ages of *c.* 595 and *c.* 554 Ma; Gehrels *et al.* 1996). These strata were deformed in the pre-Early Ordovician Wales orogeny. Arc magmatism resumed in Early Ordovician–Early Silurian time, represented by the Descon Formation. This was followed by clastic and carbonate sedimentation and pluton emplacement later in the Silurian. The Middle Silurian to Early Devonian Klakas orogeny was marked by thrust imbrication, metamorphism, ductile deformation, and deposition of the Lower Devonian Karheen Formation clastic wedge, a redbed unit that has been compared with the Old Red Sandstone of northern Europe (Bazard *et al.* 1995; Gehrels *et al.* 1996).

The combination of Ediacaran arc magmatism followed by late Neoproterozoic–early Palaeozoic orogenesis has no match in western Laurentia. It resembles tectonic events recorded at that time along the Pacific margin of Gondwana (Cawood & Buchan 2007) or the Timanide orogen of eastern Baltica (Gee *et al.* 2006). The Wales orogeny could also be coeval with the earliest phase of the Taconic orogeny (latest Cambrian) or the Penobscotian orogeny (Early Ordovician) in the northern Appalachians (van Staal *et al.* 1998; van Staal 2007), or the Finnmarkian phase of the Caledonian orogeny in Baltica (Late Cambrian–Early Ordovician; McKerrow *et al.* 2000). Timing of Ordovician–Silurian arc building and Silurian–Devonian orogenesis resembles events that are preserved in the Appalachians and Caledonides (Bazard *et al.* 1995). Detrital zircon ages from the Karheen Formation show a strong population between 400 and 500 Ma, a scatter of Proterozoic ages between 1.0 and 2.1 Ga, and a few Archaean grains, a pattern very unlike northwestern Laurentia (Fig. 7c; compare with Fig. 4a and b). Instead, they show a strong Grenvillian influence and zircons that fall within the 1.49–1.61 Ga North American magmatic gap of Van Schmus *et al.* (1993), which suggest a possible connection with Baltica (Fig. 7a and c; Bazard *et al.* 1995; Gehrels *et al.* 1996; Grove *et al.* 2008) or northeastern Laurentia (Fig. 7b; Greenland Caledonides; Cawood *et al.* 2007, and references therein). The 400–500 Ma

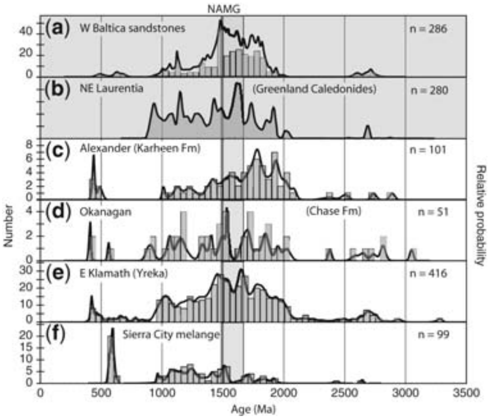

Fig. 7. Detrital zircon data for terranes of Caledonian and Baltican affinities compared with data from (**a**) Neoproterozoic–lower Palaeozoic sandstone from western Baltica (data from Knudsen *et al.* 1997; Åhäll *et al.* 1998; de Haas *et al.* 1999; Bingen *et al.* 2005) and (**b**) Neoproterozoic metasedimentary rocks from the Greenland Caledonides (northeastern Laurentia; after Cawood *et al.* 2007); (**c**) Karheen Formation, Alexander terrane (after Gehrels *et al.* 1996; Grove *et al.* 2008); (**d**) Chase Formation, Okanagan terrane, southern British Columbia (composite of samples 02TWL225, 02TWL313 and 04TWL025 of Lemieux *et al.* 2007); (**e**) Yreka terrane, Eastern Klamaths (after Grove *et al.* 2008); (**f**) Sierra City mélange, Northern Sierra terrane (after Grove *et al.* 2008). NAMG indicates the 1.49–1.61 Ga North American magmatic gap (Van Schmus *et al.* 1993).

population matches well the ages of intrusive and metamorphic events in the northern Appalachians and Caledonides, and resembles detrital mica ^{40}Ar/^{39}Ar ages from the Old Red Sandstone (Sherlock *et al.* 2002). Silurian stromatolite–sphinctozoan reef faunas resemble those in the Ural Mountains, as well as the Farewell terrane (Soja & Antoshkina 1997; Antonishka & Soja 2006). Early Devonian (Pragian–early Emsian) rugose corals from Alexander terrane show strong similarities with those of Siberia, Omulevka and Baltica (Pedder 2006). An Early Devonian palaeopole, integrated with the geological record of igneous and orogenic events, fossil affinities and detrital zircon signatures, led Bazard *et al.* (1995) to favour a mid-Palaeozoic location for the Alexander terrane near eastern Siberia and Baltica.

Devonian volcanic-derived strata and hypabyssal igneous rocks occur in a number of localities in the southern Alexander terrane, indicating that magmatic arc activity was re-established there after the Klakas orogeny. They occur, from south to north, on Prince of Wales Island (Eberlein & Churkin 1970; Gehrels & Saleeby 1987), Kupreanof Island (Muffler 1967), and Chigagof and Baranof Islands (Loney 1964), and in the Glacier Bay area (Brew & Ford 1985).

Palaeozoic strata in the northern Alexander terrane of northwestern British Columbia are generally platformal, dominated by thick shallow-water carbonate sequences with lesser clastic strata and, particularly in the Cambrian section, basalt flows and sills (Mihalynuk *et al.* 1993). Fossil data from this section are sparse and generally non-diagnostic of palaeogeographical affinity, and no detrital zircon studies have been carried out. The lowest unit comprises Cambro-Ordovician siliciclastic rocks, typically fine sandstone–siltstone couplets that display intricate cross-laminations and topsets. Abundant basalt flows and sills are interbedded with this unit. It is overlain by a thick unit of Ordovician–Silurian pure and impure carbonates deposited in shallow, subtidal marine environment. Shallowing-upwards megacycles are noted in some units. The lack of bioturbation and skeletal debris could be due to hypersaline conditions. Intraclasts are abundant in some units. Sedimentologically, these carbonates are comparable with those of the Farewell terrane as described by Dumoulin *et al.* (2002), a possible connection that it is hoped will be addressed in future studies. A minor argillite–chert facies contains early Middle Ordovician graptolites, assigned to the Pacific province; however, the almost cosmopolitan distribution of these faunas does not lend itself to robust palaeogeographical assignment (Norford & Mihalynuk 1994). Silurian siliciciclastic strata mark a transition from shallow-water carbonate platform to deltaic and possibly non-marine depositional environments (Mihalynuk *et al.* 1993). Sandstones and coarse conglomerates are present in some areas, with clasts of chert, argillite and pyritiferous volcanic(?) rocks. They locally contain abundant fern fossils. This clastic influx could reflect tectonism related to the Klakas orogeny in the southern part of the terrane. Late Devonian (Frasnian) and Mississippian (Viséan) rugose corals in the Alexander terrane resemble those of the western Canada sedimentary basin, thus suggesting proximity of the terrane to western Laurentia at that time (Pedder 2006).

At the northern end of the Alexander terrane in eastern Alaska, a Pennsylvanian intrusion, the *c.* 309 Ma Barnard Glacier pluton, cuts rocks of the oldest unit of the Kaskawulsh Group, a lower to mid-Palaeozoic metamorphic unit that forms part of the terrane and continues southeastwards into the Kluane Ranges of western Yukon (Gardner *et al.* 1988). The pluton also intrudes Pennsylvanian arc-related, and probably comagmatic volcanic strata of the Station Creek Formation, which locally is the oldest unit in Wrangellia. These relationships indicate that the late Palaeozoic arc festoon that underlies northern Wrangellia either developed upon, or at least was anchored to, older Alexander basement, perhaps in the way that the eastern end of the modern Aleutian arc laps onto the Alaska Peninsula. The latter option may be more plausible, as elsewhere in the Alexander terrane Mississippian to Pennsylvanian carbonate and fine-grained siliciclastic strata indicate platformal conditions without arc activity. In any event, as pointed out by Gardner *et al.* (1988), the Barnard Glacier pluton and its contact relationships are taken to signify that the Alexander terrane and Wrangellia were contiguous by Pennsylvanian time.

Wrangellia

Wrangellia is a long-lived, multi-episodic, Devonian and younger arc terrane. It extends over 2500 km, from southern Vancouver Island to south–central Alaska (Fig. 1). There are significant variations in Palaeozoic stratigraphy along its length, particularly between its exposures north and south of the Alexander terrane (Fig. 2). Its defining characteristic is the widespread and voluminous Carnian (Upper Triassic) Nikolai-Karmutsen basalts, which have been interpreted as the product of oceanic plateau volcanism (Lassiter *et al.* 1995).

Pennsylvanian–Permian arc deposits are widespread as the oldest unit of northern Wrangellia in eastern Alaska and Yukon (Skolai arc; Nokleberg *et al.* 2000); whereas in the Talkeetna Mountains of southern Alaska and southern Wrangellia (Queen Charlotte and Vancouver Islands), Upper Mississippian to Permian strata are typically thin and non-volcanogenic (Yorath *et al.* 1999; Schmidt & Rogers 2007), comparable with sections in most of the Alexander terrane.

The oldest rocks in southern Wrangellia on Vancouver Island are the Middle(?) and Upper Devonian Sicker Group, an intra-oceanic arc sequence (Yorath *et al.* 1999). The lowest unit is the Duck Lake Formation, which comprises basalts of tholeiitic to calc-alkaline affinity. It is overlain by pyroxene–feldspar-porphyritic basalts and basaltic andesites, and a heterogeneous Upper Devonian sequence of mafic to felsic volcanic and volcaniclastic rocks. The overlying, mainly non-volcanic Buttle Lake Group is made up of a sedimentary sequence dominantly comprising epiclastic rocks and bioclastic limestone of Mississippian to Early Permian age. Within it, the Fourth Lake Formation comprises mostly thin-bedded, often cherty sedimentary rocks with minor massive and pillowed non-arc basalt flows. The basalts are slightly undersaturated olivine tholeiites or transitional basalts, with somewhat enriched incompatible trace-element contents akin to ocean-island tholeiite or enriched ocean-floor basalt. Pennsylvanian–Permian crinoidal calcarenite, chert and argillite of the Mount Mark Formation conformably overlie the Fourth Lake Formation.

