Ongoing stratigraphic studies in the Nicola Group: Stump Lake – Salmon River area, south-central British Columbia

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Recommended citation: Schiarizza, P., 2017. Ongoing stratigraphic studies in the Nicola Group: Stump Lake – Salmon River area, south-central British Columbia. In: Geological Fieldwork 2016, British Columbia Ministry of Energy and Mines, British Columbia Geological Survey Paper 2017-1, pp. 17-33.

Abstract

A regional-scale stratigraphic framework for arc-related volcano-sedimentary rocks of the Nicola Group (Triassic), the defining supracrustal element of the Quesnel arc terrane in southern British Columbia, remains lacking. As part of a multi-year project to address this problem, and building on work started in 2015 in the Bridge Lake – Quesnel River area, mapping in 2016 covered the eastern part of the Nicola belt southeast of Kamloops, between Stump Lake and the Salmon River. Here, the Nicola Group is subdivided into 3 units, which show strong similarities to 3 of the 4 assemblages established in the Bridge Lake – Quesnel River area. Most widespread is the volcanic sandstone unit (assemblage two), consisting of plagioclase-pyroxene sandstone, locally intercalated with volcanic conglomerate and siltstone. The pyroxene basalt unit (assemblage three), overlies the volcanic sandstone unit in the western part of the area, and consists of massive pyroxene-phyric basalt and related breccia. The polymictic conglomerate unit (assemblage 4) comprises conglomerate with a distinctive clast population that includes mafic plutonic rocks. It overlies the volcanic sandstone unit in the eastern part of the area, across a suspected unconformity. Another Triassic unit, the Salmon River succession, includes conglomerate, carbonate-cemented sandstone, and siltstone that occur east of the Nicola Group, where they overlie Paleozoic schist of the Chapperon Group across an angular unconformity. These rocks are correlated with the Slocan Group, and are part of a siliciclastic basin that formed east of, and coeval with, the Nicola arc.

Keywords: Nicola Group, Upper Triassic, volcanic sandstone, pyroxene-phyric basalt, conglomerate, Salmon River succession, Slocan Group, Chapperon Group, Quesnel terrane

1. Introduction

Quesnel terrane, extending the full length of the Canadian Cordillera (Fig. 1), is an important metallogenic belt that hosts numerous Cu-Au-Mo porphyry and skarn deposits. It is characterized by a Mesozoic arc complex that includes Triassic to Jurassic volcanic and sedimentary rocks and related calcalkaline and alkaline intrusions. In south-central British Columbia the defining supracrustal component is the Nicola Group (Triassic). Although studied for more than a century, with numerous informal subdivisions applied in different areas by authors working at different times and scales, no regional-scale stratigraphy has been established. Therefore, in 2015, the British Columbia Geological Survey initiated a multi-year field-based program to synthesise Nicola Group lithostratigraphy and establish a regional stratigraphic framework. This framework, combined with space-time-composition patterns of spatially associated plutons, will contribute to a better understanding of the architecture of the arc, and help establish the settings and controls of mineral occurrences.

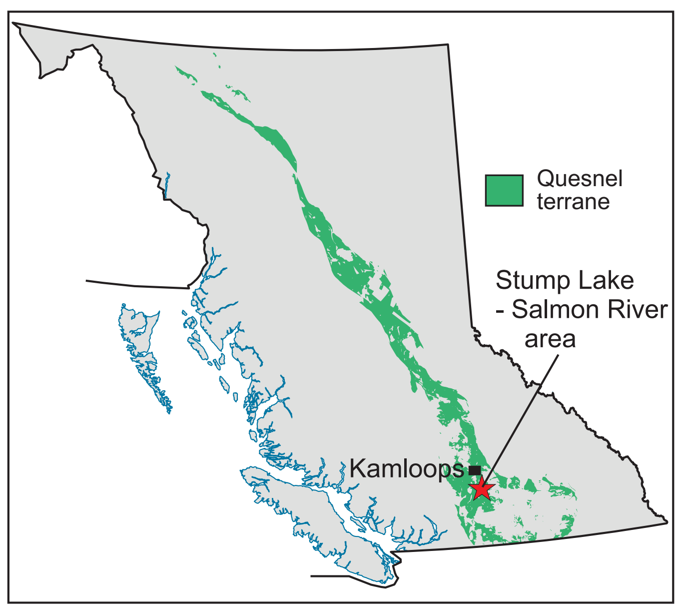


Fig. 1. Location of the Stump Lake – Salmon River area and distribution of Quesnel terrane in British Columbia.

In 2015, initial investigations were carried out in the Bridge Lake – Quesnel River area, where Triassic rocks were separated into Nicola and Slocan groups, and the Nicola rocks subdivided into four broad stratigraphic assemblages (Fig. 2; Schiarizza,

