Geology of the Nicola Group in the Bridge Lake-Quesnel River area, south-central British Columbia

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Abstract

The Nicola Group (Triassic) is the principal volcano-sedimentary component of the Quesnel arc terrane. In preliminary investigations to establish a regional stratigraphic framework for the Nicola Group, it was separated into four assemblages, which are refined here based on new work. Assemblage one is represented mainly by the Spanish Mountain unit (new informal name), exposed along the eastern margin of the Nicola belt and consisting of Middle Triassic siltstone, chert and argillite, with less common volcaniclastic sandstone and local pillowed basalt with N-MORB and E-MORB geochemical characteristics. Undated, but possibly correlative rocks in the south-central part of the Nicola belt include volcaniclastic sandstone, chert, pyroxene-phyric basalt and basalt breccia of the Wavey Lake unit (new informal name), which is locally overlain by early Carnian siltstone of the Meridian Lake unit (new informal name). Assemblage two (Carnian and early Norian), the most widespread subunit of the Nicola Group, contains volcanic sandstone and conglomerate, locally intercalated with pyroxene-phyric basalt and basalt breccia. Assemblage three is a relatively homogeneous succession of pyroxene-phyric basalt flows and related breccias and is considered Norian based on its stratigraphic position between assemblages two and four. Assemblage four (late Norian and Rhaetian) may be separated from older Nicola rocks by an unconformity or disconformity. It consists of red and maroon polymictic conglomerate with abundant hypabyssal and plutonic rock fragments, as well as red feldspathic sandstone and distinctive volcanic rocks that include analcime basalt and coarse, crowded plagioclase-phyric andesite.

The Nicola Group is flanked to the east by Middle and Upper Triassic slate, siltstone and quartz sandstone of the Slocan Group, part of a siliciclastic basin that formed east of, and coeval with, the Nicola arc. Two small fault-bounded inliers of Permian limestone and siltstone in the southern part of the Nicola belt are tentatively correlated with the Harper Ranch Group, which is therefore inferred to underlie the Nicola Group. Lower to Middle Jurassic polymictic conglomerate and sandstone of the Dragon Mountain succession overlie the Nicola Group and are the youngest stratified rocks in this part of Quesnel terrane. Upper Triassic to Lower Jurassic calcalkaline and alkaline plutonic rocks that cut the Nicola Group correlate with plutonic suites recognized regionally in Quesnel terrane, and include a latest Triassic monzodiorite suite that is coeval with assemblage four and hosts significant porphyry Cu-Au deposits.

Keywords: Nicola Group, Slocan Group, Quesnel terrane, Middle Triassic, Upper Triassic, volcanic arc, back-arc basin, basalt, basalt breccia, volcanic sandstone, Spanish Mountain unit, Wavey Lake unit, Meridian Lake unit

1. Introduction

The Nicola Group (Triassic) is the principal volcano-sedimentary component of the Mesozoic arc complex that is the defining feature of Quesnel terrane. Calcalkaline and alkaline intrusions in this arc complex host numerous porphyry Cu ±Au-Mo-Ag deposits, making it an important melallogenic belt and exploration target. In 2015, the British Columbia Geological Survey initiated a multi-year field-based program to establish a regional stratigraphic framework for the Nicola Group. This framework, combined with space-time-composition patterns of associated plutons, will contribute to a better understanding of the architecture of the arc, and improve the geologic framework within which to interpret the settings and controls of mineral occurrences.

Initial investigations in 2015 covered the entire width of Quesnel terrane in the Bridge Lake-Quesnel River area (Fig. 1), and established a preliminary stratigraphic framework for the Triassic rocks, comprising four assemblages in the

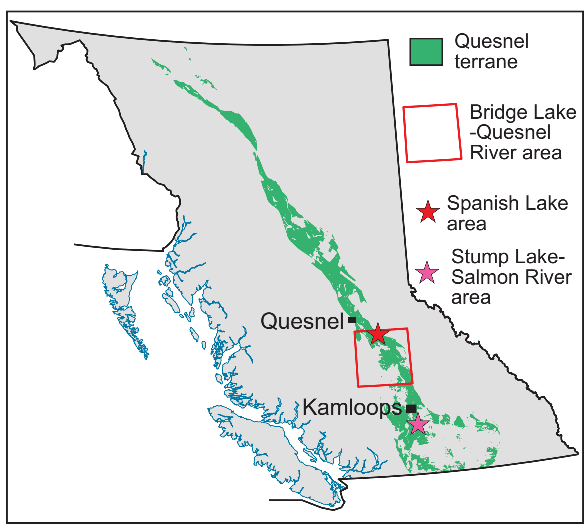

Fig. 1. Distribution of Quesnel terrane rocks in British Columbia and locations of areas studied from 2015 to 2018.

Nicola Group, and a separate assemblage to the east assigned to the Slocan Group (Schiarizza, 2016). In 2016, the eastern part of the Nicola Group and the adjacent Slocan Group were studied in the Stump Lake-Salmon River area, south of Kamloops (Schiarizza, 2017). Fieldwork in 2017 also focused on the eastern part of the Nicola Group and the adjacent Slocan Group, but in the Spanish Lake area (Fig. 1, Schiarizza, 2018). The 2018 field program included additional work in the Spanish Lake area, as well as studies at several other localities in the Bridge Lake-Quesnel River area, resulting in refinements and modifications to the stratigraphic scheme presented in Schiarizza (2016). This modified stratigraphic framework for the Nicola Group is presented here, along with descriptions of associated units, providing a summary of all Quesnel terrane map units in the Bridge Lake-Quesnel River area.

2. Overview of Quesnel terrane in southern British Columbia

Quesnel terrane (Quesnellia) was defined in the early 1980s, when the concept of tectonostratigraphic terranes was first applied to tectonic analysis of the North American Cordillera (Coney et al., 1980; Monger et al., 1982; Jones et al., 1983). It consists of upper Paleozoic and lower Mesozoic volcanic, sedimentary and plutonic rocks exposed west of pericratonic rocks and Slide Mountain terrane, and east of Cache Creek terrane (Monger et al., 1991; Wheeler et al., 1991). As with many other large terranes defined in the early days of terrane analysis, Quesnellia is not a simple or discreet tectonic entity. Instead it includes a number of different tectonic assemblages, with a variety of internal and external contact relationships.

Quesnel terrane contains mainly Triassic rocks, which record two tectonostratigraphic settings, a volcanic arc in the west, and a siliciclastic basin to the east. The volcanic arc is represented mainly by the Nicola Group (Middle and Upper Triassic), which forms a single linear belt that extends from the international boundary northward to, and beyond, Quesnel (Fig. 2). This belt also includes Late Triassic to Early Jurassic calcalkaline and alkaline arc intrusions, and Lower to Middle Jurassic arc-derived siliciclastic sedimentary rocks of the Ashcroft Formation and Dragon Mountain succession. Basement to the Nicola Group is not well exposed, but is locally represented by Permian sedimentary rocks of the Harper Ranch Group, one of the Paleozoic components of Quesnel terrane (Schiarizza et al., 2002; this study).

East of the Nicola arc, the siliciclastic basin is preserved as scattered Triassic remnants in an arcuate belt extending from Kootenay Lake northwest to beyond Quesnel Lake (Fig. 2). It is represented mainly by the Slocan Group (Little, 1960; Thompson et al., 2006), but also includes the Brooklyn Formation (Fyles, 1990), the Wallace Formation (Massey, 2010) and local occurrences of Triassic siliciclastic rocks near the eastern margin of the Nicola belt that were included in the Nicola Group by previous workers (Read and Okulitch, 1977; Ray and Dawson, 1994), but show no clear ties to the Nicola arc complex. Siltstone and slate predominate, but quartz sandstone, limestone and conglomerate are also present, as are local occurrences of calcalkaline arc volcanic rocks (Dostal et al., 2001; Massey, 2010). These Triassic rocks rest stratigraphically above a variety of units, including pericratonic rocks, Slide Mountain terrane, and Paleozoic units of Quesnel terrane, commonly across an angular unconformity (Read and Okulitch, 1977; Fyles, 1990; Thompson et al., 2006). They are overlain, mainly in the Nelson area (Fig. 2), by Lower Jurassic arc volcanic rocks of the Rossland Group (Höy and Dunne, 1997).

Paleozoic rocks assigned to Quesnel terrane include a large number of units that Monger et al. (1991) grouped into the oceanic Okanagan subterrane and the arc-like Harper Ranch subterrane (Fig. 2). The Okanagan subterrane, predominantly chert and basalt, might be part of Slide Mountain terrane (Monger et al., 1991). It crops out mainly as an east-west belt just north of the international boundary, where it is locally overlain by Triassic rocks of the Slocan basin across an angular unconformity (Read and Okulitch, 1977; Fyles, 1990).