The upper Palaeozoic Buttle Lake Group was deposited in a cool temperate setting based on the presence and dominance of crinoids, bryozoans, sponges, and temperate-water conodont faunas; warm-water taxa such as fusulinaceans are rare or absent (Katvala & Henderson 2002). Statistical analysis of marine macrofaunas (brachiopods, corals and fusulinids) led Belasky *et al.* (2002) to an Early Permian reconstruction of Wrangellia (and presumably the Alexander terrane, to which it was then attached) north of the peri-Laurentian terranes Quesnellia and Stikinia, and perhaps a few thousand kilometres west of the northern Laurentian continental margin. If their reconstruction is correct then, by late Palaeozoic time, the Alexander terrane had been transported out of the Arctic realm and into northeastern Panthalassa.

The Insular terranes apparently remained isolated from the western peri-Laurentian terranes until mid-Jurassic time. The earliest indications of their approach are in post-Triassic, pre-Late Jurassic structures that juxtapose the Alexander terrane with the Yukon–Tanana terrane in southeastern Alaska (Gehrels 2001, 2002). There, a regional, low-angle ductile fault system is crosscut by Late Jurassic (162–139 Ma) dykes (Saleeby 2000). Middle Jurassic (*c.* 177–168 Ma) volcanic rocks and Upper Jurassic–Lower Cretaceous strata of the Gravina belt unconformably overlie both terranes (Gehrels 2001). Farther north, the inboard margin of the Alexander terrane was deformed by a wide dextral shear zone of mid-Jurassic age (McClelland & Gehrels 1990). In the central Coast Mountains of British Columbia, intrusion of granitoids, ductile deformation, and metamorphism occurred at *c.* 160–155 Ma. These events were interpreted to reflect collision between the Insular and Intermontane (peri-Laurentian) terranes (van der Heyden 1992).

Okanagan

The inner terranes of southern British Columbia include the probably parautochthonous Kootenay terrane, discussed above, the Slide Mountain terrane, and the southern part of Quesnellia (Fig. 3). Both southern and northern Quesnellia contain Mississippian to Permian arc and related strata that contain faunas of McCloud affinity. In southern British Columbia, these include the Harper Ranch and Attwood groups (Fig. 2) and the Mt. Roberts Formation, which correlate with the Lay Range assemblage of central British Columbia (Beatty *et al.* 2006). The Devonian and older units of southern Quesnellia differ significantly from coeval units in the northern part of the terrane, where the peri-Laurentian Yukon–Tanana terrane forms its basement (Nelson & Friedman 2004). These older units of southern Quesnellia form a roughly east–west-trending belt: the Trail gneiss complex, the Knob Hill complex and Anarchist group between Grand Forks and Penticton, the Old Tom–Shoemaker assemblage south of Penticton, and the Chapperon Group near Kelowna (Fig. 3). Most of these were included in the Okanagan subterrane of Quesnellia (Monger *et al.* 1991). To the north, between Shuswap and Upper Arrow lakes (Fig. 3), the Chase and Silver Creek formations form a NW–SE-striking belt bordering the western Kootenay terrane and underlying late Paleozoic and younger rocks of Quesnellia (Thompson *et al.* 2006). Recently, Thompson *et al.* (2006) have interpreted these terranes as an extension of the western Laurentian margin. However, many aspects of these early, proto-Quesnellian elements are at odds with such an interpretation, and some show closer similarities to the 'outboard' terranes. What follows is a comparatively more detailed treatment than for other terranes, given that the idea of an exotic origin for the pre-Mississippian rocks of southern Quesnellia is evaluated here for the first time.

Farthest east, the Trail gneiss complex comprises paragneiss and orthogneiss that are at least in part *c.* 372 Ma (Simony *et al.* 2006; Fig. 3). Orthogneisses of the Trail complex have a primitive geochemical and isotopic character (εNd values of +4.7 to +5.6 and T_{DM} model ages of 880–1050 Ma; Simony *et al.* 2006). The lack of evidence of any continental influence in these rocks contrasts strongly with the more evolved, pericratonic arcs that characterize the basement to Quesnellia in northern British Columbia and Yukon (Yukon–Tanana terrane, Fig. 1; Nelson & Friedman 2004). Simony *et al.* (2006) related these rocks to a Late Devonian intra-oceanic arc.

West of Trail, between Grand Forks and Penticton, the Okanagan subterrane includes chert, greenstone and ultramafic rocks of the Knob Hill complex, and argillite–phyllite, chert, carbonate and greenstone of the Kobau and Anarchist groups (Massey 2007, and references therein). Greenstones of the Knob Hill complex have compositions varying from normal mid-ocean ridge basalt (N-MORB), to enriched (E)-MORB and island arc tholeiites (Dostal *et al.* 2001; Massey 2007) with a juvenile εNd value of +7.2 (Ghosh 1995). The Knob Hill complex has yielded a Late Devonian U–Pb date (*c.* 370 Ma; N. Massey, pers. comm.), coeval with the Trail gneiss complex, and Late Devonian and Pennsylvanian–earliest Permian conodont assemblages (Massey 2007, and unpubl. data). No age constraints are available for the Anarchist and correlative units, but Massey (2007) suggested that these argillite-dominated rocks are more complexly deformed lateral equivalents of the Knob Hill complex. Collectively they represent a primitive arc to back-arc assemblage.

Near Kelowna, undated basalts of the Chapperon Group are apparently depositionally overlain by Devonian to Permian strata of the Harper Ranch Group (Thompson *et al.* 2006), which comprises a volcaniclastic and carbonate succession correlated with the McCloud belt (Beatty *et al.* 2006). Little is known about the Chapperon Group depositional setting; Thompson *et al.* (2006; R. Creaser, pers. comm.) reported primitive εNd values that support an association with the Knob Hill complex to the south.

At the western end of this belt of Palaeozoic rocks, south of Penticton (Fig. 3), the Old Tom–Shoemaker assemblage comprises structurally intermixed greenstone, silicified tuff, minor limestone and chert breccia (Monger *et al.* 1991). Limestone blocks in argillite matrix have yielded conodonts of Ordovician age and enigmatic faunal affinity (Pohler *et al.* 1989). Radiolarian chert interbedded with greenstone is in part latest Devonian to Carboniferous in age. Parts of this assemblage may represent a subduction complex (Monger *et al.* 1991).

The Nicola horst is a basement high exposed in central Quesnellia south of Kamloops. A conglomerate within the horst contains metaplutonic clasts of Grenvillian age (*c.* 1038 Ma), along with Mesozoic detrital grains (Erdmer *et al.* 2002). The presence of a locally derived Grenvillian clast (as opposed to minor populations of detrital grains) suggests that basement of this part of Quesnellia was markedly different from either the adjacent autochthonous continental margin (Villeneuve *et al.* 1993) or the Yukon–Tanana terrane, with their northwestern Laurentian Archaean–Palaeoproterozoic provenance (Fig. 4).

To the north of the primitive rocks of the Okanagan subterrane described above, the Devonian Chase and Silver Creek formations are a regionally extensive platformal succession of calcareous quartzite, psammitic schist, pelite and minor marble (the 'Okanagan high' of Thompson *et al.* 2006), which forms a roughly WNW–ESE-trending belt along the southern margin of the Kootenay terrane (Figs 2 and 3). It is juxtaposed to the north with variable rock successions. To the west, it is in uncertain contact relationship with Neoproterozoic–Mississippian metasedimentary and metavolcanic rocks of the Sicamous and Tsalkom formations and Eagle Bay assemblage (Fig. 3). To the east, it is in sharp and locally highly strained contact with amphibolite-grade schist and paragneiss of the Shuswap complex (Fig. 3; probable Laurentian continental margin strata that were exhumed from mid-crustal level in Eocene time; Parrish *et al.* 1988). Thompson *et al.* (2006) interpreted these contacts as a transposed unconformity. The relationship between the platformal succession of the Chase and Silver Creek formations and the Okanagan subterrane to the south is uncertain (Fig. 3).

Detrital zircons from the schist underlying the Chase Formation near Upper Arrow Lake (Unit 1 of Lemieux *et al.* 2007) are predominantly in the range of 1.6–2.0 Ga, with a peak at *c.* 1.8 Ga, and minor populations at *c.* 2.5 and 2.7 Ga, and two grains of Grenvillian age (1.0–1.3 Ga; Fig. 8a). These ages match well with the Precambrian basement provinces of southern Alberta and the miogeoclinal detrital zircon reference for southern British Columbia (Fig. 4c and i; Villeneuve *et al.* 1993; Gehrels *et al.* 1995; Gehrels & Ross 1998), and thus confirm the continental margin setting for the amphibolite-grade rocks of the Shuswap metamorphic complex (Lemieux *et al.* 2007).

In contrast, the detrital zircon data presented by Lemieux *et al.* (2007, fig. 4) for the Devonian Chase Formation show a near-continuous spread of ages between 0.85 and 2.7 Ga, which they interpreted to indicate a mixing between adjacent Laurentian sources to the east and younger Precambrian crust to the west. In their original treatment of the data, Lemieux *et al.* (2007, fig. 4) presented only a composite age probability density plot for four samples of the Chase Formation. When considered individually, samples attributed to the Chase Formation exhibit significant differences in their distribution of detrital zircon ages, rather than a mixing of ages (Fig. 8b–e). The easternmost sample (04TWL072; Fig. 3), a calcareous quartzite occurring near the base of the Mississippian Milford Group in the Kootenay Arc region (Thompson *et al.* 2006), shows a distribution of detrital zircon ages that is strikingly similar to that of Lemieux's Unit 1 (compare Fig. 8a and b) but very different from other Chase samples collected near Upper Arrow Lake to the west (Figs 3 and 8c–e). The Kootenay Arc sample is most reasonably interpreted as having the same source as Lemieux's Unit 1 in the Precambrian basement domains of southern Alberta to the east (Fig. 4c and i).