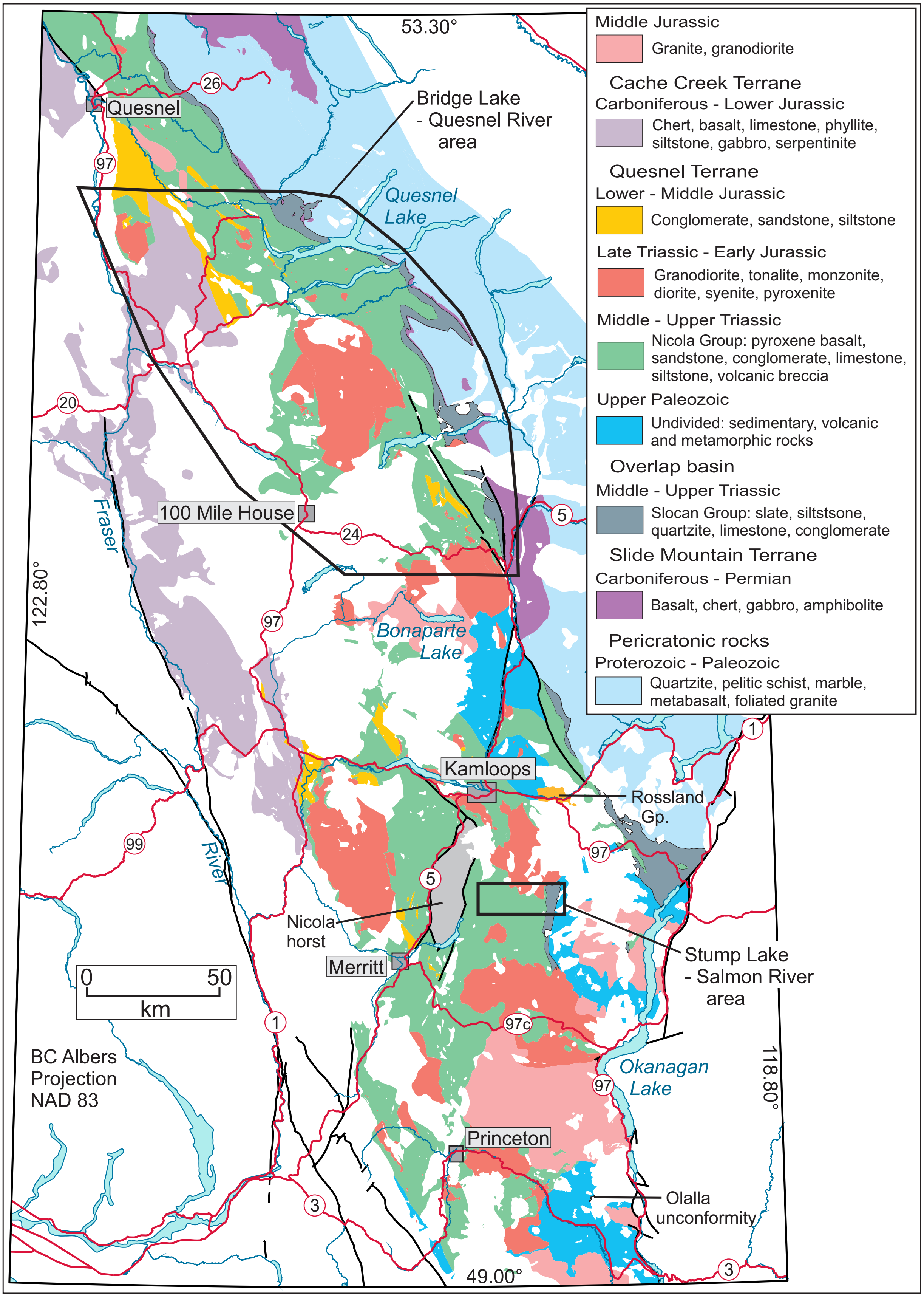


Fig. 2. Geological map of south-central British Columbia showing distribution of Nicola Group, and locations of the Bridge Lake – Quesnel River and Stump Lake – Salmon River study areas. Uncoloured areas mainly Late Jurassic to Recent intrusive, volcanic and sedimentary rocks.

2016). Summarized herein are the results of mapping in a relatively small area in the eastern part of the Nicola belt south of Kamloops, between Stump Lake and the Salmon River (Fig. 2). Nicola Group subdivisions established in this area show some strong similarities to those established to the north, and will compliment recent detailed mapping in the central part of the Nicola belt to the southwest (Mihalynuk et al., 2016).

2. Setting

The Stump Lake – Salmon River area is in the central part of the Thompson Plateau physiographic province (Holland, 1976) and encompasses parts of the traditional territories of the Nlaka'pamux, Syilx, and Secwepemc First Nations. Highway 5A, connecting Kamloops and Merritt, is along the west edge of the mapped area, Douglas Lake road crosses the eastern part of the area, and the intervening parts of the map area include numerous Forest Service and logging roads that provide good access. Most of the Stump Lake – Salmon River area is in the Ashcroft (92I) NTS map sheet. The regional geology here was described by Cockfield (1948) and updated by Monger and McMillan (1989), Moore (1989), and Moore et al. (1990). The eastern part of the area is in the Vernon (82L) NTS map sheet, and the geology was described by Jones (1959), with updates and revised interpretations by Preto (1964), Okulitch and Cameron (1976), Read and Okulitch (1977), Okulitch (1979), Daughtry et al. (2000), Daughtry and Thompson (2004), and Thompson et al. (2006).

The Nicola Group (Triassic), the predominant component of the Quesnel arc terrane, forms a continuous belt, 25 to 90 km wide, between the town of Quesnel and the international boundary (Fig. 2). This belt also includes abundant Late Triassic to Early Jurassic calcalkaline and alkaline arc intrusions, and fault-bounded panels of Lower to Middle Jurassic arc-derived siliciclastic sedimentary rocks, which are assigned to the Dragon Mountain succession in the north (Logan and Moynihan, 2009), and the Ashcroft Formation to the south (Monger and McMillan, 1989). Younger rocks in this belt include Middle Jurassic through Eocene granitic intrusions, Cretaceous and Eocene volcanic and sedimentary rocks, and flat-lying Neogene and Quaternary basalt.