The Harper Ranch subterrane is represented mainly by its namesake, the Harper Ranch Group, which in its type area northeast of Kamloops includes upper Paleozoic arc-derived volcaniclastic rocks and Carboniferous and Permian limestones (Smith, 1979; Beatty et al., 2006). Correlative rocks to the southeast include the Mount Roberts Formation (Little, 1982) and the Attwood Group (Fyles, 1990) which are exposed southwest of Nelson. These upper Paleozoic units are overlain by Triassic rocks of the Slocan basin, but Triassic rocks are locally missing, and parts of the Mount Roberts Formation and Harper Ranch Group are directly overlain by Lower Jurassic volcanic rocks of the Rossland Group (Fig. 2; Little, 1982; Acton et al., 2002; Beatty et al., 2006). Small inliers of Permian rocks in the Nicola Group in the southern part of the Bridge Lake-Quesnel River area suggest that parts of the Harper Ranch Group also underlie the Nicola arc (Schiarizza et al., 2002). A narrow fault-bounded belt of metamorphic rocks along the southwest margin of the Nicola Group, southwest of Princeton, may also be part of the Harper Ranch subterrane (Fig. 2), but its relationship to the Harper Ranch Group is unknown. These rocks comprise the Eastgate-Whipsaw metamorphic belt of Massey and Oliver (2010), and include arc-derived metasedimentary rocks intercalated with Lower Permian bimodal arc volcanic rocks (Oliver, 2011).

3. Setting of the Bridge Lake-Quesnel River area

The Bridge Lake-Quesnel River area is mainly in the Fraser Plateau, Quesnel Highland and Shuswap Highland physiographic provinces (Holland, 1976), and covers parts of the traditional territories of the Secwepemc, Esk'etemc, Tsilhqot'in, and Lhtako Dené First Nations. In this area, the Nicola Group forms a northwest-trending belt that is 30 to 70 km wide (Fig. 3). This belt also includes Upper Triassic to Lower Jurassic calcalkaline and alkaline arc intrusions, Lower to Middle Jurassic arc-derived siliciclastic sedimentary rocks of the Dragon Mountain succession, and in the south, two

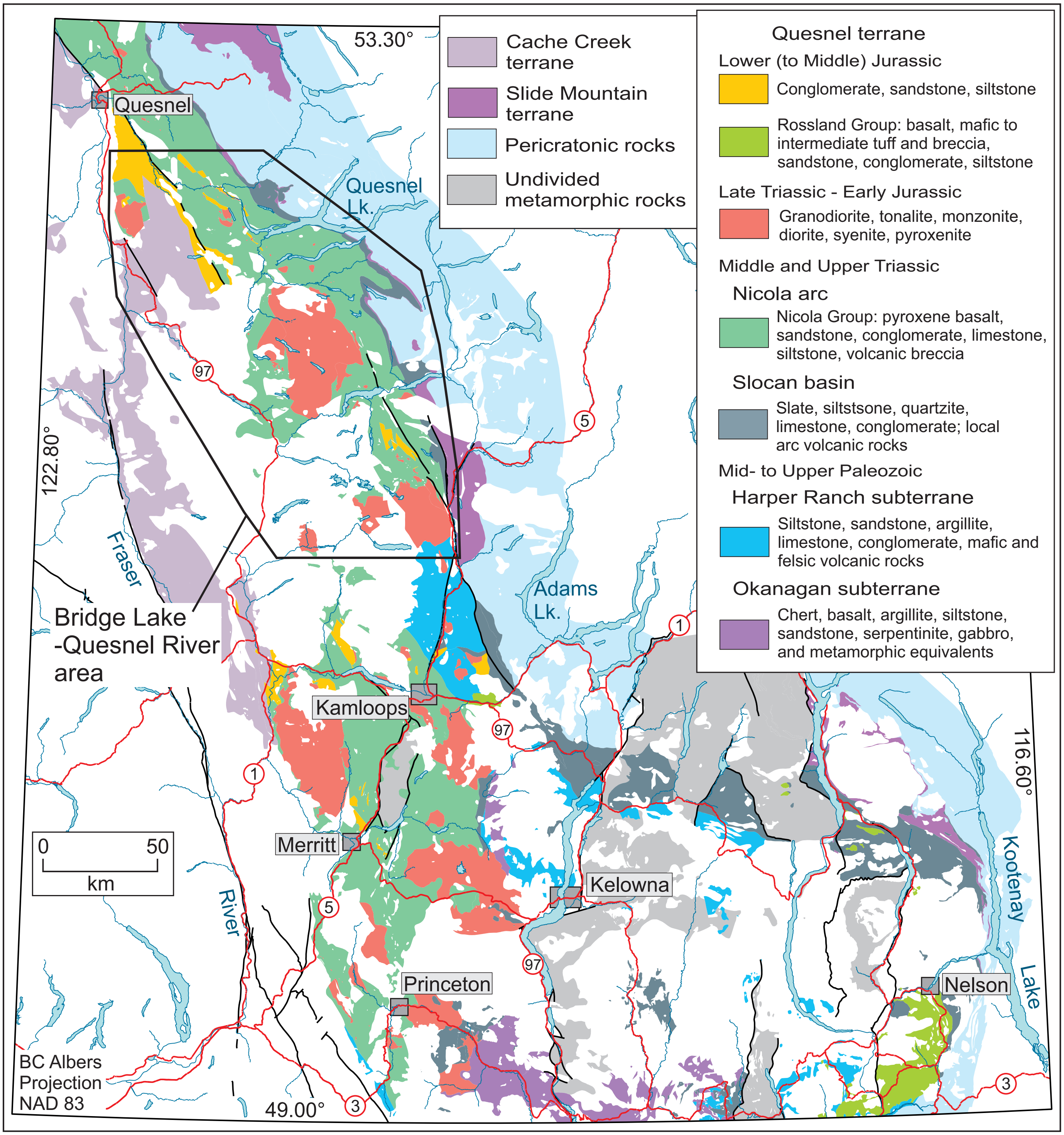

Fig. 2. Geology of south-central British Columbia highlighting the different components of Quesnel terrane. Upper Triassic-Lower Jurassic intrusions shown only where they cut the Nicola Group. Uncoloured areas mainly Middle Jurassic to Recent intrusive, volcanic and sedimentary rocks, but may include older rocks of uncertain correlation.

small fault-bounded inliers of Permian limestone and siltstone, tentatively correlated with the Harper Ranch Group.

The Nicola belt is flanked to the east by Triassic sedimentary rocks, mainly black phyllite, slate, and quartz sandstone, of the Slocan Group. Farther east are rocks of Slide Mountain terrane, including basalt, chert and gabbro of the Fennell Formation south of the Raft batholith, and a narrow belt of mafic schist, referred to as the Crooked amphibolite, to the north. East of, and structurally beneath Slide Mountain terrane are pericratonic rocks of Kootenay terrane, including Proterozoic and Paleozoic quartzites and pelitic schists (Snowshoe Group) locally cut by Devono-Mississippian granitic rocks (Quesnel Lake gneiss).