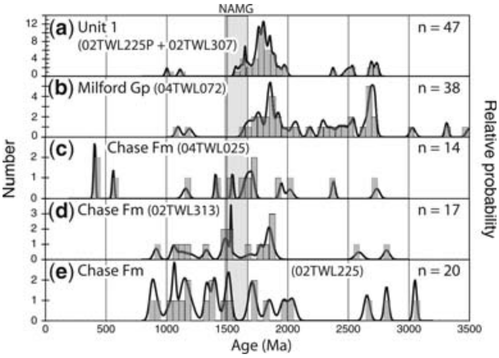

Fig. 8. Detrital zircon age-spectra for single samples reported by Lemieux *et al.* (2007). (**a**) Composite of two samples of Proterozoic–lower Palaeozoic schist (Unit 1). Single samples show identical age distribution. (**b**) Quartzite near the base of Milford Group, Kootenay Arc. (**c–e**) Chase Formation in the Upper Arrow Lake region. Sample locations are shown in Figure 3. NAMG indicates the 1.49–1.61 Ga North American magmatic gap (Van Schmus *et al.* 1993).

The two samples of Chase Formation collected SW of Upper Arrow Lake (02TWL225 and 02TWL313; Fig. 3) have similar distributions of detrital zircon ages of 0.8–0.9, 1.0–1.2, 1.3–1.4, 1.45–1.55 and 1.65–2.05 Ga, with a few Archaean grains (Fig. 8d and e). Sample 04TWL025, collected along the shore of Upper Arrow Lake (Fig. 3), contains fewer concordant analyses ($n = 14$, Fig. 8c) but displays some similarities to other Chase samples collected in the Upper Arrow Lake area (Fig. 8d and e). Its main distinction is in the presence of two Early Devonian grains (*c.* 403 and 412 Ma) and one Neoproterozoic grain (*c.* 561 Ma) (Lemieux *et al.* 2007); ages that match respectively two detrital zircon ages and a granitic cobble from the Chase Formation and related conglomerate NW of Vernon (Erdmer *et al.* 2001; Thompson *et al.* 2006).

All three Chase samples from the Upper Arrow Lake area have zircons in the 1.49–1.61 Ga range, the North American magmatic gap of Van Schmus *et al.* (1993), and a number of Grenvillian grains (1.0–1.3 Ga), and thus are probably derived from an exotic source (Fig. 8). Taken together, their detrital signatures compare remarkably well with those in other terranes of Caledonian and Baltican affinities discussed in this paper (Alexander, Yreka–Trinity, Sierra City; Fig. 7). We propose that at least part of the basement of southern Quesnellia, including the source of the Nicola horst Grenvillian clast, is of exotic, Caledonian affinity. These crustal fragments were probably first accreted to the western margin of Laurentia in mid-Palaeozoic time. A Middle Devonian episode of compressional deformation is documented in the Purcell Mountains of southeastern British Columbia (Root 2001). An Early Mississippian (354 Ma) pluton intrudes the contact between the Silver Creek Formation and rocks of the Eagle Bay assemblage west of Shuswap Lake (Fig. 3), thus suggesting that the platformal succession of the Chase and Silver Creek formations was juxtaposed with the western Kootenay terrane (i.e. distal continental margin) before development of the Late Devonian arc that characterizes the western Kootenay terrane. Occurrence of a Late Silurian (*c.* 418 Ma) granitic cobble in a conglomerate from the Milford Group (Kootenay–Slide Mountain terranes, Fig. 3; Roback *et al.* 1994) and detrital zircons in the Mt. Roberts Formation of southern Quesnellia (Roback & Walker 1995) suggest that both western Laurentia and the accreted 'Okanagan high' were available as source regions in late Palaeozoic time.

Eastern Klamath terranes

Pre-Devonian basement rocks in the Eastern Klamath Mountains of southern Oregon and northern California comprise two terranes, the Trinity and Yreka (Fig. 2; summarized by Lindsley-Griffin *et al.* 2006, 2008; Wright & Wyld 2006). The Trinity terrane is a composite Ediacaran (*c.* 565–570 Ma) and Cambro-Ordovician(?) ophiolitic complex dominated by ultramafic and mafic rocks, including ductilely deformed mantle tectonites (Lindsley-Griffin *et al.* 2008). It is crosscut by post-tectonic Ordovician plagiogranites, and also by a suite of Silurian to Early Devonian supra-subduction zone plutons with related basalt flows (*c.* 435–412 Ma). The Yreka terrane structurally overlies the Trinity ophiolite on a SE-vergent fault (Fig. 9). It consists of numerous related and unrelated tectonic slivers and mélanges, and was interpreted by Lindsley-Griffin *et al.* (2008) as a forearc complex related to Ordovician and Siluro-Devonian subduction. It includes Late Ordovician blueschist slivers (*c.* 454 Ma; Grove *et al.* 2008). Mélange units near its structural base carry Ediacaran tonalite blocks (*c.* 560–570 Ma). Most of the terrane consists of imbricated Upper Silurian to Lower Devonian sedimentary strata and sediment-matrix mélange units with mixed siliciclastic and volcaniclastic provenance. They are interpreted as forearc and/or trench sedimentary deposits. In contrast, the structurally highest unit in the terrane, the Antelope Mountain Quartzite, is a shallow-water pericontinental siliciclastic unit that has been identified as Neoproterozoic (Ediacaran) based on the presence of cyclomedusoids (Lindsley-Griffin *et al.* 2006). Waggoner (1999) defined three global biogeographical groups for Ediacaran faunas. The Antelope Mountain cyclomedusoids most closely resemble those of the 'White Sea assemblage', which includes faunas of Baltica, northwestern Laurentia, Siberia and also Australia (Lindsley–Griffin *et al.* 2008). The Trinity and Yreka terranes were juxtaposed, and internally deformed and imbricated in Early to Middle(?) Devonian time; this is modelled as a west-facing subduction complex (present coordinates) related to the onset of Devonian arc activity in the Eastern Klamath terranes (Fig. 9; Lindsley-Griffin *et al.* 2006, 2008; Wright & Wyld 2006).

Detrital zircon populations in the Yreka blueschist and in crustally derived Lower Devonian units show broad, multipeaked distributions from 1.0 to 2.0 Ga, including significant peaks in the range 1.49–1.61 Ga (Fig. 7e; Grove *et al.* 2008). These are similar to populations in the Alexander terrane and Neoproterozoic–lower Palaeozoic sandstone from western Baltica and NE Laurentia (Fig. 7a–c; Cawood *et al.* 2007; Grove *et al.* 2008), but contrast sharply with detrital zircon references for western Laurentia (Fig. 4a–e). Other arc-derived clastic units contain mostly early Palaeozoic zircons, with predominant ages from 476 to 381 Ma, and a few 550–560 Ma grains that match those of tonalite blocks in the mélange.

The Antelope Mountain Quartzite is generally considered an integral part of the Yreka terrane,

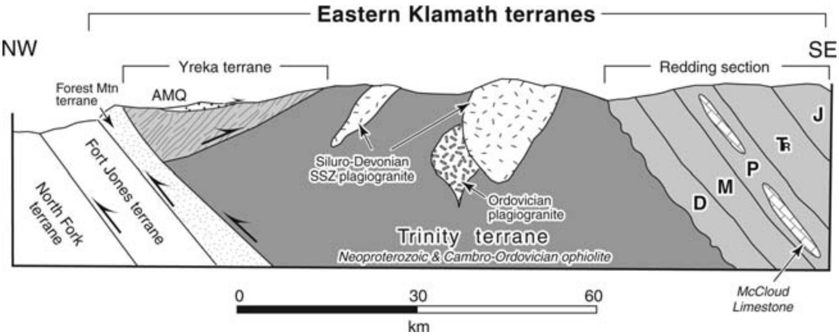

Fig. 9. Schematic cross-section of the Eastern Klamath terranes (after N. Lindsley-Griffin, pers. comm.). AMQ, Antelope Mountain Quartzite. The Forest Mountain terrane is an oceanic ophiolite, metamorphosed at *c.* 400 Ma, during accretion to the eastern Klamath nucleus. Fort Jones and North Fork terranes are late Palaeozoic to early Mesozoic oceanic terranes accreted in early Mesozoic time. Yreka and Trinity terranes and the Redding section are described in the text.

which developed in some proximity to the rest of the terrane throughout Neoproterozoic to mid-Palaeozoic time (Lindsley-Griffin *et al.* 2008, and references therein). This possibility is not refuted by the available evidence. However, its unique character raises questions. In Ediacaran time, it resided in a continental platform setting, completely different from the Trinity ophiolite. Its detrital zircon population is unlike that of any other unit in the Yreka terrane; it is dominated by Archaean and Palaeoproterozoic grains with a marked peak between 1.78 and 1.95 Ma in a pattern that closely resembles that of the northwestern Laurentian miogeocline (Fig. 4b and j; Wallin *et al.* 2000; compare with the Yreka pattern in Fig. 7e). The presence of significant feldspar contents and coarse, relatively immature siliciclastic detritus in the unit precludes large-scale sediment transport as a means of introducing a northerly zircon signature into the terrane; instead, Wallin *et al.* (2000) favoured large-scale sinistral strike-slip motion along the continental margin. Three grains out of the 46 in the Antelope Mountain sample are *c.* 1.3 Ga, which corresponds to minor populations in autochthonous Cambrian strata of Alaska (Fig. 4a; Gehrels *et al.* 1995, 1999).