The northern and central parts of the Nicola belt are flanked to the west by late Paleozoic to early Mesozoic basalt, chert, and limestone of Cache Creek terrane, which is interpreted as an accretionary complex genetically related to the subduction that generated the Nicola arc. Faulted against the east side of the Nicola belt at this latitude are Triassic sedimentary rocks, mainly black phyllite, slate, and quartz sandstone, of the Slocan Group. These rocks were deposited in a basin that formed above Late Paleozoic oceanic rocks (chert, basalt, gabbro) of Slide Mountain terrane, and Paleozoic pericratonic rocks (quartzite, pelitic schist, limestone), that were juxtaposed by east-directed thrusting in the Late Permian or Early Triassic (Schiarizza, 1989; McMullin, 1990; McMullin et al., 1990).

The southern part of the Nicola belt is flanked to the east by several assemblages of Paleozoic rocks, which have been included in Quesnel terrane and interpreted as part of the Paleozoic basement on which the Mesozoic arc formed. The Paleozoic rocks north and northeast of Kamloops, and those along and west of northern Okanagan Lake, are included in the Harper Ranch Group (Smith, 1979; Beatty et al., 2006; Thompson et al., 2006), which includes late Paleozoic arc-derived volcaniclastic rocks and Carboniferous and Permian limestone. The exposures west of northern Okanagan Lake also include an inlier of undated schists, the Chapperon Group, which has been correlated with pericratonic rocks to the northeast (Jones, 1959), or inferred to represent a deformed belt of Harper Ranch rocks (Thompson et al., 2006). The southernmost part of the Nicola belt is juxtaposed, southeast of Princeton, with an assemblage of late Paleozoic rocks, including chert, basalt, argillite, limestone, siltstone, quartzite, sandstone and conglomerate, assigned to the Old Tom, Independence, Shoemaker, Bradshaw, Barslow and Blind Creek formations (Bostock, 1940, 1941; Mortensen et al., 2011) and, in part, included in the Apex Mountain Group interpreted by Milford (1984) as a pre-Late Triassic accretionary complex. The easternmost element of this Paleozoic belt comprises undated schists of the Kobau Group, which may correlate with the Chapperon Group to the north (Okulitch, 1973, 1979).

Permo-Triassic deformation, including east-directed thrusting, is documented in Paleozoic rocks of Slide Mountain and Quesnel terranes east of the Nicola belt, and is locally reflected in angular unconformities between these rocks and overlying Triassic sedimentary rocks (Read and Okulitch, 1977; McMullin et al., 1990). Some Triassic rocks above the unconformities have been included in the Nicola Group (Read and Okulitch, 1977), but their relationship to the main belt of Nicola volcanic and volcaniclastic rocks to the west is uncertain. Episodes of Middle Jurassic to Cretaceous contractional deformation are documented in rocks adjacent to, and along the margins of, the Nicola belt (Rees, 1987; Bloodgood, 1990; Fillipone and Ross, 1990; Greig, 1992), and contractional structures occur locally in the main belt of Nicola rocks (Panteleyev et al., 1996; Schiarizza et al., 2002; Mihalynuk et al., 2016), but are poorly understood. The most prominent structures in the Nicola belt are systems of dextral strike slip and extensional faults that formed mainly in the Eocene (Ewing, 1980; Moore et al., 1990; Schiarizza and Israel, 2001). These include normal faults west of Stump Lake that bound the Nicola horst (Fig. 2), an uplifted block of amphibolite-grade metamorphic rocks that includes metavolcanic rocks correlated with the Nicola Group, as well as Late Triassic metadiorite and metatonalite that also may be components of the Mesozoic Quesnel arc (Moore et al., 1990; Erdmer et al., 2002).

3. Geologic units

The Stump Lake – Salmon River area (Fig. 3) is underlain mainly by Triassic sedimentary and volcanic rocks of the Nicola Group, which is subdivided into three lithologic units (volcanic sandstone unit; pyroxene basalt unit; polymictic conglomerate unit). Sedimentary rocks in the eastern part