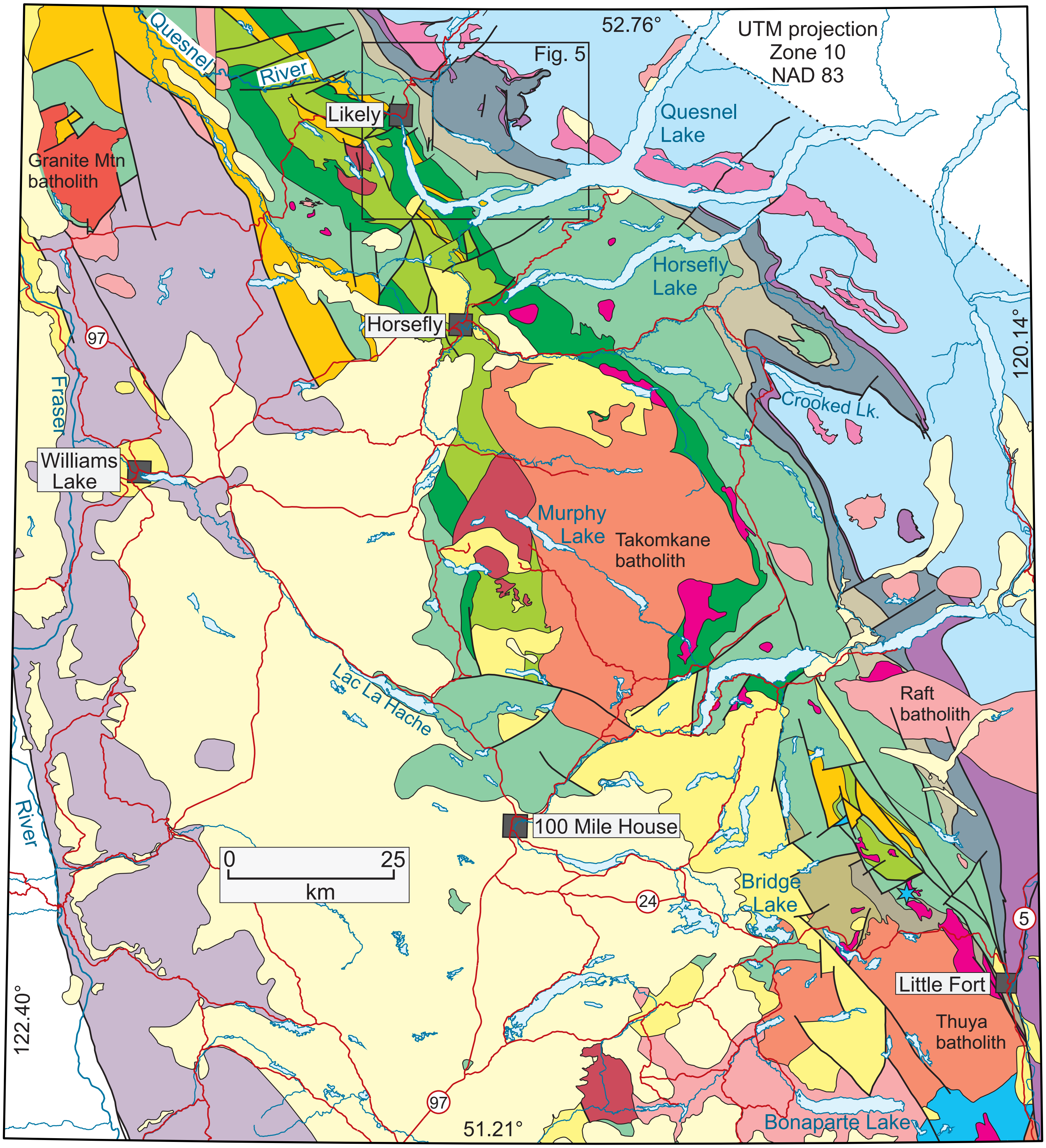

Fig. 3a. Geology of the Bridge Lake-Quesnel River area showing Nicola Group subdivisions from this study.

Cache Creek terrane, represented by late Paleozoic to early Mesozoic basalt, chert, limestone, siltstone and ultramafic rocks of the Cache Creek complex, is west of the Nicola belt and is generally interpreted as an accretionary complex genetically related to the subduction that generated the Nicola arc. Younger rocks found in the area include Middle Jurassic and Lower Cretaceous granitic intrusions, Eocene volcanic and sedimentary rocks, and flat-lying Neogene and Quaternary basalt.

The structural history of the area is protracted and complex. Early structures include an east-directed Permo-Triassic (McMullin et al., 1990) or Early Jurassic (Rees, 1987) thrust

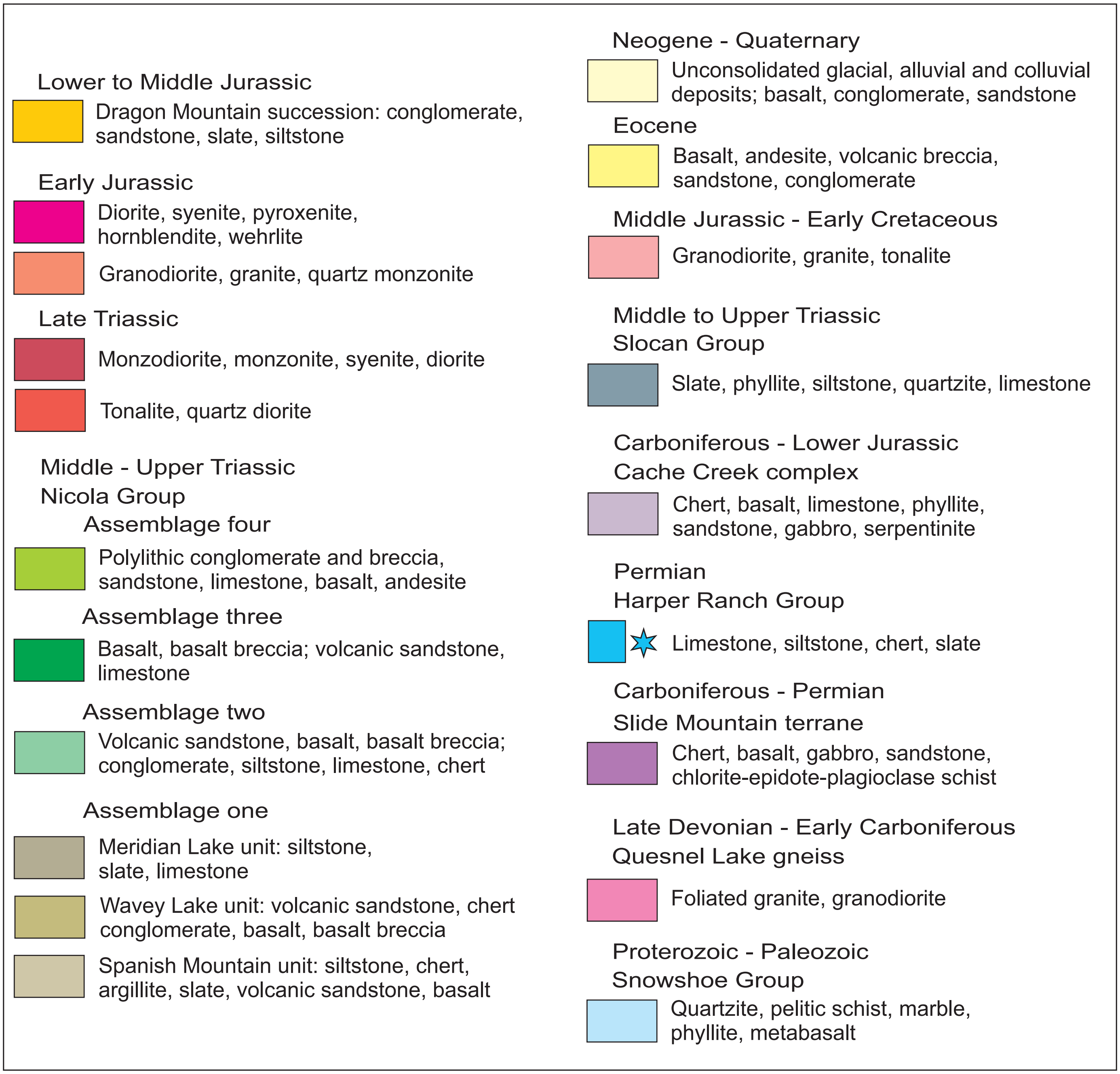

Fig. 3b. Legend for Figure 3a.

fault that separates Slide Mountain terrane from underlying pericratonic rocks, and an east-directed Early Jurassic thrust fault (Spanish thrust) that juxtaposes the Nicola Group above the Slocan Group (Struik, 1988). Subsequent contractional deformation and metamorphism that began in the early Middle Jurassic is reflected in polyphase mesoscopic structures in Kootenay terrane, Slide Mountain terrane, the Slocan Group, and eastern parts of the Nicola Group, as well as map-scale structures that fold these units and their mutual contacts (Campbell, 1971; Rees, 1987; Bloodgood, 1990; Fillipone and Ross, 1990). Equivalent structures are not well documented in the central part of the Nicola belt, but it is suspected that a regional syncline (Panteleyev et al., 1996), reflected in the distribution of the younger units of the Nicola Group (Fig. 3), formed at the same time. The youngest, and commonly most prominent structures in the region include sets of Eocene dextral strike-slip and extensional faults (Struik, 1993; Panteleyev et al., 1996; Schiarizza and Israel, 2001).

4. The Nicola Group

Schiarizza (2016) subdivided the Nicola Group in the Bridge Lake-Quesnel River area into four regional assemblages, and described how these assemblages related to Nicola subdivisions used in previous studies (Struik, 1983, 1988; Rees, 1987;

Bloodgood, 1990; Panteleyev et al., 1996; Schiarizza et al., 2013). These same four assemblages, with some modifications, are retained here (Fig. 4).

4.1. Assemblage one

Schiarizza (2016) defined assemblage one as a narrow belt of Middle Triassic rocks, predominantly siltstone and argillite, that forms the northeastern margin of the Nicola belt from Crooked Lake northward to beyond the Quesnel River (Fig. 3). Here, the definition is expanded to include these rocks and correlatives to the south (Spanish Mountain unit), and rocks that form the base of the Nicola Group east of Bridge Lake (Wavey Lake unit and Meridian Lake unit).

4.1.1. Spanish Mountain unit (new informal name)

The Spanish Mountain unit includes rocks forming the northeast margin of the Nicola belt between Crooked Lake and the north boundary of the map area, as well as a narrow belt of similar rocks that forms the east margin of the Nicola belt farther south, on both sides of the Raft batholith (Figs. 3, 5). The northern belt was assigned to assemblage one by Schiarizza (2016), but the southern belt comprises rocks that were previously included in the Slocan Group.