Macrofossils from Ordovician and Silurian limestone blocks in the Yreka mélanges comprise both endemic species and species linked to faunas of Laurentia, Siberia, Baltica, Kazakhstan, Scotland, Australia and China (Lindsley-Griffin *et al.* 2008). Late Ordovician sphinctozoan sponges are part of a rare fauna that is known only in Australia, the Farewell terrane, autochthonous rocks of northern Yukon to east–central Alaska (Potter *et al.* 1990*b*), the Montgomery limestone in the Shoo Fly Complex of the western Sierra Nevada (see below), and in the Alexander terrane on Prince of Wales Island (Rigby *et al.* 2005). The combination of highly endemic and shared faunas is suggestive of an intra-oceanic setting, and Lindsley-Griffin *et al.* (2008) favoured an Ordovician–Silurian location for the Yreka terrane as part of a chain of islands in the seaway between northern Laurentia, Baltica, Kazakhstan and Siberia.

Devonian fossils from mixed siliciclastic–volcaniclastic units, and clasts and matrix in mélange units of the Yreka terrane, include corals, brachiopods and conodonts. Like older Yreka terrane faunas, some are very restricted in occurrence whereas others have more widespread correlatives. Brachiopods in the Gregg Ranch Complex, one of the mélange units, are similar to those in Nevada and northern Canada; some conodonts and corals are found only in the Yreka terrane and in Nevada (Lindsley-Griffin *et al.* 2008). Compared with older faunas, these exhibit a greater connection to western Laurentia, as opposed to northern Laurentia–Baltica–Siberia. A Middle Devonian palaeopole from the Redding section (Fig. 9) places the combined Eastern Klamath terranes at 31° either north or south latitude (Mankinen *et al.* 2002); combined with faunal linkages the terrane probably lay near northwestern Laurentia at that time (Lindsley-Griffin *et al.* 2008, fig. 11). This pole, however, is based on only two sites, and should be considered preliminary.

In summary, the Yreka and Trinity terranes (with the exception of the Antelope Mountain Quartzite) comprise Ediacaran ophiolite, Ordovician blueschist, Silurian–Devonian supra-subduction zone ophiolite, Silurian to Lower Devonian mélange units and mixed siliciclastic–volcaniclastic marine sedimentary strata. Except for the Ediacaran oceanic crust, these characteristics and the detrital zircon signature of the Yreka terrane suggest linkages between the Eastern Klamath and Alexander terranes (Wright & Wyld 2006), and also with terranes of the northern Caledonian orogen (Grove *et al.* 2008). The favoured palaeogeographical position for these terranes during Neoproterozoic to Silurian time was offshore near the Baltican end of the Caledonides (Lindsley-Griffin *et al.* 2008). Lindsley-Griffin *et al.* considered a ‘southern’ location between Laurentia and Gondwana in Silurian time unlikely, because of the lack of faunal similarities between the Yreka terrane and Gondwana.

The Antelope Mountain Quartzite, unlike the rest of the Yreka terrane, has a detrital zircon signature that is compatible with that of northwestern Laurentia. By Early Devonian time, it was structurally incorporated into a forearc setting along with the other units of the Yreka terrane. It is possible that this was the result of an early encounter of the allochthonous Yreka and Trinity terranes and the northern Laurentian margin, in which the Antelope Mountain pericratonic sliver was transferred to the mobile plate. It is interesting to note that imbrication of the Yreka terrane is roughly coeval with the Romanzof orogeny in eastern Arctic Alaska.

The long-lived sequence of arc-related strata of the Early Devonian to Jurassic Redding section (Irwin 1981; Redding subterrane of Lindsley-Griffin *et al.* 2008) of the Eastern Klamath terrane was presumably built on Yreka–Trinity basement after its Silurian–Early Devonian amalgamation (Potter *et al.* 1990*b*; Gehrels & Miller 2000; Lindsley-Griffin *et al.* 2008). The oldest rocks in the section are greenstones and rhyolites; coeval, *c.* 390 Ma intrusions cut both the Yreka and Trinity terranes. The Redding section contains a Lower Mississippian siliciclastic unit, the Bragdon Formation, in which detrital zircon populations reflect Precambrian basement and Neoproterozoic and early Palaeozoic arc sources in the Trinity terrane (Gehrels & Miller 2000). Also within this section is the Permian McCloud Limestone, which contains the defining fusulinid genera of the McCloud faunal belt, described by Miller (1988) as the dispersed remnants of a northeastern Pacific fringing arc. Differences between the McCloud and western Laurentian faunas suggest that in Early to mid-Permian time, the various elements of this belt probably lay 2000–3000 km west of the continental margin and at somewhat more southerly latitudes than at present (Belasky *et al.* 2002). The peri-Laurentian terranes of western Canada (Stikinia, Quesnellia and Yukon–Tanana) also contain faunas of McCloud affinity (Stevens & Rycerski 1989; Stevens 1995; Nelson *et al.* 2006). In the Early Permian reconstruction of Belasky *et al.* (2002), the Eastern Klamath terrane lay south of Stikinia–Quesnellia, and somewhat south of its present location. Therefore, if the Eastern Klamath terrane was already interacting with distal parts of northwestern Laurentia in Early Devonian time, it had travelled over 3000 km southwards by the Permian. This would require sinistral motion with respect to western Laurentia that averaged slightly more than 2 cm a^{-1} for 130 Ma.

Northern Sierra terrane: the Shoo Fly Complex

The lower Palaeozoic Shoo Fly Complex forms the basement for Late Devonian to Permian arc and related strata of the Northern Sierra terrane (Fig. 2; Girty *et al.* 1990). It is composed of four allochthons (Fig. 10). The three structurally lower allochthons, the Lang sequence, Duncan Peak allochthon, and Culbertson Lake allochthon, contain siliciclastic and basinal strata. Alkalic 'intraplate' basalts occur within the Culbertson Lake allochthon. Conodonts of Middle to Late Ordovician age are present in the structurally lowest Lang sequence (Harwood *et al.* 1988). The other two allochthons are also thought to be early Palaeozoic in age, based on poorly preserved radiolaria, and tentative stratigraphic linkages with the Lang sequence. Detrital zircon signatures of the terrigenous sedimentary strata show consistency between the three allochthons (Harding *et al.* 2000). The dominant peaks are Archaean (2.55–2.70 Ga) and Palaeoproterozoic (1.80–2.10 and 2.20–2.45 Ga), consistent with the northwestern Laurentian margin in British Columbia and Yukon (Fig. 4b and k). There are no Mesoproterozoic, Neoproterozoic or Palaeozoic grains present. Although the alkalic basalts in the Culbertston Lake allochthon have been interpreted as seamounts by some workers, it is important to note that basalts of similar chemistry are widespread within lower Palaeozoic parautochthonous basinal sequences throughout the northern Cordillera (Goodfellow *et al.* 1995), where they are associated with periodic episodes of extension and second-order basin development.

The Sierra City mélange is the highest and also the most easterly unit within the Shoo Fly Complex (Fig. 10). It differs radically from the underlying allochthons in all aspects. It contains blocks of ophiolitic affinity (serpentinite, gabbro, plagiogranite, basalt), and of sedimentary origin (chert, limestone, sandstone) within a sheared matrix of slate, chert and sandstone; it is interpreted as a combination of tectonic mélange and olistostrome (Schweickert *et al.* 1984). A plagiogranite block in the mélange has yielded a Neoproterozoic (*c.* 600 Ma) U–Pb zircon age, and a felsic body (either a tuff or a dyke) is Silurian (*c.* 423 Ma; Saleeby *et al.* 1987; Saleeby 1990). Detrital zircon populations are predominantly Ediacaran in age (550–600 Ma), corresponding to the age of the single dated igneous block, and show a scatter of ages between 0.95–1.55 Ga and 1.65–1.95 Ga (Fig. 7f; Harding *et al.* 2000; Grove *et al.* 2008).

Upper Ordovician limestone blocks in olistostromes within the Sierra City mélange contain brachiopods, conodonts, rugose and tabulate corals, and sphinctozoan sponges (Potter *et al.* 1990*a*).

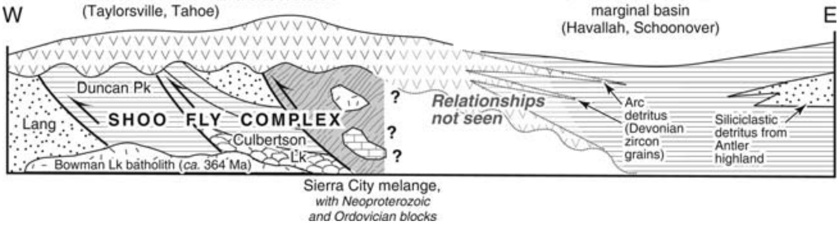

Fig. 10. Schematic cross-section of the Northern Sierra terrane and Golconda allochthon. Shoo Fly relationships after Wright & Wyld (2006). Late Palaeozoic strata and relationships conceptually after Harwood & Murchey (1990) and Miller & Harwood (1990).

Most of the brachiopod, coral and sponge genera are also present within the Yreka terrane mélanges. In particular, the sponges include *Amblysiphonolella* sp., *Corymbospongia adnata*, and *Girtyocoelia* sp., which the Montgomery Limestone shares with the Yreka terrane (Potter *et al.* 1990*b*) as well as with an Ordovician limestone block in the Alexander terrane (Rigby *et al.* 2005). *Cystothalamiella* sp., *Girtycoelia epiporata* and *Ribyetia obconica* occur in the Montgomery Limestone and in limestones of the Farewell terrane (Potter *et al.* 1990*a*). Brachiopod faunas are similar to those in the Yreka terrane and also the autochthon of northern Yukon. A rugosan coral, *Grewingkia penobscotensis*, is known only from the Montgomery Limestone, the Yreka terrane, and northern Maine (eastern Laurentia; Potter *et al.* 1990*a*). Other faunas are less provincial.

The detrital zircon signature of the Sierra City mélange, including abundant Neoproterozoic grains, Grenvillian zircons and grains with ages within the 1.49–1.61 Ga North American magmatic gap, as well as detritus that is clearly derived from an ophiolitic source favour a relationship to the other Caledonian terranes of the Cordillera, such as Yreka–Trinity and Alexander (Fig. 7). Faunal connections between the Sierra City mélange and other Arctic terranes such as Alexander and Farewell, as well as autochthonous sites in far northern Yukon, are consistent with an Arctic location in the early Palaeozoic.