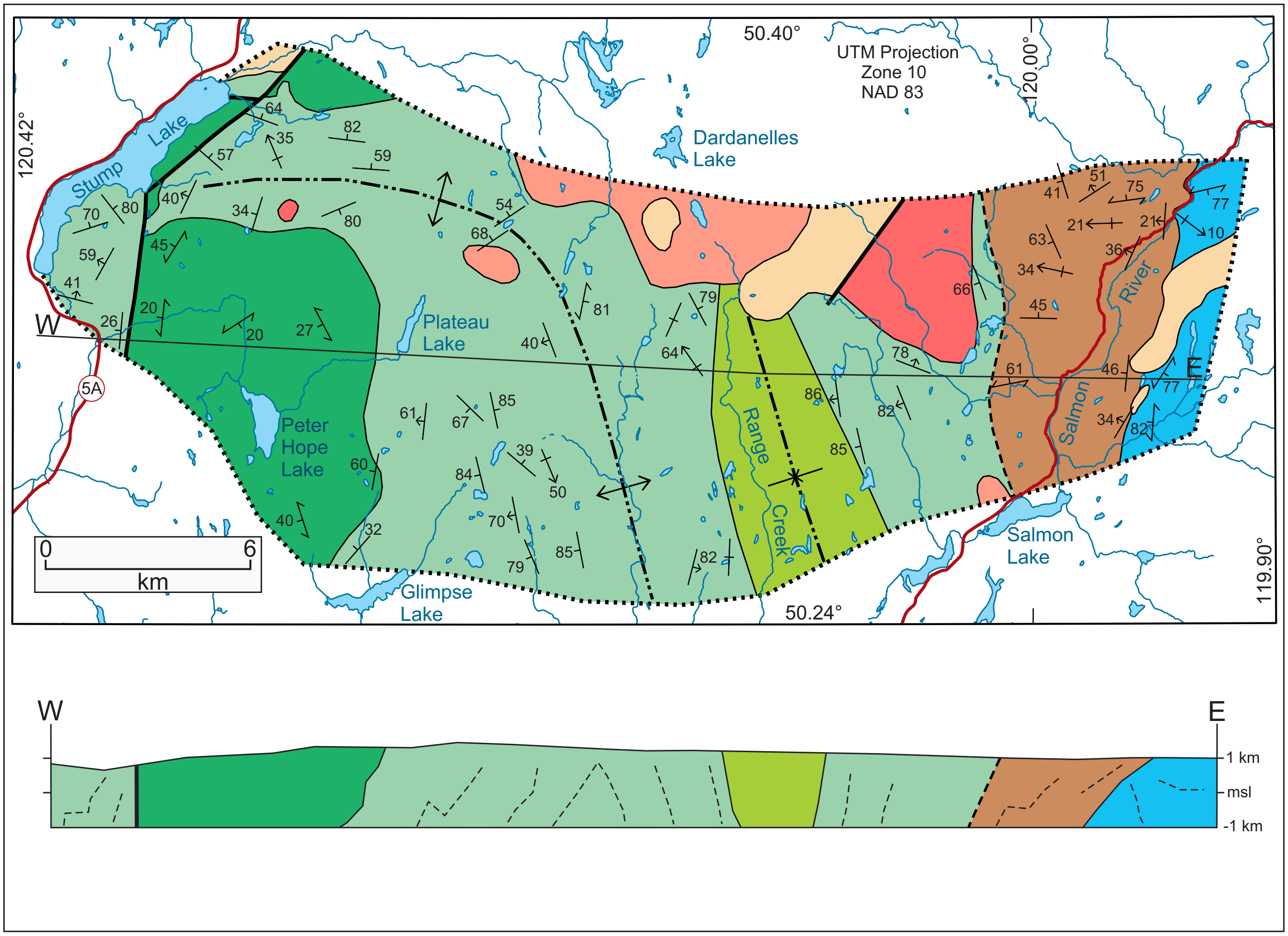


Fig. 3a. Geology of the Stump Lake – Salmon River area, with schematic vertical cross-section. Geology based on 2016 fieldwork, with distribution of Jurassic and Eocene rocks taken, in part, from Monger and McMillan (1989) and Daughtry and Thompson (2004).

of the area, also Triassic but of uncertain relationship to the Nicola Group, are assigned to the Salmon River succession. They rest unconformably above the oldest rocks in the map area, Paleozoic schists of the Chapperon Group, which crop out along its eastern edge. Younger rocks include intrusions of granodiorite, tonalite and diorite, Early Jurassic at least in part, and Eocene volcanic rocks of the Kamloops Group.

3.1. Chapperon Group

The Chapperon Group comprises greenschist-grade metamorphic rocks that crop out along the eastern edge of the Stump Lake – Salmon River map area, where they are unconformably overlain, to the west, by Triassic rocks of the Salmon River succession (see Jones, 1959; Preto 1964; Read and Okulitch, 1977; and Daughtry et al., 2000).

Much of the Chapperon Group in the current study area comprises fine-grained, medium to dark grey or greenish-grey phyllite and biotite phyllite, locally grading to weakly cleaved argillite or siltstone, and commonly containing many quartz±calcite veins. Massive and thinly bedded chert, and less common fine-grained quartzite, form local narrow (<1 m) lenses in the phyllite. A section of thinly interbedded chert and quartz phyllite more than 20 m thick forms an isolated outcrop in the southern part of the unit, a short distance east of the unconformity. Dark green calcareous chlorite schist, probably derived from mafic volcanic rocks, is also common in the group, and locally contains lenses of white recrystallized limestone up to several metres thick (Fig. 4). Grey-green, crudely foliated talc-magnesite-serpentine schist, derived from an ultramafic protolith, was observed at two localities, but external contacts were not observed. Jones (1959) referred to these rocks as the Old Dave intrusions, and interpreted them as Paleozoic ultramafic dikes.

The Chapperon Group is undated, but the unconformity at the base of the Salmon River succession shows that the group, and the strong deformation fabrics within it, are pre-Late Triassic. Okulitch (1979) reported that limestone from the group near the Salmon River contains a structure resembling Late Ordovician – Silurian Halysitid corals but, as this structure is of dubious organic origin, this age was considered unreliable.