The Spanish Mountain unit consists mainly of dark to medium grey siltstone, argillite, chert, and slate, but also includes feldspathic sandstone, basalt, and limestone. Chert, argillite, siltstone, and local quartzose siltstone commonly

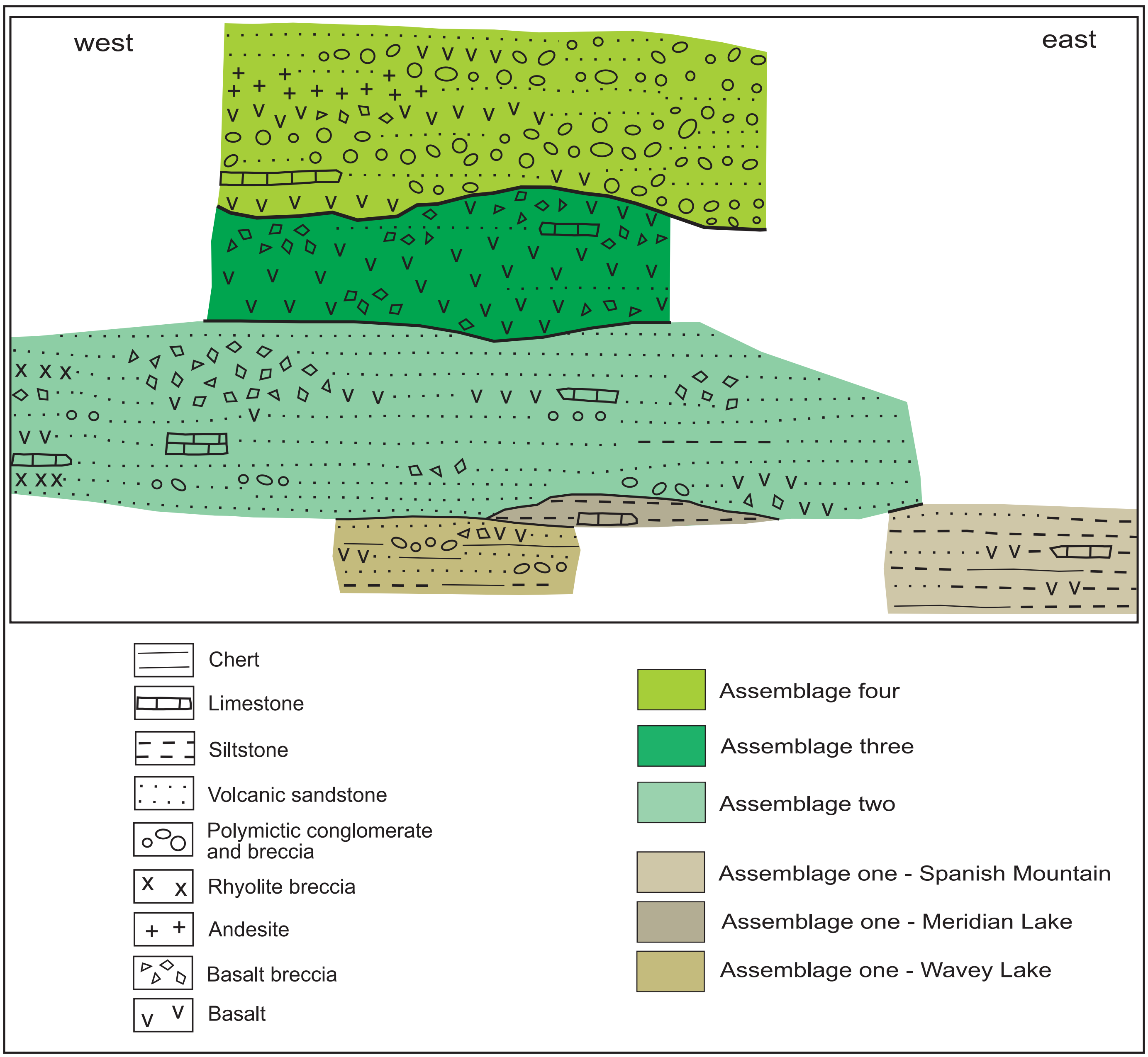

Fig. 4. Schematic summary of Nicola Group subdivisions in the Bridge Lake-Quesnel River area.

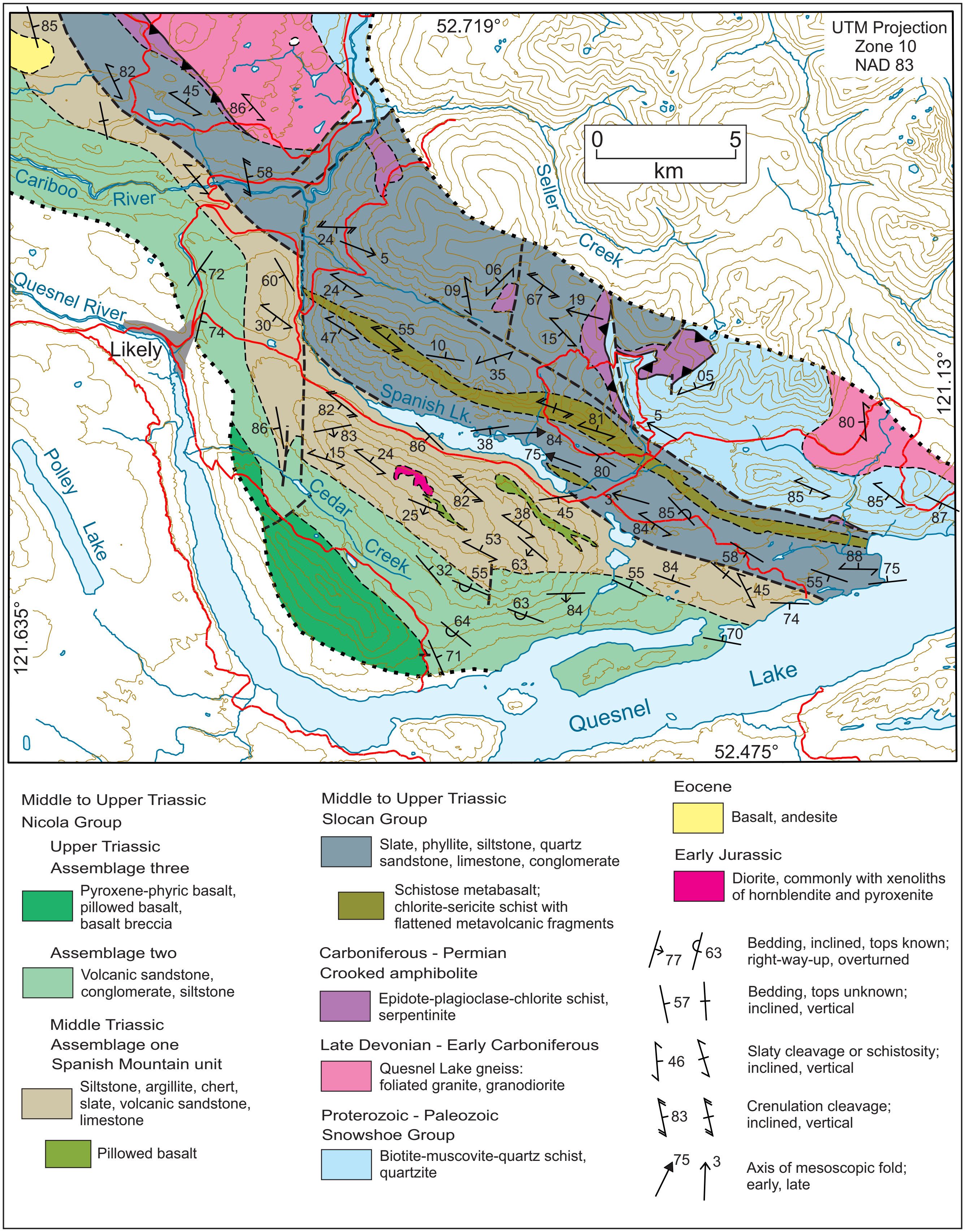

Fig. 5. Geology near Spanish Lake, in the northeast part of the Bridge Lake-Quesnel River study area. Geology based on fieldwork in 2015, 2017 and 2018, with information from Rees (1987) and Bloodgood (1990).

form thin (1-4 cm) lenticular beds separated by dark greenish -grey chloritic partings and/or thin interbeds of dark grey slate (Fig. 6). Siltstone and slaty siltstone also occur in sections of thin (1-10 cm) planar beds, and dark grey slate with lighter grey siltstone laminae occurs locally. Medium to dark grey limestone is rare, and forms layers or lenses, <2 m thick, intercalated with siltstone.

Green to grey, medium- to coarse-grained sandstone, very similar to the sandstone of assemblage two, occurs locally within the Spanish Mountain unit, as thin- to thick-bedded intervals intercalated with siltstone. Feldspar is the predominant constituent, and is accompanied by feldspathic lithic grains and altered mafic lithic and mineral grains. Volcanic quartz is a conspicuous component of some sandstone beds on the low ridge east of Likely (Fig. 5).