The assembly of the Shoo Fly Complex took place after the Late Silurian, based on the age of its youngest rocks, but prior to intrusion of the post-tectonic Late Devonian Bowman Lake batholith (*c.* 364 Ma; Miller & Harwood 1990). This event involved the tectonic juxtaposition of the lower allochthons, with their northwestern Laurentian margin detrital zircon affinities, with the inferred Caledonian Sierra City mélange. There are clear parallels between this event and the proposed Siluro-Devonian imbrication of the northwestern Laurentian Antelope Mountain Quartzite with the exotic rocks of the Yreka and Trinity terranes (Fig. 9). In both cases, initial collision of transported Caledonian crustal fragments would have been with the northernmost part of the western Laurentian margin. In the Shoo Fly Complex, the most exotic component now lies structurally inboard of less far-travelled rocks. However, if after Silurian–Devonian time the amalgamated fragment has been transported thousands of kilometres to the south, an accompanying rotation up to 180° is unsurprising.

The deformed Shoo Fly Complex is unconformably overlain by the Upper Devonian to Upper Permian arc-related Taylorsville and Tahoe sequences, which have a coarse clastic basal unit of Famennian age, the Grizzly Formation (Miller & Harwood 1990). The Late Devonian initiation of arc magmatism in the Northern Sierra terrane is younger than the Middle Devonian or older onset of arc activity in the Eastern Klamaths. In general, differences between these two terranes are probably a result of somewhat different positions within an evolving arc system (Miller & Harwood 1990). An important shared element is that McCloud faunas occur within the Permian of the Northern Sierras (Miller 1988). The Northern Sierra arc is modelled as facing west, away from the continent and towards Panthalassa. East of it, the Havallah and Schoonover sequences of the Golconda allochthon record the corresponding Devonian to Permian back-arc marginal basin, which received detritus both from the continental margin and from the Northern Sierra arc (Fig. 10; Miller *et al.* 1984; Harwood & Murchey 1990). Early Mississippian and Early Permian influxes of arc-derived sediment into the Havallah sequence correspond to discrete magmatic episodes in the Northern Sierra terrane. Lower Mississippian chert–quartz-rich siliciclastic rocks in the Havallah basin were derived from erosion of the Antler orogenic belt on the continent margin to the east (Miller *et al.* 1984; Harwood & Murchey 1990). Detrital zircon populations reflect derivation from the Devonian–Mississippian arc (338–358 Ma), and from recycled Palaeoproterozoic and Archaean sources similar to those in the Roberts Mountains allochthon (Riley *et al.* 2000).

The inferred relationships between the Northern Sierra terrane, Golconda basin and Roberts Mountains allochthon suggest that by Early Mississippian time, the Northern Sierra terrane had arrived close to its present position near the southwestern Laurentian margin. Early Mississippian emplacement of the Roberts Mountains allochthon may have been related to the arrival of this crustal fragment by sinistral transpression along the margin. Interestingly, extension within the Havallah basin began in Late Devonian to Early Mississippian time, coeval with initial development of the Northern Sierra arc (Harwood & Murchey 1990). They probably represent a conventional SW Pacific-style extensional arc–back-arc pair. The Antler collisional belt may have acted as a pinning point for the arc festoon, comparable with the role and position of the recently extinct collision zone in northern Taiwan, which is overprinted by the younger, west-migrating Okinawa back-arc trough behind the Ryukyu arc (Letouzey & Kimura 1986).

This proposed scenario would require passage of the Shoo Fly Complex (and perhaps also the Yreka–Trinity terranes, with which it was probably affiliated) from a site of collision with northwestern Laurentia to a location nearer southwestern Laurentia as Devonian in age, a maximum possible interval of 58 Ma and probably less (time scale of Gradstein *et al.* 2004). In this case average motion would need to be about 5 cm a^{-1}, comparable with rates of advance of short modern arc segments such as the Scotia and New Hebrides arcs (Schellart *et al.* 2007).

Palaeogeographical implications

The evidence summarized above clearly points to common, non-western Laurentian origins for a number of western Cordilleran terranes, as has been previously argued by many of the workers we cite. Much of the geological history (Ordovician–Silurian arcs, Cambrian–Ordovician and Silurian–Devonian deformational events) and detrital zircons from the Alexander terrane suggest early Palaeozoic interactions with the Appalachian–Caledonian orogen and a source region dominated by Mesoproterozoic and late Palaeoproterozoic igneous rocks, including significant contributions from Grenvillian (1.0–1.3 Ga) and 1.49–1.61 Ga sources (Figs 2 and 7; Wright & Wyld 2006; Grove *et al.* 2008). The occurrence of Ediacaran arc-related rocks at the base of the Alexander terrane contrasts, however, with the Neoproterozoic history of either eastern Laurentia or western Baltica, each of which was characterized by rifting and development of a passive continental margin at that time (e.g. Cawood *et al.* 2001). Wright & Wyld (2006) proposed an early affinity with Avalonia and other peri-Gondwanan terranes. But when considering Silurian–Devonian palaeomagnetic, faunal and detrital zircon data together, a position near northern Baltica, adjacent to the north end of the Caledonides, seems to provide a better fit (Fig. 11; Bazard *et al.* 1995; Soja & Antoshkina 1997; Pedder 2006; Soja & Krutikov 2008).

Neoproterozoic arc magmatism (*c.* 600–550 Ma) and tectonism characterize the Timanide orogen, which extends along eastern Baltica from the southern Urals northward to the Barents–Kara Sea region, where it is locally overprinted by the Caledonian deformation front (Gee & Pease 2004; Gee *et al.* 2006). The North Kara terrane is inferred to underlie much of the Barents–Kara Shelf and

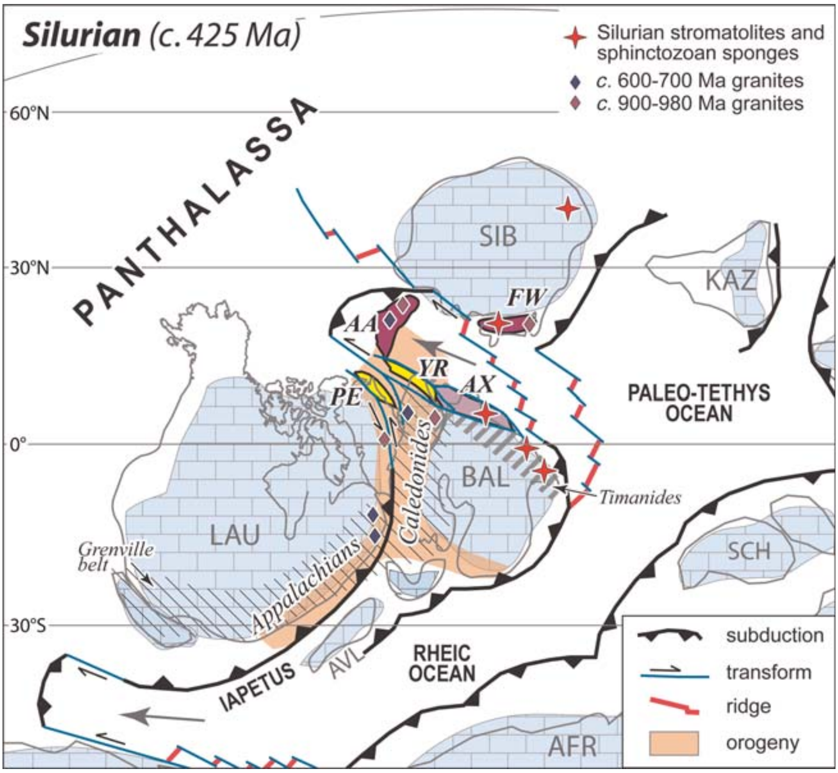

Fig. 11. Palaeogeographical setting of Cordilleran exotic terranes in Silurian time. Continental reconstructions in this and subsequent figures are modified after Scotese (2002). Continent abbreviations: AFR, Africa; AVL, Avalonia; BAL, Baltica; KAZ, Kazakhstania; LAU, Laurentia; SCH, South China; SIB, Siberia. Terrane abbreviations: AA, Arctic Alaska; AX, Alexander; FW, Farewell; PE, Pearya; YR, Yreka (including Trinity, and parts of Shoo Fly and Okanagan).

northern Taimyr. It comprises local evidence of reworked Mesoproterozoic (Grenvillian) basement, a Neoproterozoic succession of turbidite and shale with *c.* 555 Ma detrital zircons, evidence for latest Cambrian–earliest Ordovician deformation, and a lower Palaeozoic succession that includes a Lower Devonian Old Red Sandstone unit with a western, Caledonian source (Gee *et al.* 2006, and references therein). The mixed Timanian–Caledonian affinity of the North Kara terrane may be an analogue for some of the key characteristics of the Alexander terrane (Fig. 11).

Detrital zircon populations, occurrences of Ediacaran and Ordovician arc-related blocks in mélange, Upper Ordovician limestone blocks with distinctive sphinctozoan sponges, and Ordovician blueschists in the Yreka–Trinity terranes and the Sierra City mélange, ally them with the Alexander terrane (Fig. 7; Wright & Wyld 2006; Grove *et al.* 2008), and thus suggest similar origins near the northern Caledonides for at least these parts of the Eastern Klamath and Northern Sierra terranes (Fig. 11). Limited data from the Okanagan terrane of southern British Columbia, including detrital zircons from the Chase Formation, Grenvillian and Ediacaran granitoid cobbles, and enigmatic Ordovician limestone blocks from the Shoemaker assemblage, also support a possible association with the Alexander, Yreka–Trinity and Sierra City terranes in early Palaeozoic time (Figs 2 and 7). Other parts of the Eastern Klamath (Antelope Mountain Quartzite), Northern Sierra (Lang, Duncan Peak and Culbertson Lake allochthons) and Okanagan terranes may have originated in northwestern Laurentia (Fig. 4), in which case they would have been juxtaposed with Caledonian elements in mid-Palaeozoic time (see below).