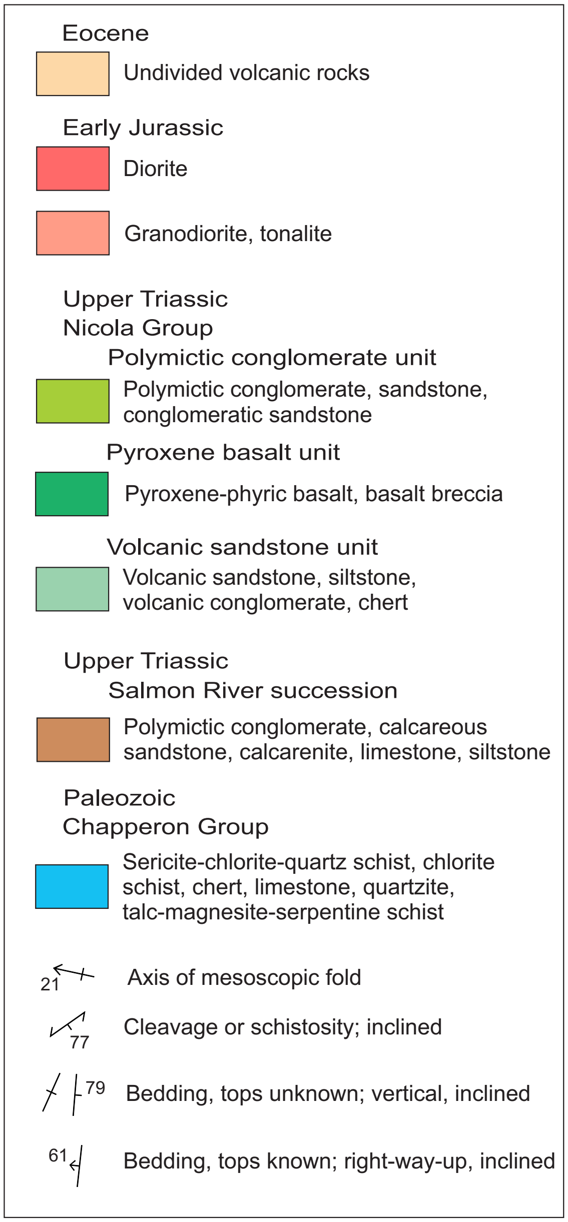


Fig. 3b. Legend for Figure 3a.

Stratigraphic relationships south of the current map area indicate that the group is pre-Permian, because it is overlain by, and infolded with, Permian conglomerate (Read and Okulitch, 1977; Okulitch, 1979). Thompson et al. (2006) included these Permian rocks in the Harper Ranch Group, and suggested that the Chapperon Group is a highly deformed belt of Harper Ranch rocks. The Chapperon Group has also been correlated with pericratonic rocks in the Shuswap Lake – Adams Lake area (Jones, 1959; Thompson and Daughtry, 1998), and with the undated, but probably Carboniferous or older, Kobau Group to the south (Okulitch, 1973, 1979).

3.2. Salmon River succession

The Salmon River succession forms a belt of Triassic sedimentary rocks, 3.5 to 6 km wide, in the eastern part of the Stump Lake – Salmon River map area. The base of the succession is exposed along the eastern edge of the belt, where it rests unconformably above the Chapperon Group. It is apparently juxtaposed against the Nicola Group (volcanic sandstone unit) to the west, but this contact is in a wide zone of poor exposure, and the nature of the contact is unknown. The rocks of the Salmon River succession were initially included in the Cache Creek Group (Carboniferous-Permian) by Cockfield (1948) and Jones (1959). Late Triassic conodonts were extracted from samples collected near the base of the succession (Campbell and Okulitch, 1973; Okulitch and Cameron, 1976), and the rocks were then assigned to the Nicola Group (Read and Okulitch, 1977; Okuliltch, 1979) or Slocan Group (Daughtry and Thompson, 2004).

The predominant rock type in the Salmon River succession is thin to medium-bedded calcareous sandstone. Conglomerate forms a basal unit, from several metres to tens of metres

Fig. 4. Chlorite schist with limestone boudin (beneath hammer), Chapperon Group, northeast corner of the study area, east of the Salmon River.

thick, and is also common elsewhere in the lower part of the succession, where it is intercalated with calcareous sandstone, limestone, calcarenite, and argillite. Siltstone and argillite form relatively thin units that are intercalated with coarser-grained units throughout the succession (above the basal conglomerate), and are apparently the predominant rock types in the poorly exposed westernmost part of the succession.

The basal unit of the Salmon River succession is medium to dark grey-green, poorly stratified polymictic conglomerate, comprising angular to subrounded clasts (mainly <1-5 cm, but locally ~20 cm) in a fine-grained carbonate-cemented sandstone matrix (Fig. 5). The clasts include chert, limestone, fine-grained quartzite, quartz phyllite, green volcanic or volcaniclastic rock, dark grey siliceous argillite, and vein quartz. Many of the clasts resemble rocks in the underlying Chapperon Group, from which they were probably derived.

The basal conglomerate is overlain by a heterogeneous section, estimated to be several hundred metres thick, which includes carbonate-cemented sandstone, conglomerate, limestone, calcarenite, siltstone and argillite. Brown-weathered carbonate-cemented sandstone predominates, and commonly occurs as intervals of thin-bedded, fine- to medium-grained sandstone, punctuated by thin to thick beds of medium- to coarse-grained sandstone. The thin sandstone beds locally display convolute lamination, cross stratification, graded bedding, and load casts, and are typically intercalated with thin beds or laminae of dark grey siltstone (Fig. 6). The medium to thick sandstone beds locally display normal grading, and may have laminated tops. The sandstones contain detrital grains of quartz, feldspar and fine-grained lithic fragments.

Pebble conglomerate is common in the lower part of the Salmon River succession (above the basal conglomerate unit), and typically forms medium to very thick graded beds

Fig. 5. Basal conglomerate of the Salmon River succession, northeast corner of the study area, west of the Salmon River.

