Rossland Group extends north: Detrital zircon U-Pb ages allow supracrustal unit reassignments in southern British Columbia and have tectonic implications

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Abstract

Sedimentary rocks preserved in a series of outliers in southeast British Columbia and considered part of Quesnel terrane were variously assigned by previous workers to the Nicola Group, the Slocan Group, and the Harper Ranch Group. New detrital zircon U-Pb results indicate that rocks at two locations previously thought to be Harper Ranch Group (Carboniferous-Devonian) are Late Triassic. Exclusively Triassic zircon in these two samples points to provenance from weathering, erosion, and deposition close to the Nicola Group and its intrusive equivalents (Late Triassic). Samples from two other locations have mostly Late Triassic to Jurassic detrital zircons, and Jurassic maximum depositional ages (ca. 200 Ma and ca. 183 Ma). These samples also contain zircon populations spreading from the Mesoproterozoic, indicating exposure to diverse older erosional sources during sedimentation. However, these ages are incompatible with derivation from currently nearby Archean and Paleoproterozoic Ancestral North America and may indicate sources now in southwestern USA or Mexico or a cryptic crustal block. The age of the ca. 200 Ma sample and its position beneath pyroxene-phyric basalts suggest a stratigraphic relationship and correlation to the Archibald and Elise formations of the Rossland Group. The younger sample has the same maximum depositional age as the recently identified Salmon River succession and Lions Head succession. This younger unit can be correlated to the Hall Formation of the Rossland Group. A fifth sample, collected from the Slocan Group, contains Triassic zircon and has a Late Triassic maximum depositional age. It also contains a spread of Mesoproterozoic (Ecclassian), Neoproterozoic (Ediacaran and Tonian), and Paleozoic (Carboniferous-Devonian and Cambrian) zircon, and currently nearby Ancestral North America-aged zircon populations appear to be lacking, again suggesting derivation from exotic sources and opening the possibility of significant orogen-parallel terrane displacements.

Beneath the Rossland Group and Triassic sedimentary units are 'quartzites' of the Chase Formation. However, North American detrital zircon from the Chase Formation are not recycled into the Rossland Group and the quartzites display mylonitic fabrics. We tentatively conclude that the Chase Formation records a previously unrecognized shear zone and that the juxtaposition preserved today is structural, not stratigraphic. Age-cumulative probability modelling support that the units in this study were deposited at a convergent margin, likely in a forearc or trench basin at the leading edge of Quesnellia as it approached the North American margin. However, where on the North American margin remains to be demonstrated. Based on detrital zircon data presented herein, we put forward a speculative yet testable alternative to current tectonic models that envisage eastward subduction during evolution of the Nicola arc by postulating westward subduction and an east-facing oceanic arc. Accordingly, we explain the exclusively Triassic zircon populations in older (Triassic) rocks to have been derived from local, roughly coeval sources, and mixed detrital zircon populations in younger (Jurassic) rocks to indicate arrival of older crust (Paleozoic to Precambrian) of uncertain origin.

Keywords: Quesnel terrane, Rossland Group, Slocan Group, Nicola Group, Harper Ranch Group, Chase Formation, detrital zircon, mylonite

1. Introduction

The transition between Quesnel terrane and Ancestral North America (Fig. 1) remains enigmatic, partly because of limited exposures and partly because of different geologists working over a span of decades making observations at isolated outcrops. Most of the rocks that form a series of hills east and west of Vernon (Fig. 2) are poorly exposed grey graphitic phyllite with only rare visible contacts (Okulitch, 1979). Thompson et al. (2006) provided the most up-to-date bedrock mapping and map compilation in the area and assigned some of the rocks that underly the hills as outliers of the Slocan Group (also see Okulitch, 1979) that were thought to be the lateral facies equivalents of Nicola Group volcanic rocks (Late Triassic; e.g., Untershutz et al., 2002; Mihalynuk and Diakow, 2020). Before this, these rocks were variously assigned to the Cache Creek Group (Jones, 1959) and the Nicola, Slocan, and Harper Ranch groups (Okulitch, 1979; Schiarizza and Church, 1996). In tectonostratigraphic terms, these rocks represent the suprastructure to an infrastructure represented by Precambrian and Paleozoic orthogneiss and paragneiss of the Shuswap metamorphic core complex (Fig. 2; e.g., Parrish et al., 1988; Glombick et al., 2006; Brown et al., 2017).

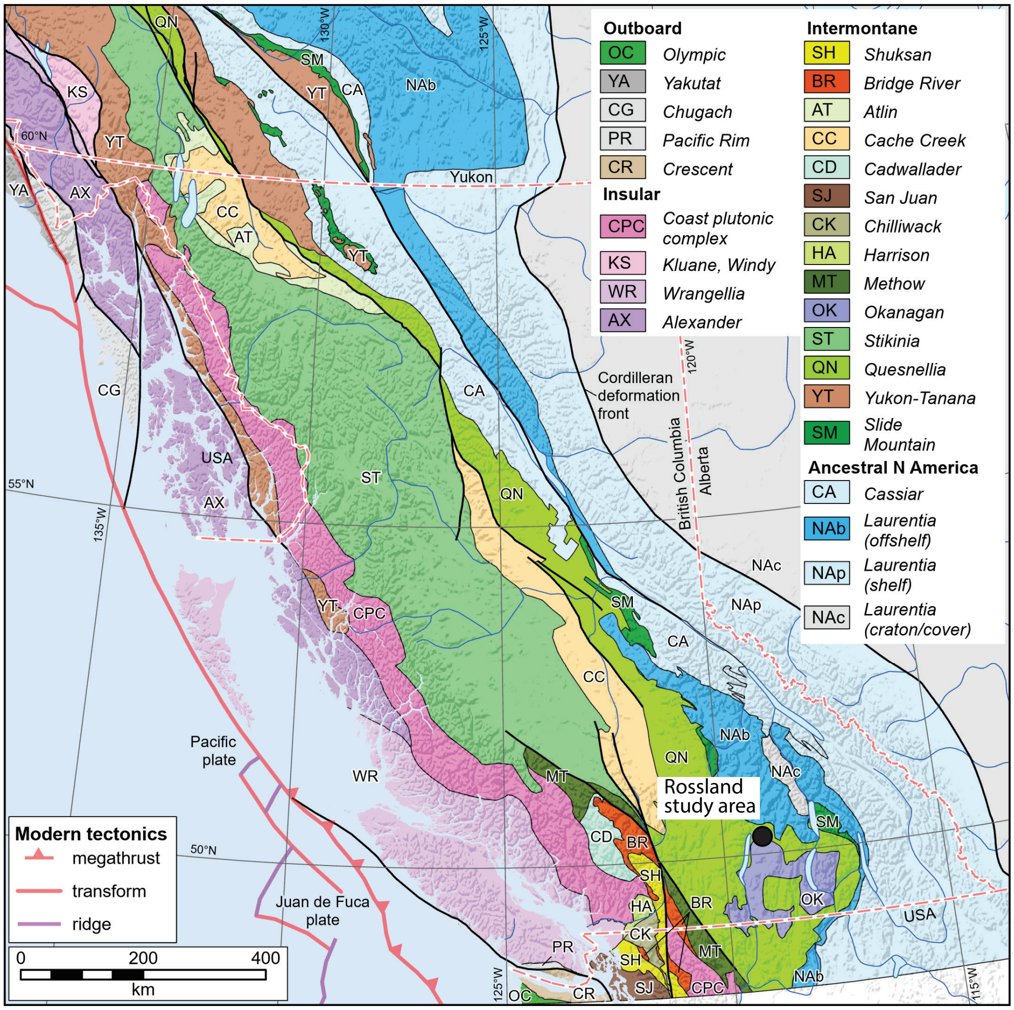

Fig. 1. Location of the study area. Terranes after Colpron (2020).