In the Spanish Lake area, two separate lenses of pillowed to massive basalt are mapped in the Spanish Mountain unit (Fig. 5). These lenses are lithologically distinct from the pyroxene-phyric arc basalts found in other parts of the Nicola Group, and display geochemical characteristics of normal mid-ocean ridge basalt (eastern lens, Logan and Bath, 2006) and enriched mid-ocean ridge basalt (western lens, this study, geochemical analysis in progress).

The Spanish Mountain unit is early Middle Triassic, at least in part, based on conodonts extracted from two different limestone lenses in the Spanish Lake area. One collection, from the northeast side of the assemblage on the north shore of Quesnel Lake is early-middle Anisian (Struik, 1988), and the other, from the central part of the unit 2 km south of the east end of Spanish Lake, is early Anisian (Panteleyev et al., 1996). Schiarizza (2016, 2018) suggested that a collection of late Ladinian to Carnian (Middle to Late Triassic) conodonts from the north shore of Quesnel Lake, about 3 km west-southwest of the Anisian locality (Struik, 1988) might also place constraints on the age of the Spanish Lake unit. However, fieldwork in 2018 shows that this collection is from Nicola assemblage two, several hundred metres south of the unexposed contact with the Spanish Mountain unit.

4.1.2. Wavey Lake unit (new informal name)

The Wavey Lake unit is an undated succession exposed north of the Thuya batholith, east and north of Bridge Lake (Fig. 3). It was recognized as a unique part of the Nicola Group by Schiarizza et al. (2002) because of its significant chert content, and because its stratigraphic position beneath Carnian rocks of the Meridian Lake unit indicated that the volcanic rocks in the Wavey Lake unit are older than Nicola volcanic units to the east and northeast. It is included in assemblage one because of this relatively low stratigraphic position, and because assemblage one (Spanish Mountain unit) is the only other section in the area with significant amounts of chert.

The Wavey Lake unit contains abundant grey to green chert, which forms thin lenticular beds intercalated with slate, argillite and siltstone (Fig. 7). Chert-rich sections, up to 10 m thick, are intercalated with massive and thin- to medium-bedded, fine- to coarse-grained volcanic sandstone, which locally forms channels that cut into the chert. The Wavey Lake unit also includes pyroxene-phyric basalt flows, pyroxene porphyry breccias (Fig. 8), and polymictic pebble to cobble conglomerate units up to several 10s of m thick. The conglomerate contains subangular to rounded clasts of mainly laminated siltstone, cherty argillite, and argillite, but also includes fragments of chert, limestone, pyroxene-plagioclase-phyric basalt, and microdiorite.

The Wavey Lake unit is overlain to the northeast by volcanic sandstone of assemblage two or by siltstone of the Meridian Lake unit (Figs. 3 and 4). The base of the unit is not exposed because it is bounded on the southwest by a system of normal faults that juxtaposed it with Eocene volcanic rocks. Although undated, it is considered Middle Triassic or very early Upper Triassic, based on its stratigraphic position beneath the Meridian Lake unit.

Fig. 6. Bedded chert, Spanish Mountain unit, assemblage one of the Nicola Group, south of Spanish Lake.

Fig. 7. Bedded chert, Wavey Lake unit, assemblage one of the Nicola Group, east of Bridge Lake.

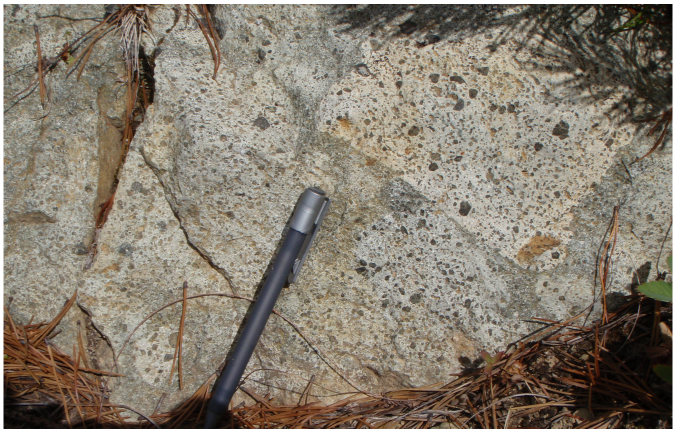

Fig. 8. Pyroxene porphyry breccia, Wavey Lake unit, assemblage one of the Nicola Group, northeast of Bridge Lake.

4.1.3. Meridian Lake unit (new informal name)

The Meridian Lake unit comprises siltstone that crops out on the north and northeast margins of the Thuya batholith (Fig. 3), where it is underlain by the Wavey Lake unit, and overlain by rocks of assemblage two. Schiarizza (2016) provisionally included it in the lower part of assemblage two, but noted that it is lithologically similar to the Slocan Group. Here, it is included in assemblage one because of its fine-grained nature and stratigraphic position beneath coarser grained volcanic sandstones and conglomerates that are typical of assemblage two.

The Meridian Lake unit consists mainly of rusty weathered, dark to medium grey, laminated to thinly bedded siltstone and slaty siltstone, locally with laminae and thin beds of light grey quartzose siltstone (Fig. 9), or thin interbeds of dark grey argillite and cherty argillite. Dark grey micritic limestone and limy argillite form local thin to thick beds intercalated with siltstone and argillite. One of these limestone beds yielded early Late Triassic (Carnian) conodonts, and another contains Middle or Late Triassic (late Ladinian to early Carnian) conodonts (Schiarizza et al., 2013).

Fig. 9. Thinly bedded light grey (quartzose) and dark grey siltstone, Meridian Lake unit, assemblage one of the Nicola Group, northwest of Little Fort.

The Meridian Lake unit is included in the Nicola Group (assemblage one) because it is both underlain and overlain by Nicola Group rocks (Wavey Lake unit and assemblage two). However, as noted by Schiarizza (2016), it is markedly similar to the Slocan Group in lithology and age. It may represent a tongue of Slocan Group-type rocks and an interfingering relationship between the Nicola Group and the Slocan Group.

4.2. Assemblage two

Assemblage two, predominantly volcanic sandstone and pyroxene-phyryic basalt and breccia, is the most widespread component of the Nicola Group in the study area (Fig. 3). The definition of the assemblage used here follows that originally proposed by Schiarizza (1016), but excludes the Wavey Lake and Meridian Lake units (here included in assemblage one), and a small area 20 km northeast of Bridge Lake (here inferred to be an outlier of assemblage four).

The predominant and characteristic lithology of assemblage two is grey to green, fine- to coarse-grained, commonly gritty, volcanogenic sandstone, consisting mainly of feldspar, pyroxene and volcanic lithic grains (Fig. 10). The sandstone is well bedded in places, but elsewhere forms massive units up to several 10s of m thick. In well-bedded sections, thin to thick sandstone beds commonly alternate with thin beds of green to grey siltstone or dark grey argillite, and locally display graded bedding, flame structures, and rip-up clasts. Pebble conglomerate and pebbly sandstone occur locally, as medium to very thick beds intercalated with sandstone. The pebbles are predominantly pyroxene-feldpar-phyric basalt, but some conglomerate units also contain limestone, siltstone, and sandstone clasts.

Basalt and basalt breccia are a common component of assemblage two, forming units up to several 100 m thick that occur at different stratigraphic levels and widespread geographic locations (Schiarizza, 2016). These volcanic units include pillowed and massive pyroxene-plagioclase-phyric basalt, but volcanic breccia (Fig. 11), locally intercalated with lenses and

Fig. 10. Parallel-stratified and massive gritty volcanic sandstone, assemblage two of the Nicola Group, east of the Takomkane batholith.

Fig. 11. Volcanic breccia with angular to subrounded pyroxene porphyry clasts in a sandy matrix with feldspar, pyroxene, and mafic lithic grains, assemblage two of the Nicola Group, southwest of Crooked Lake.

layers of dark green pyroxene-rich sandstone, is predominant. Most breccia units comprise angular to subangular fragments of pyroxene±plagioclase-phyric basalt within a gritty to sandy matrix of feldspar, pyroxene, and mafic lithic grains.

Felsic volcanic rocks are very rare in assemblage two, but rhyolite-clast volcanic breccias are in the Granite Mountain area (Schiarizza, 2014), and breccias with felsic volcanic clasts (Fig. 12) were also identified in 2018, in a small inlier 13 km south-southwest of 100 Mile House (Fig. 3). A third occurrence of felsic rocks is 23 km northwest of Little Fort, where massive and fragmental feldspar-phyric dacite forms a set of isolated outcrops in an area with mainly basalt and basalt breccia (Schiarizza and Israel, 2001; unit uTrNbf of Schiarizza et al., 2013).

Limestone is a very minor component of assemblage two, but thin intervals of dark grey limestone and silty limestone, up to a few m thick, occur locally. A thicker limestone unit forms an isolated ridge 10 km southeast of Lac La Hache (Schiarizza and Bligh, 2008), and a poorly exposed, but apparently substantial limestone interval occurs west of Antoine Lake, 14 km northwest of Horsefly (Logan et al., 2007a).