The Farewell terrane has overall stronger Palaeozoic lithological, faunal and provenance ties to Siberia (Blodgett *et al.* 2002; Dumoulin *et al.* 2002; Bradley *et al.* 2007); however, it also shares distinctive Silurian stromatolite–sphinctozoan reefs with the Alexander terrane, and its early Neoproterozoic igneous rocks are more akin to northeastern Laurentia and Barentsia than Siberia (Fig. 11). The Arctic Alaska terrane shares this igneous suite and Devonian and older lithological character with the Farewell terrane. Its Palaeozoic faunal affinities are transitional between Siberian and Laurentian provinces, therefore suggesting that Arctic Alaska may have been situated between Siberia and Laurentia in early Palaeozoic time (Fig. 11; Dumoulin *et al.* 2002). Arc magmatism of Ediacaran age on the Seward Peninsula and Ordovician age in the Doonerak fenster parallels that of the Alexander terrane (Fig. 2).

In summary, most of the outer Palaeozoic terranes of the North American Cordillera appear to have originated from the same general region near the northern end of the Caledonides, in a position intermediate between Baltica, Siberia and northeastern Laurentia in early Palaeozoic time (Fig. 11). This implies that they have travelled thousands of kilometres around northern Laurentia during the Palaeozoic, before finding their final resting place in the Cordillera in Mesozoic time.

Pearya: an Arctic connection

If the exotic, Caledonian and Siberian terranes of the Cordillera migrated around northern Laurentia in Palaeozoic time, then the geological record of Arctic Canada may have recorded this history. The early Palaeozoic record of northern Laurentia is to a large extent identical to that of its western continental margin, with passive margin deposition along the Arctic platform, Franklinian shelf, and adjacent slope and basin (Fig. 2; Trettin *et al.* 1991*a*). Pearya is the only exotic, accreted terrane exposed in Arctic Canada along the northern Laurentian margin (Figs 1 and 5), although related crustal fragments may also form part of the Arctic Ocean sea floor. Pearya lies on the northern side of Ellesmere and Axel Heiberg Islands, juxtaposed against lower Palaeozoic miogeoclinal strata and Silurian–Lower Devonian flysch deposits of the Clements Markham fold belt (Trettin 1991; Trettin *et al.* 1991*a*). Pearya is a composite terrane (Fig. 2). The oldest rocks in it, Succession I of Trettin (1991), are schists and gneisses of Grenvillian age (*c.* 1060–1040 Ma), based on limited Rb–Sr and U–Pb dating. The crystalline rocks are overlain by Succession II, a Neoproterozoic to Lower Ordovician rift-related and passive margin sequence. The Lower to Middle Ordovician, suprasubduction zone related Maskell Inlet assemblage was juxtaposed with the continental margin rocks during the Middle Ordovician M'Clintock orogeny (Trettin 1991). This tectonic event is age-equivalent to the Taconic orogeny in the peri-Laurentian terranes of the Canadian Appalachians, and similarly juxtaposes intra-oceanic arc and Grenvillian continent-margin crustal blocks (van Staal 2007). The characteristic features of Pearya, in particular the evidence for Early Ordovician subduction and Middle Ordovician tectonism, are strikingly similar to those of the southwestern terranes of Spitsbergen (western Svalbard), thus suggesting a derivation of Pearya from the northern end of the Caledonian orogen (Trettin 1991; Gee & Teben'kov 2004). The Middle Ordovician to Upper Silurian strata of Succession IV represent a successor basin and arc sequence developed across the M'Clintock orogen. Late Ordovician faunas have diagnostic elements in common with faunas from Siberia, northern Greenland and the Arctic platform (Trettin 1991).

The initial approach of Pearya to the present Arctic Islands is suggested by quartzite and marble clasts in coarse Upper Silurian conglomerates of the Danish River Formation in central Ellesmere Island (Trettin *et al.* 1991*b*). Its actual emplacement is probably marked by the sub-Middle Devonian unconformity that overlies strata as young as Silurian (and possibly Lower Devonian) in the Clements Markham fold belt (Trettin *et al.* 1991*b*). A *c.* 390 Ma post-tectonic pluton cuts rocks of the terrane. The southern boundary of Pearya is a high-angle, sinistral fault, which curves northward near its western end into a thrust (Fig. 5). Along its northwestern extent, Pearya has been dissected into a set of slivers, possibly structurally interleaved with parautochthonous strata. Trettin *et al.* (1991*b*) favoured a model of westward transpressional emplacement. Sinistral transcurrent motion dominated in Silurian time, with Pearya acting as an indentor or indentors into the continental margin (Trettin *et al.* 1991*b*; see their fig. 12B.2). This was succeeded by a more widespread shortening in latest Devonian and Early Mississippian time: the Ellesmerian orogeny, which produced a broad, south-verging fold-and-thrust belt in the Canadian Arctic region.

At present there are no detrital zircon data available from Pearya, and study of its basement rocks is fairly limited. Although remote, this terrane is a crucial target for further studies, in that it solely represents the most proximal of the possible Caledonian crustal blocks that were located between Laurentia and Siberia (Fig. 11).

Geodynamic model

The geological record of the Alexander and parts of the Eastern Klamath, Northern Sierra and Okanagan terranes indicates decreasing affinity with the Caledonides through mid-Palaeozoic time, and for some terranes (with the exception of Alexander) a firm position in eastern Panthalassa by late Palaeozoic time as basement terranes to the McCloud arcs (Fig. 2). Dispersion of these terranes and their westward travel around northern Laurentia began as the Iapetus and Rheic oceans closed and the Appalachian–Caledonian orogen developed along eastern Laurentia and western Baltica in mid-Palaeozoic time (Fig. 11). We postulate that upper mantle flow out of the shrinking Iapetus–Rheic oceans opened a mid-Palaeozoic 'gateway' between Laurentia and Siberia, termed here the Northwest Passage, similar to the Miocene to recent development of the Scotia Sea through Drake Passage between South America and Antarctica (Pearce *et al.* 2001). Initial rifting and rapid westward migration of a narrow subduction zone (Schellart *et al.* 2007) led to dispersion of the crustal fragments that once lay between Baltica, Siberia and northeastern Laurentia (Fig. 11). The southern boundary of the Northwest Passage developed as a sinistral transpressive zone along which Pearya, the least displaced of these terranes, was emplaced along the northern Laurentian margin in Late Silurian–Early Devonian time (Fig. 12). This sinistral transpressive zone was probably kinematically linked with Silurian to Devonian sinistral transpression that characterized the late Caledonian deformation of Svalbard and NE Greenland (eastern Laurentia; Figs 11 and 12; Gee & Page 1994; Gee & Teben'kov 2004).

The early record of a Scotia-style arc is probably preserved in the Early to Middle Devonian magmatism of the Ambler district in the southern Brooks Range and the Seward Peninsula. By late Early Devonian time, the Arctic Alaska terrane was accreted to the northwestern margin of Laurentia during the Romanzof orogeny (Lane 2007). We speculate that the Caledonian-derived elements of the Eastern Klamath, Northern Sierra and perhaps Okanagan terranes also came into contact with their northwestern Laurentian counterparts (Figs 9 and 10) during the Romanzof orogeny and later migrated southward along western Laurentia as composite terranes (see also Wallin *et al.* 2000). This southward transport of terranes most probably occurred along a sinistral transform fault system that developed along the western edge of Laurentia in Middle Devonian time (Fig. 13). Progressively younger deformation in continental margin strata, from the late Early Devonian Romanzof orogeny in northern Yukon and Alaska (Lane 2007), to early Middle Devonian (Eifelian) folding and faulting in the Purcell Mountains of southeastern British Columbia (Root 2001), and the Late Devonian to Early Mississippian Antler orogeny of the SW USA (Johnson & Pendergast 1981), may record the southward propagation of this transpressional fault system. The pre-Late Devonian deformation recorded in the Snowcap assemblage of the Yukon–Tanana terrane could be related to this event. The Okanagan terrane appears to have been emplaced against the western Kootenay terrane by Late Devonian time (Thompson *et al.* 2006), an event that could relate to Middle Devonian deformation in the Purcell Mountains to the east. Also, arrival of the Northern Sierra terrane before intrusion of the 364 Ma Bowman Lake batholith could have triggered the emplacement of the Roberts Mountains allochthons during the Antler orogeny.

The question of how Devonian subduction was initiated along the entire western margin of Laurentia in Devonian time remains an enduring problem. The expected strength of old oceanic lithosphere at a passive margin is considered to be too great to be

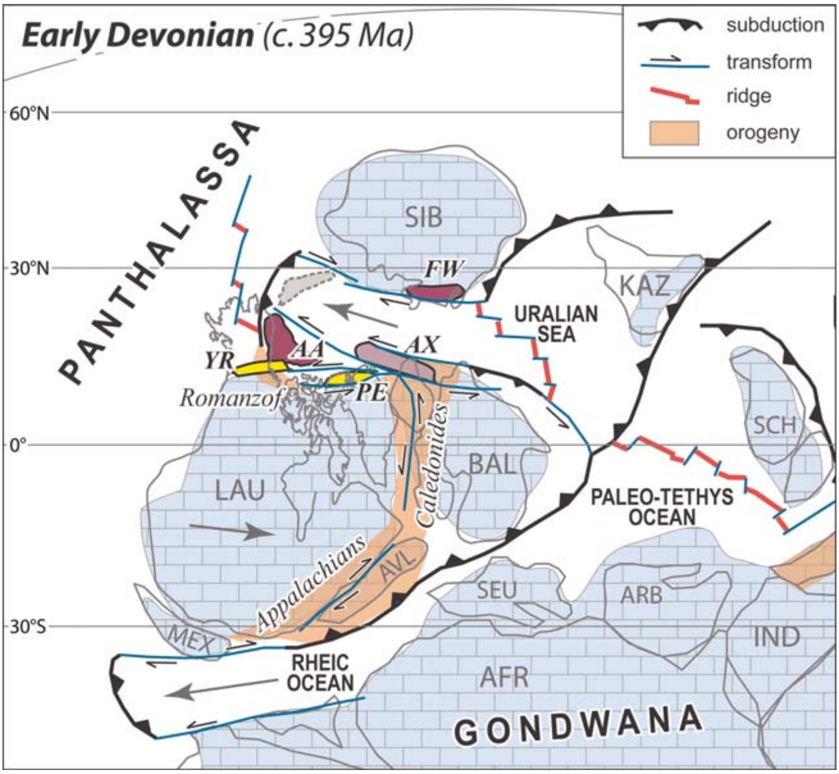

Fig. 12. Early Devonian palaeogeography and development of the Northwest Passage between Laurentia–Baltica and Siberia. Light grey terrane with dashed outline represents possible additional crustal fragments now submerged in the Arctic Ocean. ARB, Arabia; IND, India; MEX, Mexico; SEU, southern Europe. Other abbreviations as in Figure 11.