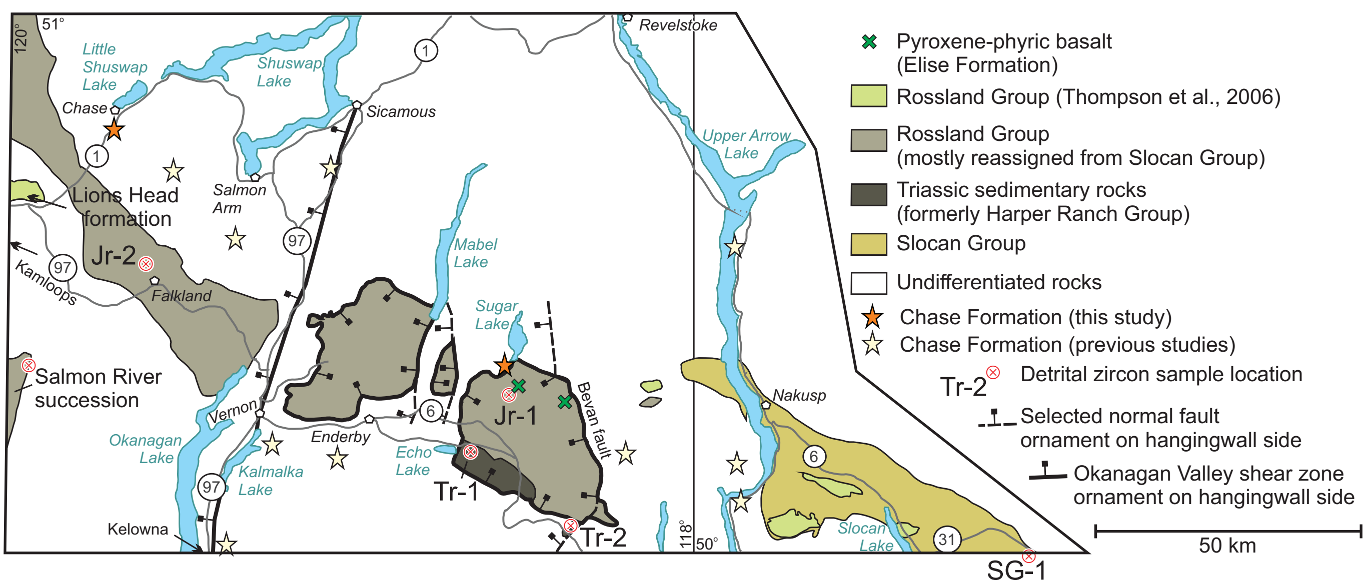

Fig. 2. Simplified geological map highlighting units that were previously assigned to the Nicola and Slocan groups. Based on the results in this study, these units may be best included in the Rossland Group. The distribution of Harper Ranch Group rocks is also in question. Undifferentiated units range from Paleoproterozoic gneissic rocks to Miocene basalt. Geology is simplified after Thompson et al. (2006); known exposures of the Chase Formation from Thompson et al. (2006); Glombick et al. (2006), and Lemieux et al. (2007). The Okanagan Valley shear zone is from Parrish et al. (1988) and Brown et al. (2017).

Unterschutz et al. (2002) provided radiogenic isotopic data for these supracrustal rocks and, because they were considered as stratigraphic equivalents to Nicola Group volcanic rocks, these data were interpreted to represent the isotopic signature of the Late Triassic volcanic arc component of Quesnel terrane. Accordingly, these data were thought to indicate that Ancestral North American basement was present during the development of the Nicola arc (Unterschutz et al., 2002; Thompson et al., 2006). New detrital zircon and field data presented herein address unit assignments in the area and open the possibility of a speculative but testable model for the nature of the transition between Quesnel terrane and Ancestral North America.

This study was initiated to field check the available bedrock geology of the Vernon area before updating the BC Digital Geology database (British Columbia Geological Survey, 2019). We collected samples to establish detrital zircon U-Pb provenance and maximum depositional ages of units in the area. This paper provides an overview of five new detrital zircon U-Pb results from: 1) a turbiditic unit with graded sandstone-mudstone beds that outcrops west of Arrow Lake, previously considered as Harper Ranch Group (Thompson et al., 2006); 2) an isolated sandstone-bearing outcrop from east of Echo Lake, previously assigned to the Harper Ranch Group (Thompson et al., 2006); 3) a rare, strongly deformed sandstone bed within graphitic phyllite southeast of Sugar Lake, previously assigned to the Slocan Group (Thompson et al., 2006); 4) a turbiditic unit with graded sandstone-mudstone beds that outcrops north of Falkland, previously assigned to the Slocan Group (Thompson et al., 2006); and 5) for comparison, a rare sandstone sample from the Slocan Group east of Slocan Lake.

2. Past unit assignments and reassignments

Bedrock mapping of the Vernon NTS sheet in the 1950s (Jones, 1959) identified a mixed unit of orthogneiss and paragneiss that was called the Monashee Group and a northwest-trending belt of supracrustal rocks that were assigned to the Cache Creek Group. Okulitch (1979) updated this geology, reassigning Cache Creek rocks to other units, including the Harper Ranch, Nicola, and Slocan groups (Quesnel terrane) and was later updated for BC Digital Geology by Schiarizza and Church (1996). Currently, the Nicola Group is reserved for Late Triassic volcanic and volcanosedimentary rocks in Quesnel terrane, sensu stricto (e.g., Mihalynuk and Diakow, 2020; Schiarizza, 2024). Sedimentary rocks that are considered equivalent to the Nicola Group are commonly referred to as Slocan Group (e.g., Schiarizza, 2024) but nowhere have stratigraphic or chronological links been clearly demonstrated and the relationship remains conjectural. Thompson et al. (2006) referred to most of the rocks in the Vernon area as Slocan Group because they almost entirely appear to be of sedimentary origin.

East of Kamloops, sedimentary rocks that unconformably overly the Harper Ranch Group (Devonian) were assigned to the Nicola Group (Okulitch, 1979). Using fossil assemblages, Beatty et al. (2006) recognized these rocks were deposited in the Jurassic and referred to them as the Lions Head succession. To the south near Salmon River, Schiarizza et al. (2022) used detrital zircons to demonstrate that some sedimentary units that had been assigned to the Nicola Group were deposited after ca. 183 Ma (Jurassic) and they referred to these rocks as the Salmon River succession (Fig. 2). They suggested that these rocks may correlate to the Lions Head succesion and the Hall Formation of the Rossland Group to the south (Höy and Dunne, 1997).

3. Sampling

The area investigated (Fig. 2) is commonly covered by vegetation, and Quaternary cover is extensive; the best exposures are typically in roadcuts along highways, resource roads, and logging slashes. Most of the Mesozoic supracrustal rocks are fine-grained strongly deformed graphitic phyllite and slate or calcareous sandstones and mudstones (Fig. 3) that are less than ideal candidates for undertaking detrital zircon provenance and maximum depositional age work. Fortunately, we were able to find rare sandstone beds more suitable for sampling (Fig. 3; Table 1) but mostly from isolated outcrops. Because stratigraphic relationships are not typically preserved, regional correlations from the results we present below are interpretations constrained by the available data. For regional comparison, we include a sample from an exposure east of Slocan Lake that is typical of the Slocan Group in its eponymous area.