Fig. 12. Breccia with felsic volcanic fragments, assemblage two of the Nicola Group, 13 km south-southwest of 100 Mile House.

Conodonts and macrofossils from a few scattered localities in assemblage two (summarized by Schiarizza, 2016) indicate that it is Late Triassic, early Carnian to early Norian.

4.3. Assemblage three

Schiarizza (2016) described assemblage three as a succession of mafic volcanic flows and breccias that occur above assemblage two. As originally defined, the upper part of the unit included analcime basalt (Horsefly-Likely area), and hornblende-bearing basalt (north of the Quesnel River). However, subsequent work has shown that these basalts are intercalated with sedimentary rocks of assemblage four, within which they are now placed. As thus redefined, assemblage three is a relatively homogeneous succession of pyroxene-phyric basalt flows and related breccias. It lies between assemblage two and assemblage four, and crops out as two separate belts that define the limbs of a regional syncline (Fig. 3).

Assemblage three contains mainly dark green, locally grey or maroon, brownish-weathered, massive and pillowed basalts, typically with abundant pyroxene phenocrysts that are commonly up to 1 cm (Fig. 13). Plagioclase crystals, smaller and less abundant than pyroxene, are locally part of the phenocryst assemblage; olivine, replaced by iddingsite and other secondary minerals, is also local. Typically the groundmass is defined by an alteration assemblage of calcite, epidote and chlorite, but it may retain relict plagioclase laths and/or small clinopyroxene grains. Amygdules, filled with various combinations of calcite, epidote, chlorite and quartz, are common.

Breccia, consisting mainly or entirely of pyroxene-phyric basalt fragments, is a common, and locally predominant component of assemblage three. Some are flow breccias, but

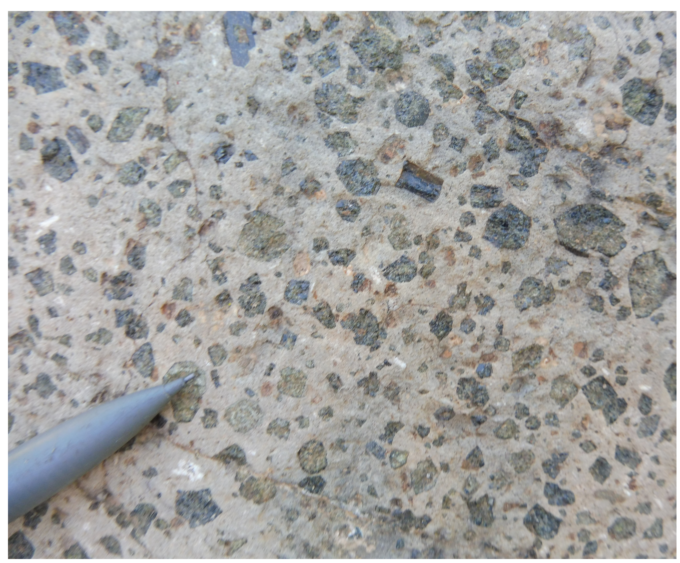

Fig. 13. Basalt with abundant coarse pyroxene phenocrysts, assemblage three of the Nicola Group, northeast side of Quesnel Lake south of Likely.

most are interpreted as locally derived epiclastic deposits. These form massive to weakly stratified units, up to several 10s of m thick, with poorly sorted basalt fragments supported by a sandy to gritty matrix with predominantly plagioclase, pyroxene and mafic lithic grains. These breccia units may include thin to thick beds of feldspar-pyroxene sandstone and gritty sandstone. Locally they are intercalated with narrow units of limestone, calcareous mudstone, and siltstone (Schiarizza, 2016).

Assemblage three is not well dated, but is inferred to be Norian, based on its stratigraphic position between assemblage two (Carnian and early Norian), and assemblage four (latest Triassic).

4.4. Assemblage four

Assemblage four is a lithologically distinct succession of conglomerates, sandstones and volcanic rocks forming the uppermost part of the Nicola Group, and possibly separated from older parts of the group by an unconformity or disconformity. Schiarizza (2016) noted that it was characterized by polymictic conglomerates containing abundant hypabyssal and plutonic clasts, a common red colour, and a volcanic suite that included a distinctive coarse, crowded plagioclase-phyric andesite. Here, the assemblage is expanded to also include analcime basalt and hornblende-bearing basalt (included in assemblage three by Schiarizza, 2016), making the volcanic component even more distinctive. As currently defined, assemblage four is exposed mainly as a single belt, in the core of the regional syncline, that extends from the north boundary of the study area to the west margin of the Takomkane batholith. As now shown in Figure 3, this belt does not extend as far south as portrayed by Schiarizza (2016) because rocks on the south flank of Mount Timothy are now known to be Eocene. A small outlier of assemblage four occurs 20 km northeast of Bridge Lake (Fig. 3), and consists of polymictic conglomerates and sandstones previously included in assemblage two (Schiarizza, 2016).

The predominant and most characteristic sedimentary rocks in assemblage four are polymictic conglomerates bearing a diverse clast population not seen in older parts of the Nicola Group (Fig. 14). They are commonly green or greenish-grey, but red to purple conglomerates occur throughout the section and are predominant at higher stratigraphic levels. Common clasts include: fine-grained, equigranular to weakly porphyritic feldspathic hypabyssal rocks; fine- to coarse-grained plutonic rocks, including gabbro, diorite, monzodiorite, monzonite, hornblendite, and pyroxenite; and mafic volcanic rocks containing variable proportions of feldspar, pyroxene and hornblende phenocrysts. Clasts are typically angular to subrounded, poorly sorted (from a few mm to 20 cm), and supported in a sandy feldspar-rich matrix, that may also include substantial hornblende and/or pyroxene grains. The conglomerates are commonly massive, but locally display weak stratification that may be accentuated by intercalations of sandstone and pebbly sandstone.

Medium- to coarse-grained, locally gritty, feldspathic sandstone is a common component of assemblage four, and is locally predominant in the upper part of the assemblage west of the Takomkane batholith (Schiarizza and Bligh, 2008; Schiarizza et al., 2009). The sandstones are mostly green to grey-green, but may be red or mottled red and green. They consist largely of feldspar (both plagioclase and pinkish grains that are K-spar and/or hematite-altered plagioclase), along with variably-altered mafic grains (hornblende and/or pyroxene) and fine-grained, chlorite-epidote-calcite-altered matrix. Thin to medium beds are locally well defined by distinct units of contrasting grain size, ranging from coarse, gritty sandstone to siltstone, but in some areas the sandstone is massive, or displays only vague laminations or indistinct platy to flaggy partings.

Fig. 14. Polymictic conglomerate with volcanic and plutonic clasts, assemblage four of the Nicola Group, northwest of Murphy Lake.

Grey limestone, locally at least several 10s of m thick, is intercalated with sandstone and conglomerate in the lower part of assemblage four west of Likely. It is exposed on both limbs of the regional syncline and on the southwest limb is traced, intermittently, for 6 km southeast from the Likely highway. Narrow lenses of skarn-altered limestone are intercalated with sandstone and conglomerate in the lower part of assemblage four also on the west side of the Takomkane batholith, south and southwest of Murphy Lake (Schiarizza and Bligh, 2008).

Volcanic rocks are a substantial part of assemblage four and include pyroxene-phyric basalt and basalt breccia not unlike volcanic units of assemblages two and three, as well as analcime basalt, hornblende-bearing basalt and plagioclase-phyryic andesite, found only in assemblage four. Analcime basalt is particularly prominent in the Horsefly-Likely area (Campbell, 1978; Panteleyev et al., 1996; Logan et al., 2007a). Analcime (Fig. 15) forms euhedral crystals in pyroxene±plagioclase±olivine-phyric basalt flows and related breccias that are intercalated with conglomerates and sandstones in the lower part of the assemblage, locally directly overlying assemblage three. Hornblende-pyroxene-plagioclase-phyric basalt along the northern boundary of the study area north of the Quesnel River (Panteleyev et al., 1996; Logan et al., 2007a), was not examined during this study,

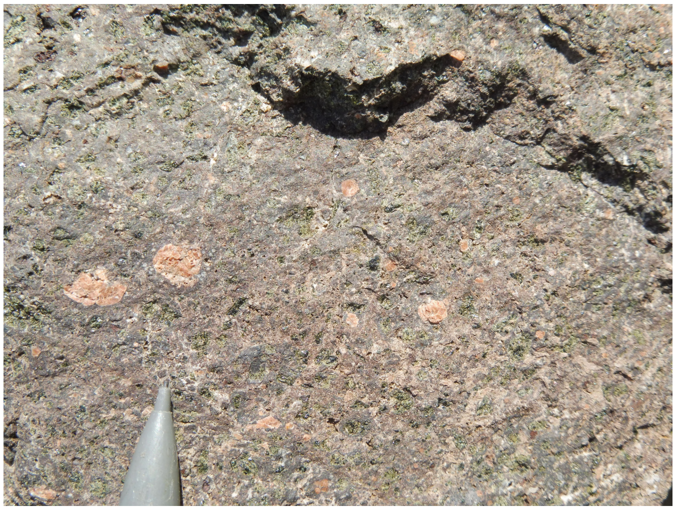

Fig. 15. Analcime-bearing pyroxene-phyric basalt, assemblage four of the Nicola Group, west of Likely.

but is tentatively included in assemblage four because it is associated with sedimentary rocks typical of this assemblage, and because hornblende-pyroxene-plagioclase-phyric basalt occurs in assemblage four in the Stump Lake-Salmon River area (Schiarizza, 2017). Coarse, crowded plagioclase-phyric andesite is a distinctive assemblage four volcanic rock along the west side of the Takomkane batholith, near its north end. It forms a single mappable unit (uTrNtp of Schiarizza et al., 2013), intercalated with conglomerate, sandstone, and pyroxene-phyric basalt, that has been traced for about 5 km. Schiarizza (2016) suggested that similar andesite exposed farther south, on the south flank of Mount Timothy, might also be part of assemblage four, but these rocks are now known to be Eocene (unpublished U-Pb zircon age of 50.84 ±0.04 Ma, Richard Friedman, The University of British Columbia), as originally mapped by Schiarizza and Bligh (2008) and Schiarizza et al. (2013).