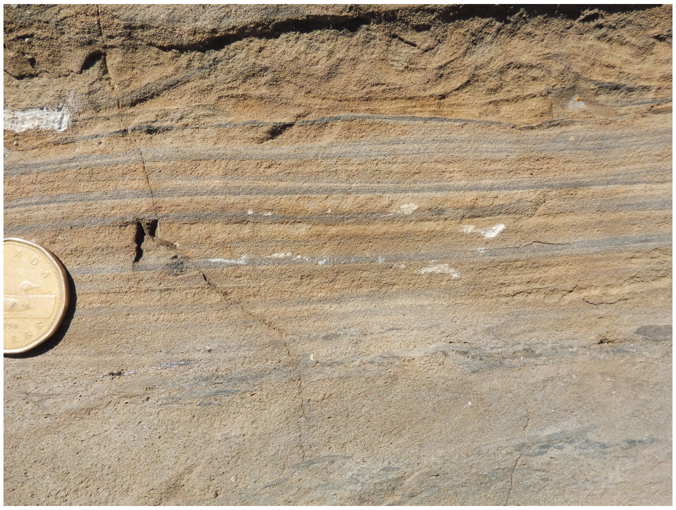


Fig. 6. Thin-bedded, medium-grained carbonate-cemented sandstone (brown) and siltstone (grey); grey mudchip intraclasts lower right; likely ripple-drift cross-stratification at top. Lower part of the Salmon River succession, 4 km northeast of Salmon Lake.

in sandstone intervals. Less common is poorly sorted pebble to cobble conglomerate that forms poorly stratified intervals more than 10 m thick. The conglomerate units contain a heterogeneous clast population similar to that of the basal conglomerate.

Limestones, including calcarenites, are relatively minor components in the lower part of the Salmon River succession, forming thin units intercalated with sandstone and siltstone. However, they form local intervals several tens of metres thick, such as a 25 to 30 m thick section exposed on the steep slopes northwest of the Salmon River, 7.5 km north-northeast of Salmon Lake. The lower third of this section consists mainly of platy to flaggy fine-grained limestone and argillaceous limestone; the middle part comprises thin-bedded calcarenite with calcareous shale interbeds, and local interbeds of flaggy limestone and pebbly limestone; and the upper part consists of fissile, gritty to pebbly limestone, containing rare thin interbeds of dark grey fine-grained limestone (Fig. 7). Pebbles within the pebbly limestone units are mainly chert, quartz, and weakly foliated quartz tectonites. Chert, quartz and quartz-rich lithic grains also occur in the calcarenite beds, but are less common than the predominant carbonate grains.

Preto (1964) mapped two narrow mafic igneous units in the lower part of the Salmon River succession, which he interpreted as altered mafic crystal tuffs or flows. Only one of these units was located during the 2016 mapping program. It is a grey plagioclase-hornblende-pyroxene porphyry with scattered xenoliths of hornblendite, which I interpret as a sill, based on its slightly discordant lower and upper contacts with the enclosing thin-bedded sandstone-siltstone sequence.

Higher stratigraphic levels of the Salmon River succession are represented by generally poorly exposed rocks in the western two-thirds of the outcrop belt. Exposures in this part of the belt consist of variable proportions of dark grey siltstone

Fig. 7. Pebbly limestone, lower part of the Salmon River succession, northwest side of the Salmon River, 7.5 km north-northeast of Salmon Lake. Resistant weathering pebbles and granules of chert, quartz, and weakly foliated quartz tectonites in a recessive fine-grained limestone matrix.

and fine- to coarse-grained carbonate-cemented sandstone, which occurs as thin to thick beds and contains mainly quartz, feldspar and chert grains (Fig. 8). A single occurrence of pebble conglomerate is exposed at the north end of the belt, 2.4 km east of the inferred contact with the Nicola Group. The conglomerate forms a single bed, about 1.5 m thick, in an interval of carbonate-cemented sandstones. It is predominantly framework supported, and contains small subrounded pebbles of mainly chert and quartz, with some dark grey argillite and beige volcanic(?) lithic grains. Although exposure is poor, it appears that the proportion of siltstone increases westward in the upper part of the Salmon River belt. The westernmost exposures of the succession, in the southern part of the belt, are of dark grey siltstone and argillite without sandstone interbeds.

Fig. 8. Brown-weathered carbonate-cemented sandstone beds intercalated with siltstone, central part of the Salmon River succession, near north boundary of the map area.

The Salmon River succession is considered Late Triassic on the basis of late Carnian conodonts extracted from samples of limestone and limy conglomerate from the lower part of the succession east of the Salmon River (Okulitch and Cameron, 1976).

3.3. Nicola Group

The Nicola Group underlies most of the Stump Lake – Salmon River map area, where it is subdivided into three components: the volcanic sandstone unit; the pyroxene basalt unit; and the polymictic conglomerate unit. Cockfield (1948) applied a two-fold subdivision to these same rocks, assigning some (the pyroxene basalt unit) to the Nicola Group, but most to the Cache Creek Group (Carboniferous-Permian). Monger and McMillan (1989) mapped Cockfield's Cache Creek rocks (the volcanic sandstone unit of this report) as a sedimentary facies of the Nicola Group, and included both the pyroxene basalt unit and the polymictic conglomerate unit in the eastern volcanic facies of the Nicola Group. Moore et al. (1990) used the same subdivisions as Monger and McMillan, but included the volcanic conglomerate unit in the sedimentary facies of the group, and mapped rocks east of southern Stump Lake, included in the eastern volcanic facies by Monger and McMillan (1989), as part of the sedimentary facies.