4. Detrital zircon analysis

4.1. Methods

Analytical details follow those in Ootes et al. (2022). Detrital zircon were separated from rock samples at the Pacific Centre for Isotopic and Geochemical Research at the University of British Columbia. Zircon crystals (>75 mm) were selected from conventional density and magnetic mineral separation methods. The entire zircon separate was annealed at 900°C for 60 hours, then individual grains were hand-picked and mounted, polished, and imaged by cathodoluminescence (CL) on a scanning electron microscope. From these images, grains were selected for U-Pb isotopic analysis, conducted using a Resonetics RESOlution M-50-LR, connected via a Teflon squid to an Agilent 7700x quadrupole ICP-MS. After data reduction, data were further screened using trace elements and analytical results >10% discordant were removed. To test the maximum deposition age of some samples, the youngest zircon grains were plucked from the grain mount and analyzed by chemical abrasion-thermal ionization mass spectrometry (CA-TIMS) following the methods in Ootes and Wall (2024).

4.2. Results

4.2.1. Tr-1; 22lo5-30

Sample Tr-1 (Triassic 1) was collected along the southern leg of the Creighton Valley road, southeast of Echo Lake (Fig. 2; Table 1). The sample is from an isolated outcrop of sandstone and carbonate (Fig. 3a), previously assigned as

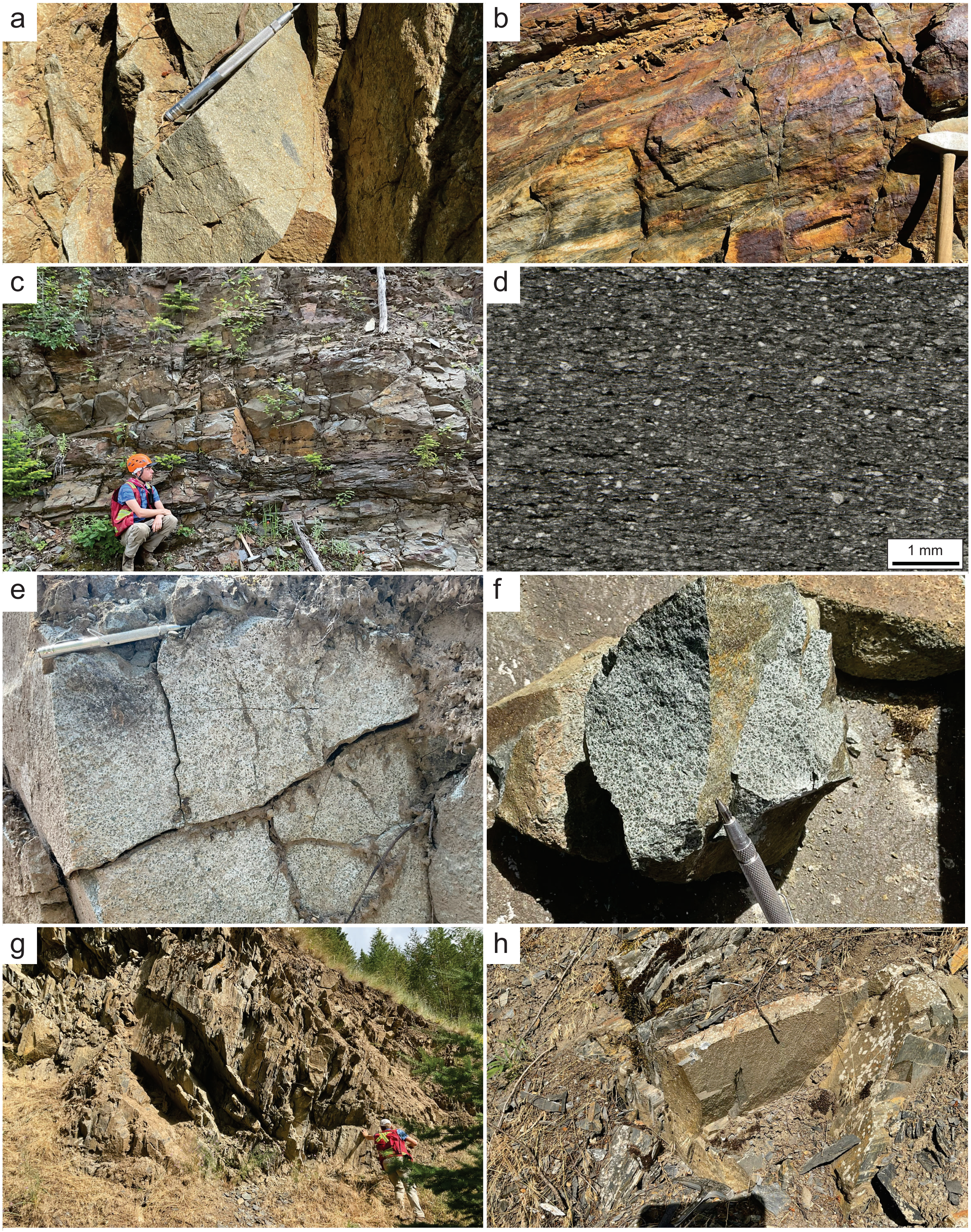

Fig. 3. Outcrop photographs of sample locations in this study. **a)** Sandstone, sample Tr-1, **b)** Rusty sandstone-mudstone beds at sample location Tr-2. **c)** Deformed phyllitic rocks with a rare sandstone bed at sample location Jr-1. **d)** Thin section photomicrograph of fine-grained and strongly deformed sample Jr-1; plane polarized light. **e-f)** Massive pyroxene-phyric basalt outcrops topographically above Jr-1 sample location. **g)** Steeply dipping sandstone to mudstone fining-upward sequences at sample location Jr-2. **h)** Rare, ~20 cm thick beige sandstone bed; sample Jr-2.

Table 1. New U-Pb zircon samples, unit reassignments, and maximum depositional ages.

Sample	Station ID	New^	Previous Group*	Maximum depositional age (Ma)*	Lat.	Long.
Jr-2	22lo18-93	Rossland Group	Slocan	182.73 ±0.05	50.542508	119.600851
Jr-1	22lo6-38	Rossland Group	Slocan	199.914 ±0.036	50.29986	118.541245
Tr-2	22lo4-23	Triassic sedimentary unit	Harper Ranch	ca. 220	50.03599	118.363879
Tr-1	22lo5-30	Triassic sedimentary unit	Harper Ranch	ca. 230	50.19397	118.655057
SG-1	MMI21-12-01	Slocan Group	Slocan	ca. 210	49.9795	117.0116

^New assignments are from detrital zircon results in this study and Schiarizza et al. (2022) and previous Group assignments are from Okulitch (1979) and Thompson et al. (2006 and references therein).
*Estimated maximum depositional age from LA-ICP-MS is given as circa (ca.).

Harper Ranch Group (Thompson et al., 2006). Sixty-seven concordant zircons (of 85 analyses) have a unimodal age population between 250 and 225 Ma (Fig. 4a). Using the 'minimum' option in a radial plot (Vermeesch, 2021), a maximum depositional age is estimated at ca. 230 Ma (Fig. 4a).