Assemblage four is mainly or entirely Late Triassic because it rests above Norian rocks of assemblages two and three, and is locally cut by latest Triassic plutonic rocks (202-205 Ma; Logan et al., 2007b; Schiarizza et al, 2013). A very late Triassic age is confirmed by a U-Pb zircon date of 203.9 ±0.4 Ma from the plagioclase-phyric andesite that is part of the assemblage on the northwest margin of the Takomkane batholith (Schiarizza et al., 2013).

5. Other components of Quesnel terrane in the Bridge Lake-Quesnel River area

The Nicola Group in the Bridge Lake-Quesnel River area is spatially associated with several other Quesnel terrane units. These include: the Slocan Group (Triassic), east of the Nicola Group; rare exposures of Late Paleozoic rock (correlated with the Harper Ranch Group) inferred to underlie the Nicola Group; and Jurassic siliciclastic rocks (Dragon Mountain succession) stratigraphically above the Nicola Group. Plutonic rocks of Quesnel terrane include two Upper Triassic suites, coeval with the Nicola Group, and two Lower Jurassic suites.

5.1. Paleozoic rocks

Upper Paleozoic rocks, tentatively correlated with the Harper Ranch Group, outcrop on the south side of the Thuya batholith, east of Bonaparte Lake, and as two small fault-bounded inliers in the Nicola belt north of the batholith (Fig. 3). The rocks south of the Thuya batholith comprise undated siltstone, limestone and volcaniclastic sandstone that form the north end of a belt that extends southward into the type area of the Harper Ranch Group, east of Kamloops (Fig. 2; Smith, 1979; Beatty et al., 2006). The largest inlier in the Nicola belt north of the batholith forms a triangular fault block on the west slopes of Windy Mountain, 35 km northwest of Little Fort (Fig. 3). It includes fossiliferous limestone, limestone breccia with chert fragments, and laminated to massive chert intercalated with argillite and siltstone (Campbell and Tipper, 1971; Schiarizza et al., 2002). One fossil collection (brachiopods, corals and bryozoans) from this fault block is Permian, and another (fusulinids) is Early Permian (E.W. Bamber and C.A. Ross in Campbell and Tipper, 1971). In a second, smaller Paleozoic inlier, 20 km northwest of Little Fort (blue star on Fig. 3), are a few 10s of m of fossiliferous limestone with thin interbeds of dark grey argillite and chert (Schiarizza et al., 2002). The limestone contains Permian foraminifers and Early-Middle Permian conodonts (Schiarizza et al., 2013). External contacts are not exposed, but these Paleozoic rocks are apparently enclosed in Nicola assemblage two sandstones and conglomerates, a short distance from their contact with underlying Triassic siltstones of the Meridian Lake unit (assemblage one). The Paleozoic rocks might be a large olistolith or a small fault block.

Although exposure is limited, the lithologic attributes and fossil content of the Paleozoic rocks forming the two inliers north of the Thuya batholith suggest correlation with chert-rich carbonate rocks in the McGregor Creek succession (Lower-Middle Permian), which forms the upper unit of the Harper Ranch Group in its type area (Beatty et al., 2006). Stratigraphic contacts are not preserved, but the location of these inliers in the interior of the Nicola belt suggests that the Harper Ranch Group represents, at least in part, basement to the Nicola arc.

5.2. Slocan Group

The Slocan Group (Middle and Upper Triassic) forms a continuous belt that extends the full length of the Bridge Lake-Quesnel River area, and separates the Nicola Group to the west from Slide Mountain terrane and underlying pericratonic rocks to the east (Fig. 3). It consists mainly of dark grey to black phyllite, slate, and slaty siltstone, commonly with laminae and thin interbeds of lighter grey quartzose siltstone, and locally with thin to thick beds of quartzite and quartz-rich sandstone (Schiarizza et al., 2002; Schiarizza and Macauley, 2007; Schiarizza, 2018). Dark grey limestone occurs mainly as rare discontinuous lenses (1-2 m), but north of Little Fort, forms thin to thick beds intercalated with siltstone and slate for stratigraphic intervals approaching 100 m (Schiarizza et al. 2002).

Slocan Group volcanic rocks are only in the Spanish Lake area. Based on 2018 fieldwork, volcanic and volcaniclastic rocks shown as several separate lenses by Schiarizza (2018) are actually part of a single mappable unit, up to several 100 m thick, that can be traced for more than 20 km (Fig. 5). This unit includes coherent metabasalt and fragmental metavolcanic rock, as well as biotite-sericite-quartz schist that may have been derived from a fine-grained quartz-rich sedimentary protolith. The metabasalt is a pale to medium green, plagioclase-actinolite-biotite-chlorite (±epidote±calcite) schist that contains relict phenocrysts (1-2 mm) altered to actinolite-biotite-chlorite, and flattened amygdules (1-5 mm) of quartz±biotite. The fragmental rocks are mainly plagioclase-quartz-biotite-chlorite-sericite schists that contain variably flattened metabasalt clasts, but locally include ankerite-chlorite-sericite schists with granules of quartz and feldspar, and strongly flattened fragments of pale grey quartz-sericite schist. Metabasalt from the Slocan Group has geochemical characteristics of subduction-generated arc basalt, but is distinct from typical arc basalt of the Nicola Group to the west (Logan and Bath, 2006).

The age of the Slocan Group is constrained by conodont collections north of Little Fort, and in the Spanish Lake area, north of the west end of Quesnel Lake. Those near Little Fort are Middle and early Late Triassic (Anisian, Ladinian and early Carnian; Schiarizza et al., 2013), and the most diagnostic forms near Spanish Lake (Struik, 1988; Panteleyev et al., 1996) are Middle Triassic (late Anisian-early Ladinian, and Ladinian).

The Slocan Group is inferred to rest unconformably above the Crooked amphibolite of Slide Mountain terrane (Campbell, 1971; Rees, 1987; McMullin et al., 1990; Schiarizza, 2018), but the eastern contact of the group is, in many areas, marked by Jurassic and younger faults (Campbell and Tipper, 1971; Bloodgood, 1990; Schiarizza et al., 2013). The east-directed Spanish thrust (Early Jurassic) is inferred to mark the contact between the Slocan and Nicola groups (Struik, 1988; Bloodgood, 1990), but it too, is commonly overprinted by younger structures (Schiarizza et al., 2013; Schiarizza, 2018).

5.3. Dragon Mountain succession

Lower to Middle Jurassic siliciclastic rocks that overlie the Nicola Group and associated Late Triassic plutonic rocks are assigned to the Dragon Mountain succession, following Logan and Moynihan (2009). These rocks are exposed mainly in the northern part of the study area, but also occur in several fault panels northeast of Bridge Lake (Fig. 3; Windy Mountain succession of Schiarizza et al., 2013).

The Dragon Mountain succession consists mainly of interbedded conglomerate and sandstone. Conglomerate units are polymicitic and typically include quartz-bearing plutonic clasts (granite, granodiorite, tonalite), and a variety volcanic clasts derived from the underlying Nicola Group (Schiarizza et al., 2002; Logan and Moynihan, 2009; Schiarizza, 2015). Sandstone units may be very similar to Nicola sandstone (assemblage two), but commonly have a significant proportion of detrital quartz. Sandstone is locally interbedded with substantial amounts of siltstone and argillite. A distinctive facies exposed in the Granite Mountain area (Schiarizza, 2015) and along the Quesnel River north of the study area (Logan and Moynihan, 2009) consists of dark grey slate with laminae and thin interbeds of lighter grey siltstone, and local thin to medium beds of yellowish-brown-weathered quartz-rich sandstone.