3.3.1. Volcanic sandstone unit

The volcanic sandstone unit is the oldest and most widespread component of the Nicola Group in the Stump Lake – Salmon River map area. It consists mainly of volcanogenic sandstone, but also includes volcanic conglomerate, siltstone and, rarely, chert.

Sandstone is grey to green, medium to coarse grained, and commonly gritty (Fig. 9). It is characteristically very feldspathic, but also includes mafic mineral grains (pyroxene

Fig. 9. Upper part of thick, gritty, volcanogenic sandstone bed, volcanic sandstone unit of the Nicola Group, east limb of anticline, 8.5 km east of Glimpse Lake. Top of frame is north, beds are right-way-up and dip steeply east.

and less common hornblende), and both feldspathic and mafic volcanic-lithic grains. Much of the sandstone forms massive intervals, metres to tens of metres thick, in which bedding is not apparent, or is defined locally by narrow intervals of vaguely laminated sandstone or thin-bedded siltstone. Elsewhere, sandstone forms thick sections of well-defined thin to very thick beds. Thick to very thick-bedded intervals are fairly common in the central part of the area, on both limbs of the map scale anticline (Fig. 3), and the beds here locally display partial to complete Bouma sequences. Some of the thick-bedded intervals in this part of the area include distinctive dark grey-green gritty sandstone that is very rich in pyroxene grains, and is easily mistaken for gabbro in poor exposures (Fig. 10). Sandstone in the eastern part of the area, east of the polymictic conglomerate unit, commonly forms thin, locally medium or thick, graded beds with laminated tops, in part separated by thin beds of laminated siltstone.

Volcanic conglomerate occurs at several places in the volcanic sandstone panel that crops out adjacent to the south end of Stump Lake, where it forms units from a few metres to ten metres thick, intercalated with volcanic sandstone. The conglomerates are typically matrix supported, comprising angular to subrounded pebbles and small cobbles in a sandy, commonly epidote-altered matrix rich in feldspar and mafic mineral grains. The clasts are mainly pyroxene±plagioclase±hornblende porphyry, but aphyric mafic volcanic rock and fine-grained diorite may also be present, and one conglomerate unit also contains angular sandstone and siltstone fragments probably derived from underlying beds. Volcanic conglomerate also occurs in the main volcanic sandstone belt to the east, where it is represented by exposures 4.5 km east-northeast of Glimpse Lake. Another set of exposures, suspected to be part of the same unit, are 3.7 km east of Plateau Lake (Fig. 11). The conglomerates here are similar to the conglomerate units east of Stump Lake, but are at least several tens of metres thick. Volcanic conglomerate and pebbly sandstone noted elsewhere in the main volcanic

Fig. 11. Volcanic conglomerate, volcanic sandstone unit of the Nicola Group, 3.7 km east of Plateau Lake.

sandstone belt comprise the basal parts of thick and very thick sandstone beds.

Siltstone is a common but minor component of many sandstone intervals , where it occurs at the tops of graded sandstone beds, as distinct thin beds, or as laminae separating sandstone beds. Medium to dark grey siltstone, as thin to medium, commonly laminated beds, also occurs as the predominant component of intervals many tens of metres thick, observed mainly in the largest exposure belt of the unit, encompassing both limbs of the major anticline (Fig. 12). These siltstone-predominant intervals typically include some beds of fine- to medium-grained sandstone.

Chert was observed at only one location, near the southern boundary of the map area, 700 m west of the contact with the polymictic conglomerate unit. Here, in an isolated outcrop, medium grey chert occurs as distinct beds, 2-7 cm thick, intercalated with dark grey slaty siltstone (Fig. 13). The exposed

Fig. 10. Gritty pyroxene-rich sandstone from a very thick bed, volcanic sandstone unit of the Nicola Group, 4.3 km south of Dardanelles Lake.

Fig. 12. Thin-bedded siltstone, volcanic sandstone unit of the Nicola Group, 4 km east of Plateau Lake.

Fig. 13. Thin-bedded chert and slaty siltstone, volcanic sandstone unit of the Nicola Group, 8 km west-southwest of Salmon Lake.

Fig. 14. Pyroxene porphyry, pyroxene basalt unit of the Nicola Group, east side of northern Stump Lake.

section is about 15 m thick, with subequal proportions of chert and siltstone in the west, but with siltstone predominating, in laminated beds up to 30 cm thick, in the east. Nearby outcrops, 300 m to the northeast, consist of dark grey laminated siltstone that is similar to the siltstone units intercalated with chert.

Monger and McMillan (1989) reported probable Norian conodonts from a sample collected 4 km northwest of Plateau Lake, near the contact with overlying volcanic rocks of the pyroxene basalt unit (GSC Loc. No. C-087407; identified by M.J. Orchard). No macrofossils were found during the 2016 field season, and most rocks in the unit are unlikely to contain microfossils, although samples collected from the single chert outcrop will be processed for radiolarians and conodonts.

3.3.2. Pyroxene basalt unit

The pyroxene basalt unit comprises pyroxene-phyric basalt flows that overlie the volcanic sandstone unit in the western part of the map area. The main exposures form a large belt encompassing Peter Hope Lake, on the southwest limb of a major anticline with an arcuate axial trace (Fig. 3). The unit is also exposed on the north limb of the anticline, and as a fault panel that forms the eastern shore of northern Stump Lake.