4.2.2. Tr-2; 22lo4-23

Sample Tr-2 was collected from a resource roadcut north of Highway 6, west of Arrow Lake (Fig. 2; Table 1). At this location, a switchback road provides outcrops of rusty turbiditic sandstone-mudstone beds with preserved primary and locally graded bedding (Fig. 3b). Previously, this was assigned as Harper Ranch Group (Thompson et al., 2006). A sample was collected from a fine-grained sandstone bed, but only a modest number of zircon was retrieved (n=9). Uranium-lead results (n=7) have a narrow range of unimodal ages between 225 to 215 Ma (Fig. 4b). The limited number of zircon allows a weighted mean calculation of ca. 220 Ma, interpreted as the maximum depositional age (Fig. 4b).

4.2.3. Jr-1; 22lo6-38

This sample (Jurassic 1) was collected from a rare arenaceous bed in otherwise strongly deformed phyllitic rocks along a resource road southeast of Sugar Lake (Fig. 2; Table 1). Primary sedimentary structures are not preserved because of the strong deformation (Figs. 3c, d) indicating the layering may be compositional and structurally transposed rather than bedding. From the sample location, the resource road climbs to higher elevations where exposures of fine-grained mafic rock with pyroxene phenocrysts (basalt) occur (Figs. 3e, f). These rocks appear less deformed than the underlying phyllitic rocks but no primary volcanic features were observed (Figs. 3e, f). The strongly deformed fine-grained arenaceous sample yielded 121 detrital zircons. Concordant U-Pb ages (n=107) are predominantly ca. 200 Ma (n=75), with minor Paleozoic (n=12) and Precambrian (n=20) populations (Fig. 5a). To test the maximum depositional age, six zircon grains were removed from the laser ablation mount, dissolved and analyzed by CA-TIMS, yielding a weighted mean U-Pb age of 199.914 ±0.036 Ma (n=5/6), interpreted as the maximum time of deposition (Fig. 5a; Table 1).

4.2.4. Jr-2; 22lo18-93

This sample was collected from northwest of Falkland, where the Chase-Falkland road intersects the Six Mile Creek road (Fig. 2; Table 1). The creek-side outcrop consists of 2 to 3 m cliff faces of vertically dipping thin (~5 cm) sandstone-mudstone beds. A well-preserved foliation is clockwise to bedding and an intersection lineation on the bedding planes has a shallow plunge to the southeast. The outcrop was thoroughly searched for sandstone layer coarse grained enough for detrital zircon work, and a bed ~20 cm thick was sampled. Concordant U-Pb results (n=116) have a tight range from Late Triassic to Early Jurassic (n=114). In addition, one zircon yielded an age of ca. 280 Ma, and another zircon yielded an age of ca. 1030 Ma (Fig. 5b). Six single zircon grains were analyzed by CA-TIMS and yielded three populations younger than ca. 186 Ma, with the two overlapping results providing a maximum depositional age of 182.73 ±0.05 Ma (Fig. 5b; Table 1).

4.2.5. SG-1; MMI21-12-01

This sample was collected south of Highway 31A near a bridge crossing the Kaslo River (Figs. 2, 6a; Table 1). A single fine to medium-grained, 1.5 cm thick sandstone layer within dark grey to black argillite (Fig. 6b) was sampled for detrital zircon analysis. One-hundred and twenty-two zircon grains were analyzed by LA-ICP-MS, of which 84 passed further filtering and are <10% discordant. Multiple age populations are in the sample including a minor Mesoproterozoic mode (ca. 1300 Ma; Eclassian), a Neoproterozoic (Tonian) mode, and significant Neoproterozoic (Ediacaran) to Cambrian (580 to 500 Ma), Devonian through Carboniferous (400 to 300 Ma), and Late Triassic (240 to 220 Ma) modes (Fig. 6). Using the 'minimum'

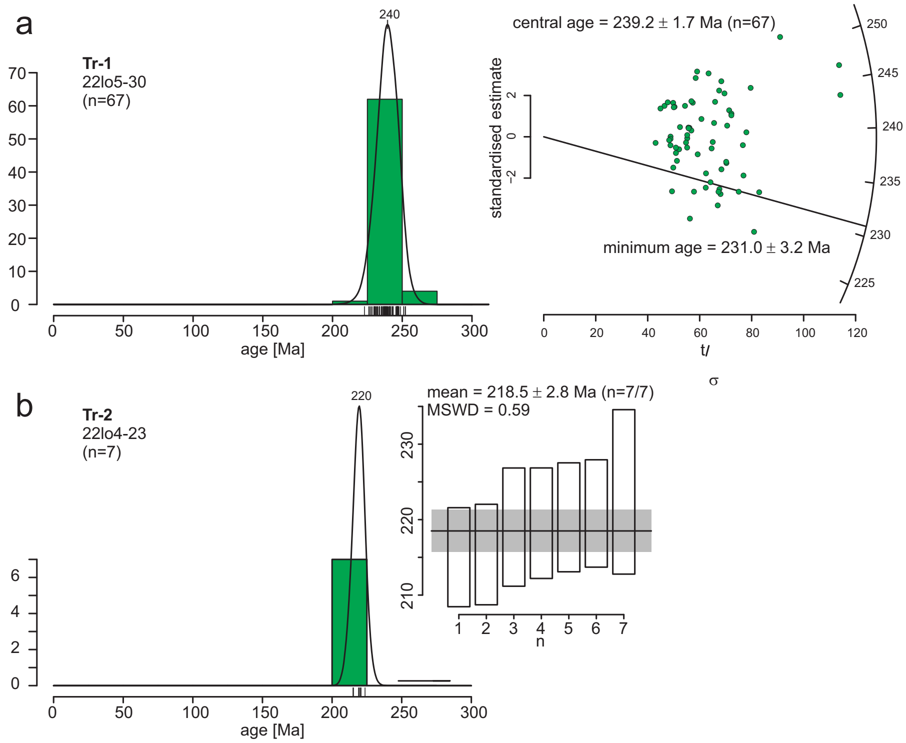

Fig. 4. Detrital zircon geochronology of Triassic samples. **a)** Kernel density estimate (KDE) with rug plot and radial plot of concordant zircon U-Pb ages of sample Tr-1, with an estimated maximum depositional age of ca. 230 Ma and a single population at ca. 240 Ma. **b)** Sample Tr-2 KDE and weighted mean age of ca. 220 Ma from concordant zircons in the sample, interpreted as the maximum depositional age of the sample. All plots generated using IsoplotR (Vermeesch, 2018) and maximum depositional ages are derived following Vermeesch (2021).