Volcanic rocks are generally absent from the Dragon Mountain succession, but Logan and Moynihan (2009) reported that it includes rare pyroxene-phyryic basalt flows north of the study area, and Schiarizza et al. (2002) note that it hosts dikes of pyroxene porphyry in the area northeast of Bridge Lake. Early Jurassic dacitic tuff near the Mount Polley mine, west-southwest of Likely (U-Pb zircon age of 196.7 ±1.3 Ma; Logan et al., 2007b) is apparently part of the succession, but is within an enigmatic panel of rocks that apparently overlies the mineralized Mount Polley intrusive complex nonconformably, but is lithologically very similar to assemblage four of the Nicola Group (Logan et al., 2007a, b).

Macrofossils identified from a number of localities in the Dragon Mountain succession (Panteleyev et al., 1996; Peterson et al., 2004; Logan and Moynihan, 2009; Schiarizza et al., 2013) indicate that it is mainly Lower Jurassic (Sinemurian and Pliensbachian), but locally includes Middle Jurassic (Aalenian and possibly Bajocian) rocks. The composition of conglomerates and sandstones suggests derivation mainly from the Nicola Group and associated plutonic rocks (Panteleyev et al., 1996; Peterson et al., 2004; Logan and Moynihan, 2009). The outcrop distribution of the succession suggests that it may have accumulated, in part, in a number of linear fault-bounded sub-basins (Fig. 3).

5.4. Plutonic rocks

Plutonic rocks of Quesnel terrane are subdivided into two Late Triassic intrusive suites which are coeval with parts of the Nicola Group, and two Early Jurassic suites (Fig. 3). Here, and to the south, Quesnel plutons show a general pattern of alternating calcalkaline and alkaline belts, becoming progressively younger from west to east.

5.4.1. Upper Triassic plutons

The oldest Quesnel plutonic rocks in the Bridge Lake-Quesnel River area are tonalites of the Granite Mountain batholith and adjacent Burgess Creek stock, which cut assemblage two of the Nicola Group in the northwest corner of the study area (Fig. 3), and have U-Pb zircon crystallization ages ranging from 215 to 223 Ma (Schiarizza, 2015; Mostaghimi, 2016). They are part of a suite of Late Triassic calcalkaline plutons cutting western exposures of the Nicola Group. South of the study area this suite includes the Guichon Creek batholith (210 Ma; Mortimer et al., 1990) and Allison pluton (223 Ma; Mihalynuk et al., 2016). The Granite Mountain and Guichon Creek batholiths host major calcalkaline porphyry Cu-Mo deposits.

A younger, latest Triassic intrusive suite includes alkaline plutons consisting of monzonite, monzodiorite, diorite and syenite (Fig. 3). This suite includes the Mount Polley intrusive complex and Bootjack Lake stock southwest of Likely (Logan et al., 2007a, b), the Spout Lake pluton and Peach Lake stocks near Murphy Lake (Schiarizza and Bligh, 2008), and the Rayfield River syenite pluton west of Bonaparte Lake (Logan and Schiarizza, 2014). U-Pb zircon ages are mainly 202-205 Ma (Mortensen et al., 1995; Logan et al., 2007b; Schiarizza et al, 2013), although the Rayfield River pluton may be slightly younger (ca. 200 Ma; Logan and Schiarizza, 2014). This linear belt of latest Triassic alkaline plutons continues southward to include the Iron Mask batholith near Kamloops and the Copper Mountain intrusions near Princeton (Schiarizza, 2014). This belt is remarkably well endowed with alkalic porphyry Cu-Au deposits, including the currently producing Mount Polley, New Afton and Copper Mountain mines.

5.4.2. Lower Jurassic plutons

The most prominent Lower Jurassic intrusions in the study area are calcalkaline rocks that form the Thuya and Takomkane batholiths (Fig. 3). They consist mainly of hornblende-biotite granodiorite and granite with U-Pb zircon ages ranging from 193 to 197 Ma, although an eastern border phase of the Takomkane batholith (granodiorite and quartz monzodiorite) ranges from 199 to 202 Ma (Schiarizza et al., 2013). These two batholiths are part of a linear belt of five large Early Jurassic calcalkaline batholiths, including the Wild Horse, Pennask and Bromley batholiths to the south, which extends for 300 km and cuts the central and eastern parts of the Nicola belt (Schiarizza, 2014). These batholiths locally host calcalkaline porphyry Cu-Mo deposits, including the past-producing Brenda Mine in the Pennask batholith, and the Woodjam SE zone in the northwestern part of the Takomkane batholith (Logan et al., 2011).

A variety of smaller Early Jurassic intrusions cut the central and eastern parts of the Nicola belt in the Bridge Lake-Quesnel River area (Fig. 3). Diorite, monzonite, quartz monzonite and syenite are most common, but this suite also includes ultramafic-mafic intrusions that are mainly gabbro, diorite, hornblendite and pyroxenite, locally with wehrlite and dunite (Panteleyev et al., 1996; Schiarizza et al., 2013). U-Pb zircon ages range from 196 to 184 Ma (Schiarizza et al., 2013). The youngest dated intrusion (184 Ma; Schiarizza et al., 2013) is an ultramafic-mafic body that cuts the Spanish Mountain unit of assemblage one on the north side of the Raft batholith (Fig. 3). Similar ages (185.6 to 187.3 Ma; Rhys et al., 2009) come from small diorite stocks and dikes, commonly with hornblendite and pyroxenite xenoliths, that cut the Spanish Mountain unit on the south side of Spanish Lake (Fig. 5).

6. Summary

With some modifications, the four-fold subdivision presented by Schiarizza (2016) provides a useful stratigraphic framework for the Nicola Group in the Bridge Lake-Quesnel River area. Assemblage one is represented mainly by Middle Triassic siltstone, chert and argillite, with less common volcaniclastic sandstone and local pillowed basalt (N-MORB and E-MORB), along the eastern margin of the Nicola belt (Spanish Mountain unit), but also includes rocks in the south-central part of the belt that were previously included in assemblage two. These include volcaniclastic sandstone, chert, pyroxene-phryic basalt and basalt breccia of the Wavey Lake unit, and overlying early Carnian siltstone of the Meridian Lake unit. Assemblage two (Late Triassic, Carnian and early Norian) is the most widespread component of the Nicola Group, and is mainly volcanic sandstone and conglomerate, locally intercalated with pyroxene-phyric basalt and basalt breccia. Assemblage three is above assemblage two, and is a relatively homogeneous succession of pyroxene-phyric basalt flows and related breccias that are similar to the volcanic rocks in the underlying assemblage. Assemblage four (late Norian and Rhaetian) forms the top of the Nicola Group, and may be separated from underlying rocks by an unconformity or disconformity. It includes red and maroon polymictic conglomerate with abundant hypabyssal and plutonic rock fragments, red feldspathic sandstone, and distinctive volcanic rocks that include analcime basalt and hornblende-bearing basalt (previously included in assemblage three), and coarse, crowded plagioclase-phyric andesite.

Assemblage one is significant in showing that the Nicola arc, represented mainly by Late Triassic rocks, was initiated during, or before, the Middle Triassic. This older part of the arc is not well understood, but includes an eastern back-arc basin represented by the Spanish Mountain unit. The main Late Triassic constructional phase of the Nicola arc is represented by assemblages two and three, which include abundant pyroxene-phyric basalt and related breccia, as well as volcanic sandstones and conglomerates derived from these volcanic rocks. Assemblage four reflects regional uplift and partial unroofing of the arc in the very late Triassic, with continuing volcanism that generated some distinctive volcanic products, including analcime basalt.

The Nicola Group was deposited above upper Paleozoic rocks of the Harper Ranch Group, at least in part, as indicated by two small Harper Ranch inliers in the southern part of the study area. Lower to Middle Jurassic polymictic conglomerate and sandstone of the Dragon Mountain succession, the youngest stratified rocks in this part of Quesnel terrane, overlie the Nicola Group unconformably, and were derived mainly from the Nicola Group and associated plutonic rocks. The four Late Triassic to Early Jurassic plutonic suites cutting the Nicola Group are distributed in a general pattern of alternating calcalkaline and alkaline belts, becoming progressively younger from west to east. The oldest calcalkaline suite includes Late Triassic tonalite of the Granite Mountain batholith, which hosts the Gibraltar porphyry Cu-Mo mine. A younger, latest Triassic alkaline suite, coeval with assemblage four of the Nicola Group, includes rocks that host the Mount Polley porphyry Cu-Au mine.

The Nicola Group is flanked to the east by Middle and Upper Triassic slate, siltstone and quartz sandstone of the Slocan Group, part of a siliciclastic basin that formed east of, and coeval with, the Nicola arc. The Meridian Lake unit may represent a tongue of Slocan Group that interfingers with the Nicola

Group, demonstrating proximity of the two groups during their formation. An additional link may be provided by the arc volcanic rocks intercalated with Middle Triassic sedimentary rocks of the Slocan Group. These may be part of an early stage of volcanism within the arc system, and westward migration to the main Late Triassic arc axis (Nicola Group) may have been linked to formation of the back-arc basin represented by the Spanish Mountain unit.

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