overcome by either gravity or compression, unless it has been previously weakened (Stern 2004). Propagation of a sinistral transform fault that apparently nucleated out of the Northwest Passage in Devonian time could have provided the weakness along which the oceanic lithosphere collapsed and subduction propagated southward (Figs 13 and 14). Onset of subduction and its southward propagation is recorded by magmatism of 380–400 Ma in the Arctic Alaska terrane, 380–390 Ma in the Yukon–Tanana terrane of the Coast Mountains (which probably restored near present-day Alaska in Palaeozoic time; Mihalynuk *et al.* 1994), 360–370 Ma in the parautochthonous continental margin of eastern Alaska and Yukon, and *c.* 360 Ma along the entire margin of western Laurentia (Nelson *et al.* 2006). These events were probably the result of a global plate reorganization that followed the Middle Devonian Acadian orogeny in the Appalachians and continued with the Carboniferous collision of Gondwana (Fig. 14). A narrow subduction zone that propagated westward through the Northwest Passage in Silurian–Devonian time could have provided the seed point from which subduction was initiated along western Laurentia (Figs 11–14).

Along northern Laurentia, this change in plate motion led to a collision with an enigmatic crustal block, the mythical Crocker Land of Arctic explorers, and development of the Late Devonian–Early Mississippian Ellesmerian orogeny as Laurentia apparently tracked north during collision with Gondwana (Fig. 14). Crocker Land was possibly one of the Caledonian crustal fragments associated with the Alexander and other terranes (Fig. 5). It apparently supplied sediments intermittently to the Sverdrup basin to the south until mid-Mesozoic time (Davies & Nassichuk 1991) and was probably removed during Jurassic–Cretaceous opening of the Arctic Ocean. Future provenance studies will provide more information about the nature and origins of Crocker Land (Omma *et al.* 2007).

Shortly after initiation of subduction along western Laurentia, slab rollback is thought to have caused extension in the back-arc region, which led to rifting of parts of the distal continental margin, such as the Snowcap assemblage (basement to

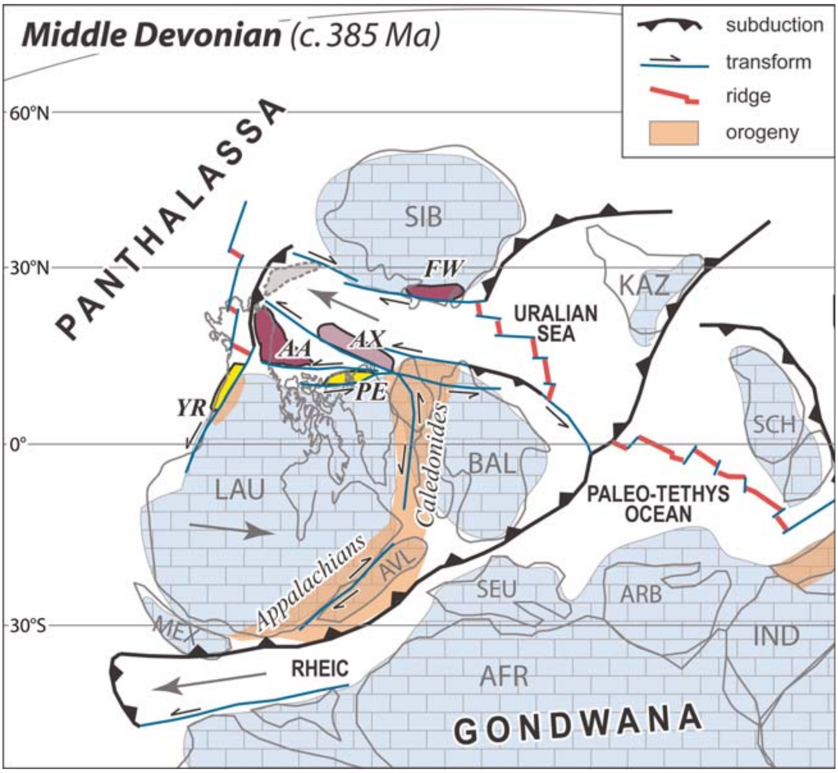

Fig. 13. Middle Devonian palaeogeography and development of a transform margin along western Laurentia. Light grey terrane with dashed outline represents possible additional crustal fragments now submerged in the Arctic ocean. Abbreviations as in Figures 11 and 12.

Yukon–Tanana) and possibly the Shoo Fly Complex (basement to the Northern Sierra terrane; Fig. 14). This rifting culminated in opening of the Slide Mountain ocean in Early Mississippian time and hence migration of the late Palaeozoic peri-Laurentian arcs away from the continental margin (Figs 14 and 15). The Yukon–Tanana terrane shares Late Devonian to earliest Mississippian (370–355 Ma) magmatism with the Laurentian margin, but younger Carboniferous to Permian arc magmatism is unique to the terrane (Nelson *et al.* 2006). The western Kootenay terrane (Eagle Bay assemblage; Fig. 3) of southern British Columbia appears to be a portion of the Late Devonian–earliest Mississippian remnant arc that remained stranded on the Laurentian margin after opening of the Slide Mountain ocean. The exact distribution of the Slide Mountain terrane in southern British Columbia has been obscured by the penetrative Mesozoic deformation and severe early Cenozoic extension that affected this region. However, the occurrence of upper Palaeozoic arc sequences with McCloud faunal elements overlying parts of the Okanagan terrane (Harper Ranch and Attwood groups, Mt. Roberts Formation; Figs 2 and 3) requires a more southerly palaeolatitude in Early Permian time (Belasky *et al.* 2002). The Havallah and Schoonover basinal sequences in the Golconda allochthon are probably the southern extension of the Slide Mountain ocean (Figs 1 and 10; Miller *et al.* 1984; Harwood & Murchey 1990).

The Slide Mountain ocean apparently reached its maximum width in Early Permian time (Fig. 15; Nelson *et al.* 2006). Differences between the McCloud and western Laurentian faunas, based on statistical analysis, suggest that the McCloud belt probably lay 2000–3000 km west of the continental margin (Belasky *et al.* 2002), providing a maximum estimate for the width of the Slide Mountain ocean. By Middle Permian time (*c.* 270 Ma), subduction polarity was reversed and the Slide Mountain lithosphere was being subducted beneath the Yukon–Tanana and related terranes. This is recorded in the belt of high-pressure rocks that lies along the eastern edge of the Yukon–Tanana terrane and Middle to Late Permian magmatic rocks of the Klondike arc (Fig. 2). By Triassic time, the Slide Mountain ocean had closed and the

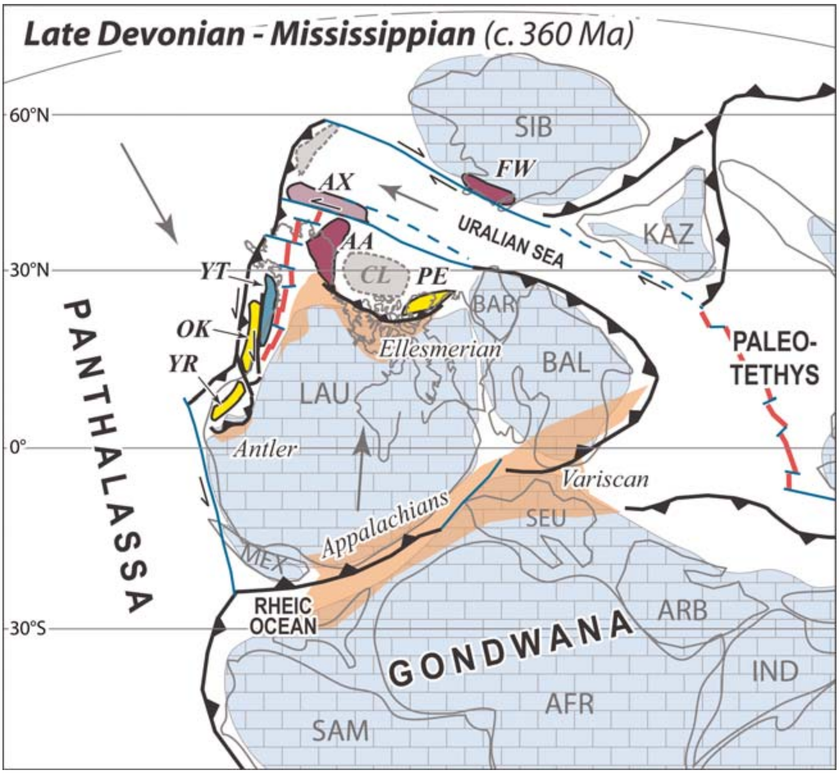

Fig. 14. Late Devonian to Early Mississippian palaeogeography. Development of the Antler and Ellesmerian orogens, initiation of subduction along western Laurentia and onset of rifting in the back-arc region. BAR, Barentsia; CL, 'Crocker Land'; OK, Okanagan terrane; SAM, South America; YT, Yukon–Tanana terrane. Other abbreviations as in Figures 11 and 12.

late Palaeozoic peri-Laurentian arcs were accreted to western Laurentia, by then a part of Pangaea, during the Sonoma orogeny (Fig. 16; Dickinson 2004). Triassic synorogenic clastic rocks overlying the Yukon–Tanana and Slide Mountain terranes, as well as the Laurentian continental margin, and amphibolite-facies metamorphism in the Yukon–Tanana terrane provide records of the Sonoman event in the northern Cordillera (Beranek & Mortensen 2007; Berman *et al.* 2007).