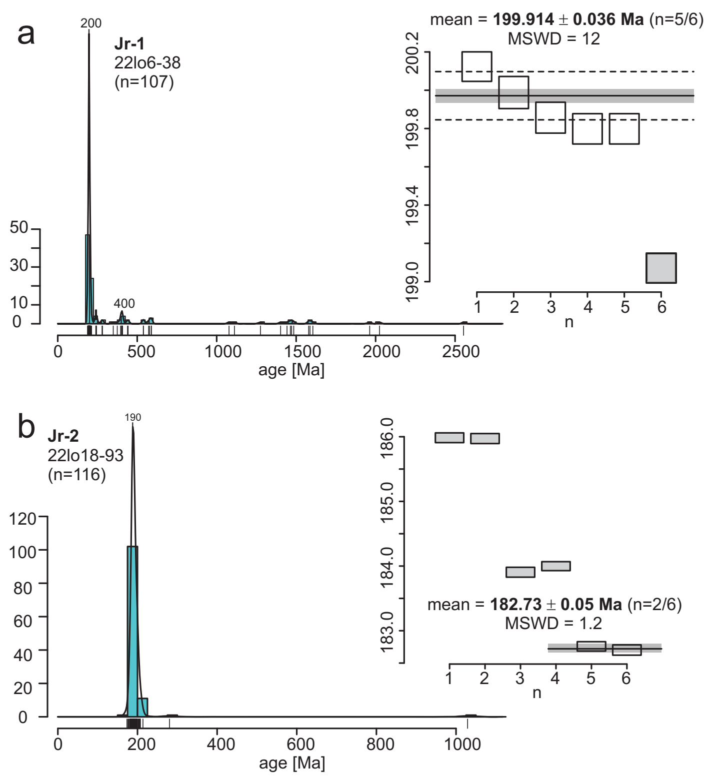

Fig. 5. Detrital zircon geochronology of Jurassic samples. **a)** Sample Jr-2 KDE plot and weighted mean of concordant zircon from CA-TIMS, yielded a maximum depositional age of 199.914 ±0.036 Ma. One younger zircon at 199 Ma was excluded from the weighted mean. **b)** Sample Jr-2 KDE and weighted mean ages from concordant zircon from CA-TIMS. The two youngest overlapping zircon grains yield a weighted mean age of 182.73 ±0.05 Ma, interpreted as the maximum depositional age of the sample.

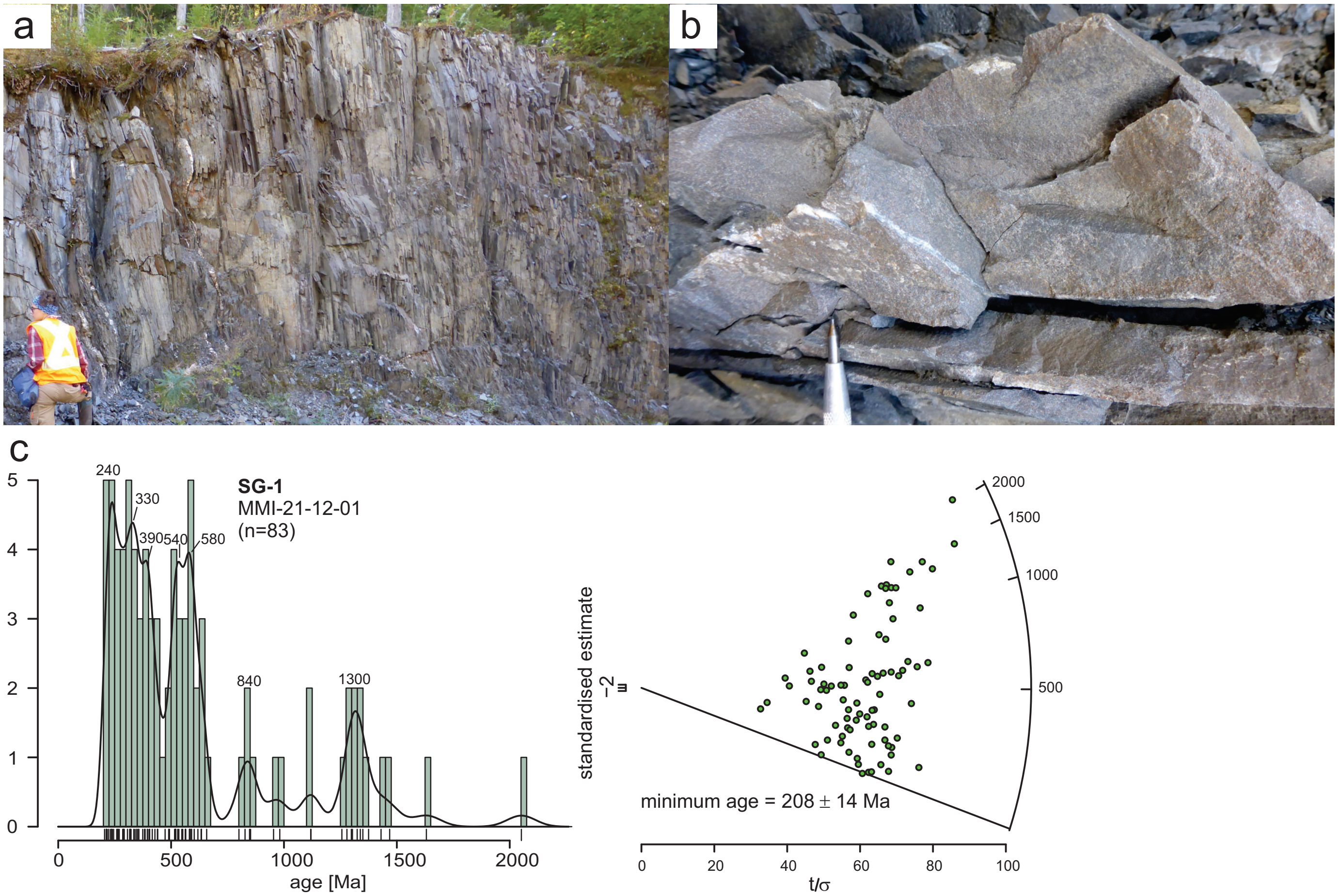

Fig. 6. a-b) Outcrop photographs of the Slocan Group sample location in a roadside quarry and photograph of the rare sandstone sampled for this study. **c)** Sample SG-1 KDE plot showing a range of <10% discordant zircon ages with age modes labelled. Radial plot with estimated maximum depositional age of the sample at ca. 210 Ma. All plots generated using IsoplotR (Vermeesch, 2018).

option in a radial plot (Vermeesch, 2021), a maximum depositional age is estimated at ca. 210 Ma (Fig. 6) that is consistent with Carnian to Norian conodont ages reported from the same area by Orchard (1985).

5. Discussion

5.1. Triassic sedimentary rocks

Both Tr-1 and Tr-2 contain Late Triassic zircon populations and maximum depositional ages. Sample Tr-1 has a relatively older population (ca. 240 Ma) compared with a slightly younger population in Tr-2 (ca. 220 Ma), although this sample has a low number of age results (Figs. 4, 7). Both are consistent with detritus derived from the Nicola Group, or intrusive equivalents, and do not include zircon from any other sources. Both samples are from isolated enclaves and the ability to correlate them to localities elsewhere is difficult without other supporting information. Rocks at the Tr-2 sample location were previously assigned to the Harper Ranch Group (Thompson et al., 2006) probably because of resemblance to turbiditic sandstone-mudstone beds at the type locality near Kamloops (Fig. 2) as described by Beatty et al. (2006). However, the detrital zircon results indicate that sample Tr-2 is ~150 million years younger than the Harper Ranch Group (Devonian to Carboniferous; Beatty et al., 2006). These results call into question the true distribution of the Harper Ranch Group away from its type locality.

The Slocan Group sample has Triassic U-Pb zircon ages but also contains abundant older populations (SG-1; Figs. 6, 7). The Triassic ages are similar to Tr-1 and Tr-2 (Fig. 7). The Devonian to Carboniferous zircon populations could record derivation from the oldest units in Quesnel terrane such as the Lay Range assemblage in northern Quesnellia (Ootes et al., 2022), but the older Paleozoic and Precambrian populations (Fig. 6) are unlike the ages of Quesnel terrane rocks, currently nearby Archean and Paleoproterozoic Ancestral North America, or of second-cycle zircons that may have been reworked from passive margin sedimentary rocks deposited on nearby Ancestral North American basement. However, these older zircon ages are similar to the ages of rocks now exposed in the southwestern USA and Mexico (e.g., Matthews et al., 2018).

In summary, samples Tr-1 and Tr-2 indicate that a single source was exposed to erosional levels during sedimentation: the

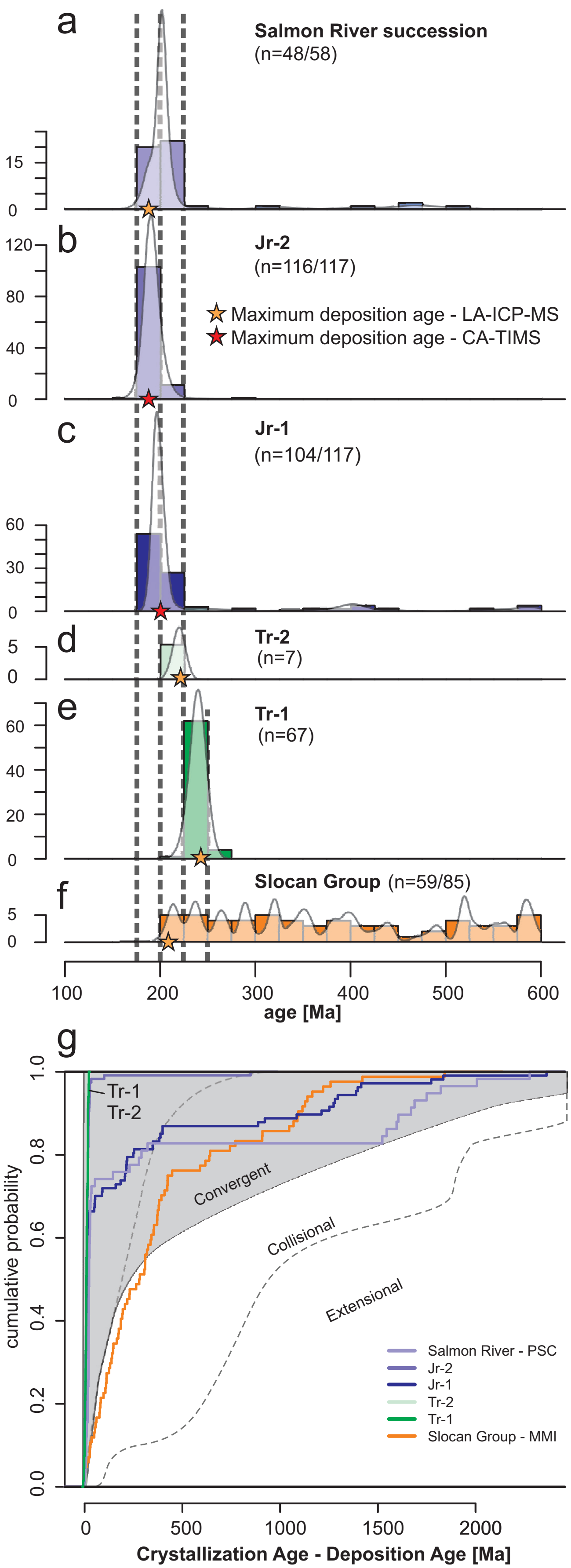

Fig. 7. a-f) Kernel density estimate plots (600-100 Ma) showing a stepwise variation in zircon provenance and maximum depositional age of each sample. Concordant (<10% discordant) ages used for the plot. Maximum depositional ages from LA-ICP-MS and CA-TIMS are differentiated by coloured stars. Salmon River succession sample is from Schiarizza et al. (2022). **g)** Zircon crystallization (Crystallization Age) minus the time of deposition (Deposition Age) versus cumulative probability plot. The steep trends of all samples show that >75% of the detrital zircons in the samples are near the depositional age, consistent with sedimentation in a trench or forearc at a convergent margin, rather than in a back-arc or foreland basin (collisional field), or continental rift to passive margin basins. Samples Tr-1 and Tr-2 contain only zircon populations that are close to when source rocks crystallized. Samples Jr-1 and Slocan Group contain zircon populations that record derivation from older sources. Diagram and fields modified from Cawood et al. (2012).

Nicola Group and allied intrusions (Figs. 4, 7). In contrast, the Slocan sample indicates erosion of both significantly older and diverse sources and Triassic sources (Fig. 7). What these older sources may have been remains unclear; further detrital zircon, trace element, and eHf^{T} isotopic work may help resolve the question.

5.2. Jurassic sedimentary rocks: Rossland Group?

The sandstones represented by sample Jr-1 were deposited after ca. 200 Ma (Figs. 5, 7). Because of the pyroxene-phyric basalts exposed at higher elevation (Figs. 2, 3e, f), these rocks may best be correlated to the Rossland Group (Höy and Dunne, 1997). The phyllites may be equivalent to the Archibald Formation (Sinemurian; 199.5 to 192.9 Ma) and the basalts equivalent to the Elise Formation (Sinemurian to Pliensbachian; Höy and Dunne, 1997). It remains unclear where the ca. 400 Ma zircon population in Jr-1 may have been derived from. East of the sample location and west of Arrow Lake (Fig. 2), Okulitch (1979) and Thompson et al. (2006) identified an outlier of Rossland Group volcanic rocks (unit lJR). An adjacent outlier was re-assigned to Slocan Group by Thompson et al. (2006). Given the evidence in this study this outlier is likely also part of the Rossland Group (Fig. 2).

The sandstone represented by sample Jr-2 was deposited close to or after ca. 183 Ma (Toarcian; Figs. 5, 7). This is the same maximum depositional age determined by Schiarizza et al. (2022) for the Salmon River succession to the southwest (Figs. 2, 7), which they correlated to the Lions Head succession above the Harper Ranch Group east of Kamloops (Beatty et al., 2006) and, potentially, to the Hall Formation of the Rossland Group (Höy and Dunne, 1997). The Hall Formation has never been tested with detrital zircon geochronology, but its depositional age is constrained by Toarcian fossil assemblages (184.2 to 174.7 Ma; Höy and Dunne, 1997), supporting that these units are equivalent to the Hall Formation.

We interpret that the Jurassic depositional ages determined in this study represent all similar rocks (mostly grey graphitic phyllite) in the outliers that form the hills east of Vernon and continue to the west, past Falkland to the Kamloops area (Fig. 2). Most of the rocks in this area were assigned to the Slocan Group and interpreted to be equivalent to the Nicola Group to the west (Okulitch, 1979; Untershutz et al., 2002; Thompson et al., 2006). Reassignment to the Rossland Group is more consistent with depositional ages <200 Ma (Figs. 5, 7; Höy and Dunne, 1997; Beatty et al., 2006; Schiarizza et al., 2022). In contrast to Unterschutz et al. (2002), we consider that their whole-rock radiogenic isotope (eNd^T) data represent rocks that are younger than 200 Ma and do not represent the relationship between Nicola Group (Late Triassic) and Ancestral North America. These data likely indicate mixing of juvenile and more evolved sources or reflect minor input of older detritus as recorded by older zircon in the samples (Figs. 5, 7). Detrital zircon eHf^T data should help clarify this.