The Alexander terrane is inferred to have migrated out of the Northwest Passage during Carboniferous time (Fig. 14). By Pennsylvanian time, it had joined Wrangellia in northern Panthalassa, where they apparently evolved in an isolated intra-oceanic setting until their Middle Jurassic accretion (Figs 15 and 16).

The Farewell terrane is thought to have originated from the northern margin of the Northwest Passage, where it originally evolved as part of the Siberian Platform until at least Early Permian time, when it was deformed during the *c.* 285 Ma Browns Fork orogeny, an event related to development of the Uralian and Taimyr fold belts (Figs 11–15; Bradley *et al.* 2003). Details of its Mesozoic history are sparse. The Farewell terrane may have been expelled from its site of origin during or following Uralian tectonism (Figs 15 and 16).

By Middle to Late Triassic time, east-dipping subduction was re-established along the entire western margin of Laurentia (now part of Pangaea; Fig. 16), giving rise to voluminous Triassic–Jurassic arc magmatism of Stikinia, Quesnellia and related terranes of the western USA, which were in part built upon Palaeozoic basements of the Yukon–Tanana, Okanagan, Eastern Klamath and Northern Sierra terranes (Fig. 2). This more stable, wide-slab geometry (Schellart *et al.* 2007) apparently persisted more or less in its original form along western North America until at least early Cenozoic time.

Convergence between the North American plate and the various oceanic plates that succeeded Panthalassa (e.g. Farallon, Kula and Pacific) began with the Jurassic opening of the North Atlantic

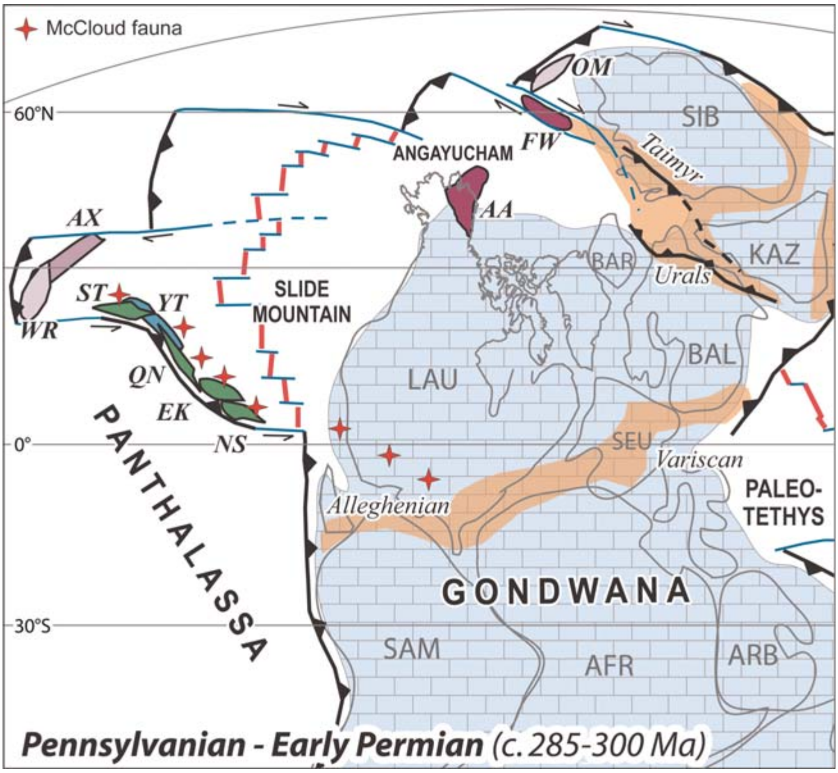

Fig. 15. Pennsylvanian to Early Permian palaeogeography. By this time, the Slide Mountain ocean had reached its maximum width and volcanic arcs of the McCloud belt (late Palaeozoic sequences of Stikinia (ST), Quesnellia (QN), Eastern Klamaths (EK) and Northern Sierra (NS) terranes) were developing on top of pericratonic mid-Palaeozoic and older fragments of Yukon–Tanana (YT), Yreka–Trinity and Shoo Fly terranes. Onset of Uralian tectonism along northern Baltica, Kazakhstania and Siberia, and inferred expulsion of the Farewell terrane (FW) from the Siberian margin. OM, Omulevka ridge; WR, Wrangellia. Other abbreviations as in Figures 11–14.

Ocean and the westward drift of North America over its western subduction zone (Monger & Price 2002).

It is possible that another Caribbean- or Scotia-style subduction system developed between southern Laurentia and Gondwana (Wright & Wyld 2006) and coexisted with the Northwest Passage in Silurian–Devonian time (Figs 11–13), much like the modern Caribbean and Scotia systems developed at either end of South America. However, our review of the geological evidence leads us to conclude that Cordilleran terranes of inferred Caledonian and Siberian affinities were more probably introduced into eastern Panthalassa via the Northwest Passage rather than its southern equivalent.

Conclusions

Palaeozoic to early Mesozoic terranes of the North American Cordillera are proposed to have originated from three major regions in Palaeozoic time: (1) the western peri-Laurentian margin; (2) western Panthalassa in proximity to the Palaeo-Tethys realm; (3) in proximity to the northern Caledonides, occupying an intermediate position between NE Laurentia, Baltica and Siberia (Figs 1 and 11). Dispersion of the Caledonian–Siberian terranes and their westward migration into eastern Panthalassa is interpreted to result from development of a Caribbean- or Scotia-type subduction system between northern Laurentia–Baltica and Siberia in mid-Palaeozoic time: the Northwest Passage. This system was probably driven by upper mantle outflow from the closing Iapetus–Rheic oceans along eastern Laurentia, as Pangaea was being amalgamated (Figs 11–14). The rapid westward migration of a narrow subduction zone through the Northwest Passage entrained Caledonian and Siberian terranes into eastern Panthalassa and provided a seed point for propagation of subduction along western Laurentia in

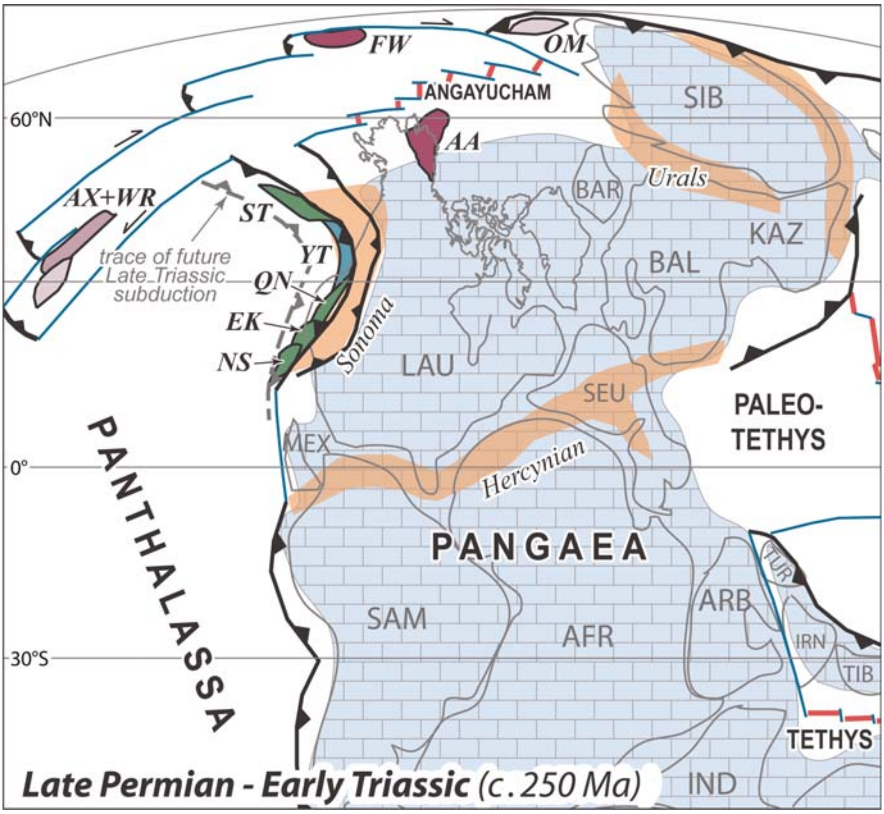

Fig. 16. Late Permian to Early Triassic palaeogeography. By then, all Caledonian, Baltican and Siberian terranes now found in the North American Cordillera had entered Panthalassa. The Slide Mountain ocean was closing and the late Palaeozoic peri-Laurentian arcs were accreted to western Laurentia, by then a part of Pangaea. IRN, Iran; TIB, Tibet; TUR, Turkey. Other abbreviations as in Figures 11–15.

Late Devonian–Early Mississippian time. Subduction along western Laurentia is inferred to have been initiated as a result of a global plate reorganization related to Devonian convergence in the Appalachian orogen of eastern Laurentia and Carboniferous collision with Gondwana. By early Mesozoic time, this subduction system had evolved to a stable, wide-slab geometry that persisted along western North America at least until early Cenozoic time.

This paper, as indeed our entire learning experience in the Cordillera, has been shaped by the observations and inferences of many others. As well as citing their papers, we highlight here some principal influences on our grasp of the Caledonian–Siberian terranes: P. Belasky, D. Bradley, J. Dumoulin, G. Gehrels, D. Harwood, E. Katvala, L. Lane, N. Lindsley-Griffin, W. McClelland, M. Mihalynuk, E. Miller, M. Miller, J. Monger, T. Moore, B. Murchey, and C. Soja; it is hoped that their ideas appear here in forms that are true to the originals. In particular, we wish to acknowledge recent conversations with J. Wright, whose innovative solution to some problems of Cordilleran terrane origin was the spark for the present endeavour. Thanks to P. Cawood for encouraging us to submit a western Laurentian story to this volume. We are grateful to N. Lindsley-Griffin for her careful corrections to the section on the eastern Klamaths. Formal reviews by D. Bradley, G. Gehrels and C. van Staal have helped to clarify our arguments. This is Yukon Geological Survey Contribution YGS2008-001.

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