5.3. Comparison of detrital sources

Each of the samples in this study has a different provenance (Fig. 7). The Jurassic samples have similar ca. 200 Ma zircon populations, but they differ slightly in detail. Sample Jr-1 has a zircon population (ca. 200 Ma) that is older than sample Jr-2 and the sample from the Salmon River succession, which contain predominantly 190 Ma zircon (Fig. 7; Schiarizza et al., 2022). The Triassic samples have older populations, and each sample locality has different populations (Fig. 7). The Slocan Group sample contains equal amounts of both Triassic zircon and older Neoproterozoic to Paleozoic populations (Fig. 7f).

The steep trends on cumulative probability plots (Fig. 7g) indicate most of the detrital zircon ages (i.e., crystallization age of the zircon) are close to the maximum depositional age of the rocks, consistent with sedimentation at a convergent margin. Given unimodal ages from the Triassic samples we would interpret deposition in a trench or forearc basin (Fig. 8). There is little evidence for detritus from nearby Archean and Paleoproterozoic Ancestral North America (Figs. 4-8). Based on these data, we introduce a speculative westward subduction tectonic model as an alternative interpretation. This alternative differs from conventionally held views (e.g., Nelson et al., 2013) that envisage the Nicola arc as having been generated by eastward subduction beneath North America. Instead, we explain exclusively Triassic zircon populations to have been derived from roughly coeval local sources, and mixed populations in younger (Jurassic) rocks to indicate arrival of evolved crust of uncertain origin. This alternative interpretation corroborates results from northern Quesnel terrane (Jones et al., 2022; Ootes et al., 2022), where the influence of Ancestral North American rocks on the magmatic evolution of Quesnel terrane, even to Early Cretaceous, is absent.

5.4. Chase Formation mylonite

The Chase Formation (Jones, 1959) is a white to grey weathered calcareous quartzite with a diagnostic pitted appearance, traced from Chase to east of Arrow Lake and south to the Kelowna area (Figs. 2 and 8; Okulitch, 1979; Glombick et al., 2006; Thompson et al., 2006; Lemieux et al., 2007). The unit was thought to be overlain by Slocan Group rocks, considered as lateral facies equivalent of the Nicola Group volcanic

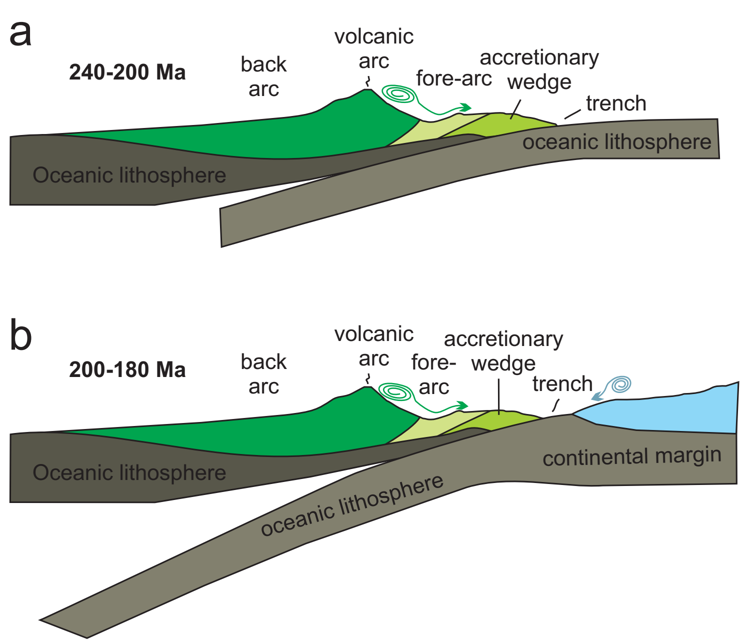

Fig. 8. Schematic diagram of westward subduction and an east-facing oceanic arc in the Triassic, with sedimentation in a forearc or trench; erosion and transport detrital zircon indicated by swirls and arrows. **a)** 240 to 200 Ma with unimodal zircon derived from arc. **b)** 200-180 Ma, the arrival of evolved crust of uncertain origin accounts for the appearance of older (pre-Triassic) zircon populations that are not typical of northern Ancestral North America.

rocks, and therefore it was regarded to link North America passive margin stratigraphy to Quesnel terrane (Unterschutz et al., 2002; Thompson et al., 2006; Lemieux et al., 2007).

Although there are different views on correlating these distinctive rocks across a wide area (cf. Lemieux et al., 2007 with Colpron and Nelson, 2009), the unit displays high-strain features. For rocks west and away from Arrow Lake, Thompson et al. (2006) referred to both primary bedding and structurally transposed compositional layering, and Glombick et al. (2006) described exposures at Kalamalka Lake and Kelowna airport as mylonites. We examined the Chase Formation at a new highway exposure along Highway 1 southwest of the town of Chase, and at a new resource roadcut southwest of Sugar Lake (Figs. 2 and 9a). No primary depositional features are preserved in these rocks, but the rocks display a prominent compositional layering (Fig. 9a), and petrographic examination reveals a lineation suggestive of dynamic recrystallization (Fig. 9b; see also Glombick et al., 2006). In short, we consider that the Chase Formation may represent a mylonitic shear zone.

A separate question is if the outlier phyllites (now Rossland Group) were deposited on the Chase Formation (Fig. 10a) or if the superposition is structural (Fig. 10b). Although we cannot negate stratigraphic interpretations (cf. Okulitch, 1979; Thompson et al., 2006), we favour a structural interpretation. Rossland Group rocks are topographically above the Chase Formation at Sugar Lake (sample Jr-1; also see figure 5a of Glombick et al., 2006) but no contacts have been observed in the field. We consider that this relationship represents a relatively flat lying shear zone that continues for the extent of the Chase Formation (>80 km) from the town of Chase in the northwest to Sugar Lake in the southeast and as far south as Kelowna (Fig. 2). Highly strained Chase Formation rocks occur both north and south of and at lower elevations than phyllitic rocks of the Rossland Group that constitute the hills east and west of Vernon and we consider that the Rossland Group is preserved in a nappe that overrides the Chase Formation (Fig. 10b). Glombick et al. (2006) present U-Pb zircon and titanite geochronology from Chase Formation mylonitic quartzite that indicates a long and complex structural and metamorphic history from Late Jurassic to Eocene. Parrish et al. (1988) included the Sugar Lake location as part of the Okanagan Valley shear zone (Eocene; Brown et al., 2017), but the Chase location is too far to the west to be part of this deformation zone (Fig. 2). It is possible that the deformation in each Chase Formation location: 1) developed before the Okanagan Valley shear zone; 2) is diachronous; or 3) the Okanagan Valley shear zone, or equivalent structure, needs to be extended to the area near the town of Chase.

A structural relationship between Quesnel terrane and nearby Ancestral North America is likely because northern Quesnel magmatic rocks lack evidence of contributions from continental basement (Jones et al., 2022; Ootes et al., 2022) and similar structural relationships between southern Quesnel rocks and Ancestral North America has been inferred by Acton et al. (2002). A potential test of the stratigraphic link between the

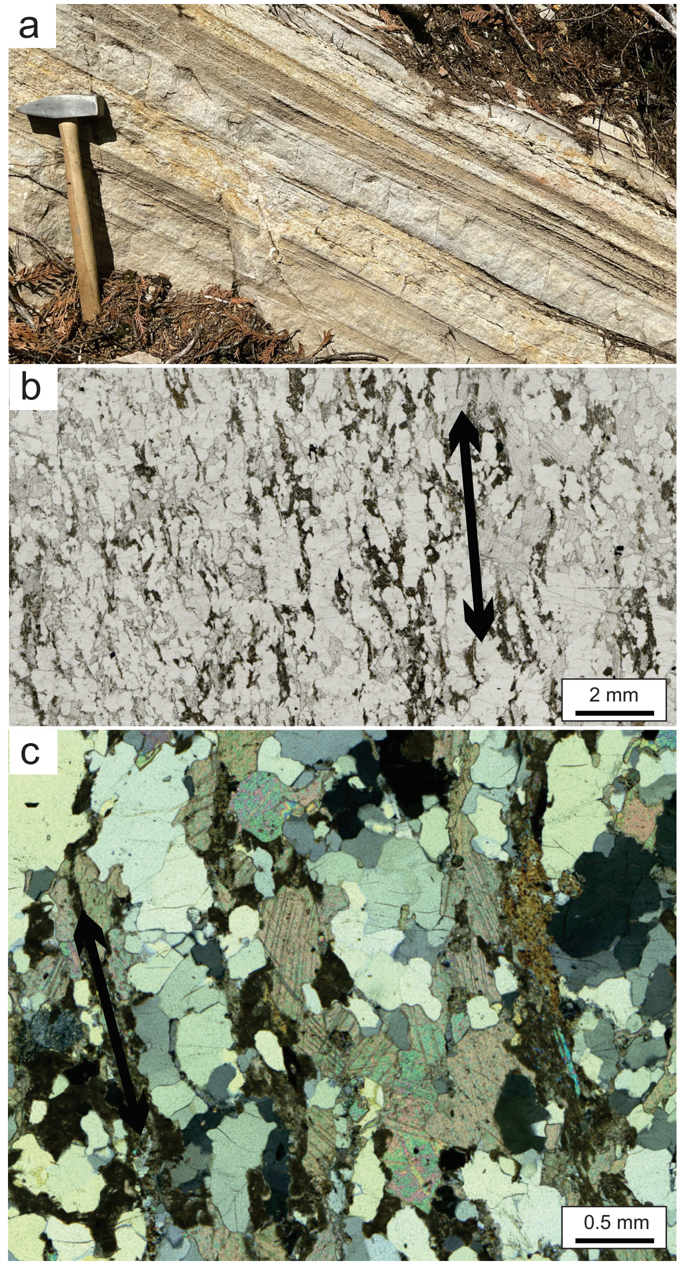

Fig. 9. a) Outcrop of the Chase Formation pitted quartzite southwest of Sugar Lake (Figure 2). No primary depositional features are preserved. **b)** Plane-polarized and **c)** Cross-polarized light photomicrographs of Chase Formation quartzite from south of the town of Chase. Recrystallized quartz ribbons define a lineation (arrow) supporting that this rock unit is a mylonite and that the layering in a) is compositional from transposition during ductile strain and not primary.

Chase Formation mylonite and the Rossland Group rocks could be through the detrital zircon record. If there was a stratigraphic relationship, there should be recycling of zircons from the Chase quartzites (North American detritus; Lemieux et al., 2007) into the younger Rossland Group rocks. However, except for minor amounts of ca. 430 Ma zircon, evidence that would indicate recycling of nearby material with North American affinity (particularly Archean and Paleoproterozoic

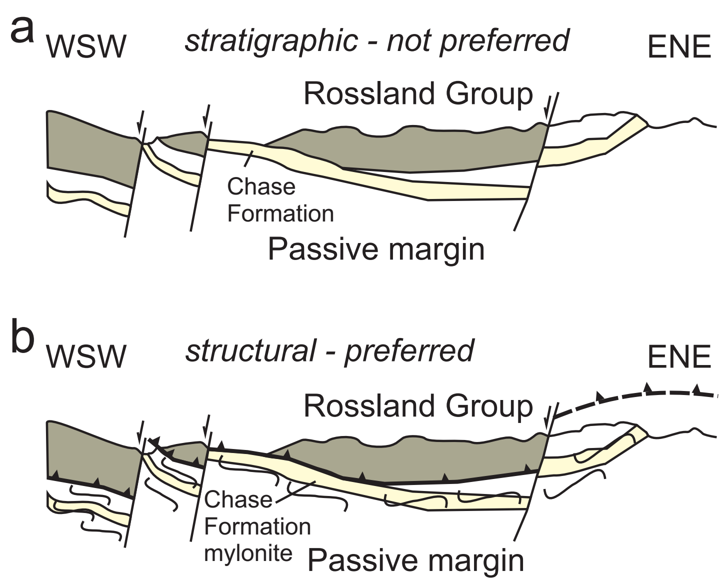

Fig. 10. Schematic cross-sections depicting two possible models for the relationship between the Rossland Group (this study) and underlying units that include the Chase Formation. **a)** The relationship is stratigraphic and later deformed. **b)** The relationship is structural and Rossland Group is preserved as a thrust nappe (teeth on hangingwall side of thrust line). This is the preferred interpretation because it accounts for the deformation of the Chase Formation mylonite, the deformation of the Rossland Group rocks close to the Chase Formation and the lack of recycled detrital zircon from the underlying stratigraphy into this part of the Rossland Group. Sugar Lake area (Figure 2) and simplified after Glombick et al. (2006, their Figure 3). The Okanagan Valley shear zone (Eocene; Parrish et al., 1988; Brown et al., 2017) is not depicted in this figure.

rocks; see Matthews et al., 2018) is absent in this study (Fig. 7), which would favour a structural imbrication model where the Rossland Group is the hangingwall of a shear zone (Fig. 10b). Given the zircon populations (Fig. 7f), the Vernon area may represent part of the Nicola arc as it evolved from initiation in the oceanic realm to arrival with North America (Fig. 8). Where it arrived adjacent to North America remains ambiguous, but given the lack of currently nearby North America detrital zircons in these rocks, the location was probably not at present latitudes.

6. Conclusion

New detrital zircon and field data presented herein lead to stratigraphic unit reassignments in the Vernon area. Some of the rocks in the area are likely part of the Rossland Group, expanding the unit's areal extent. The results also open the possibility of a speculative but testable model for the nature of the transition between Quesnel terrane and Ancestral North America as preserved in the Canadian Cordillera. Key interpretations and tests are as follows.

First, we interpret that rocks in this area now assigned to the Rossland Group lie structurally on rocks of possible North American affinity. A possible test of this interpretation is the comparison of detrital zircon U/Pb-Hf data between these rocks and the underlying rocks.

Second, we consider that this area of the Cordilleran orogen preserves a forearc or trench basin that evolved from the Late Triassic through Early Jurassic. This is counter to established models for the evolution of the Quesnel terrane but can be tested by tracer isotope studies of Quesnel terrane rocks and those of Ancestral North American affinity.

Third, the Chase Formation is laterally extensive. Detrital zircon U/Pb-Hf data from the Chase Formation rocks may help influence regional correlations and provide a provenance record of this unit.

Finally, the Chase Formation represents a deformation zone that: 1) developed before the Okanagan Valley shear zone; 2) is diachronous; or 3) the Okanagan Valley shear zone, or equivalent structure, needs to be extended to the area near the town of Chase. If stratigraphic correlations can be proved through U/Pb-Hf studies, a directed structural and a strategic geochronological approach is required to resolve the regional tectonic relationships.

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