The pyroxene basalt unit is represented mainly by uniform exposures of medium to dark green, brown-weathered pyroxene porphyry (Fig. 14) interpreted as a succession of basalt flows, although contacts between distinct flow units were not identified. The characteristic pyroxene phenocrysts are commonly 1-5 mm long, and form 10-20% of the rock, but in places are considerably larger (to 1.5 cm) and more abundant. These may be accompanied by smaller and less conspicuous plagioclase phenocrysts and, locally, by amygdules containing combinations of calcite, epidote, and quartz. The fine-grained groundmass may include relict plagioclase laths, but is typically overprinted by a predominantly epidote and calcite alteration assemblage. Foliated varieties are calcite-epidote-chlorite schists that contain relict pyroxene phenocrysts, typically chlorite-altered and flattened in the foliation plane.

Breccia, consisting of pyroxene porphyry fragments in a matrix of the same material, forms poorly defined units at a number of localities in the main exposure belt of the unit. Some contain angular to amoeboid fragments with sharp to indistinct boundaries enclosed by apparently crystalline pyroxene porphyry, and are interpreted as flow breccias (Fig. 15). Elsewhere, pyroxene porphyry fragments, displaying textural variation, are in an apparently clastic matrix, rich in pyroxene and plagioclase grains, and probably represent local epiclastic accumulations.

Medium to dark green hornblende-pyroxene porphyry is a minor component of the unit. Locally, the hornblende-bearing porphyries are clearly dikes that crosscut adjacent pyroxene-phyric basalt and basalt breccia units but, elsewhere, contact relationships are not displayed, and it is possible that some

Fig. 15. Pyroxene porphyry flow(?) breccia, pyroxene basalt unit of the Nicola Group, 3.4 km west-northwest of Plateau Lake.

could be flows. Hornblende-pyroxene±plagioclase porphyry also occurs as dikes in the underlying volcanic sandstone unit, and forms a sill or flow at one locality in the polymictic conglomerate unit.

The pyroxene basalt unit overlies the volcanic sandstone unit across a transition that features a mixture of the rock types found in the two units. The lower part of this transition contains volcanic sandstone cut by dikes of pyroxene porphyry and pyroxene-hornblende porphyry, and the upper part comprises pyroxene-phyric basalt containing screens of volcanic sandstone and siltstone. The pyroxene basalt unit is not directly dated in the Stump Lake – Salmon River map area, but it is suspected to be Norian, because it is a characteristic lithology of Carnian and Norian Nicola rocks, and the upper part of the underlying volcanic sandstone unit yielded conodonts of probable Norian age.

3.3.3. Polymictic conglomerate unit

The polymictic conglomerate unit contains conglomerates with a distinctive clast population including medium- to coarse-grained mafic plutonic rocks. These conglomerates are intercalated with minor sandstone to pebbly sandstone, and rare pyroxene-hornblende-plagioclase porphyry. This unit forms a single belt, up to 4 km wide, in the central part of the map area. It is underlain by the volcanic sandstone unit to both the east and west, and is therefore inferred to form the core of a NNW-trending syncline.

The polymictic conglomerate unit commonly forms massive, rounded outcrops that contrast with the more recessive exposures of the adjacent volcanic sandstone unit. The rocks are light to medium green or greenish-grey and weather to lighter shades of brown, brownish-green, or beige. The conglomerates are unstratified, poorly sorted, and matrix-supported, with angular to subrounded clasts that commonly range from several millimetres to 10 cm (locally 20-30 cm; Fig. 16). Common clast types include pyroxene (±plagioclase±hornblende)-phyric volcanic rocks, fine-grained equigranular to weakly porphyritc hypabyssal rocks composed of plagioclase, pyroxene and hornblende, and medium to coarse-grained gabbro/diorite. Small pebbles of hornblendite and pyroxenite are also common, whereas clasts of fine-grained quartz diorite, quartz-feldspar porphyry and chert were noted locally, but are rare. The matrix is typically a medium- to coarse-grained feldspathic sandstone that includes sparse to abundant mafic lithic and mineral grains, including hornblende and pyroxene.

Massive, medium to coarse-grained feldspathic sandstone, lithologically similar to the conglomerate matrix, forms a relatively minor proportion of the polymictic conglomerate unit, and locally contains scattered granules and pebbles that display the same range of compositions seen in the conglomerate clasts. In some locations the proportion of sandstone may be overestimated, because conglomerates contain mainly even-textured feldspathic clasts that are difficult to distinguish from the sandy feldspathic matrix.

Pyroxene-hornblende-plagioclase porphyry was observed at one location in the southeastern part of the unit, about 5 km west of Salmon Lake. It comprises 1-5 mm pyroxene phenocrysts (2-5%), sparse hornblende phenocrysts of the same size, and smaller, indistinct, plagioclase phenocrysts, in a fine-grained groundmass. A few metres of coherent porphyry is exposed along the edge of a single outcrop, and passes into conglomeratic sandstone via a zone, several metres wide, of peperite breccia (Fig. 17). This porphyry unit is interpreted as a volcanic rock intercalated with the conglomeratic sandstone, or a sill that cut the host rock before it was completely lithified.

The polymictic conglomerate unit is undated in the Stump Lake – Salmon River area. It is included in the Nicola Group, and suspected to be uppermost Triassic, on the basis of a very strong lithologic similarity with conglomerates in the upper part of the group elsewhere (assemblage four of Schiarizza, 2016).

Fig. 16. Matrix-supported conglomerate with angular gabbro and diorite clasts, polymictic conglomerate unit of the Nicola Group, 5.5 km west-northwest of Salmon Lake.

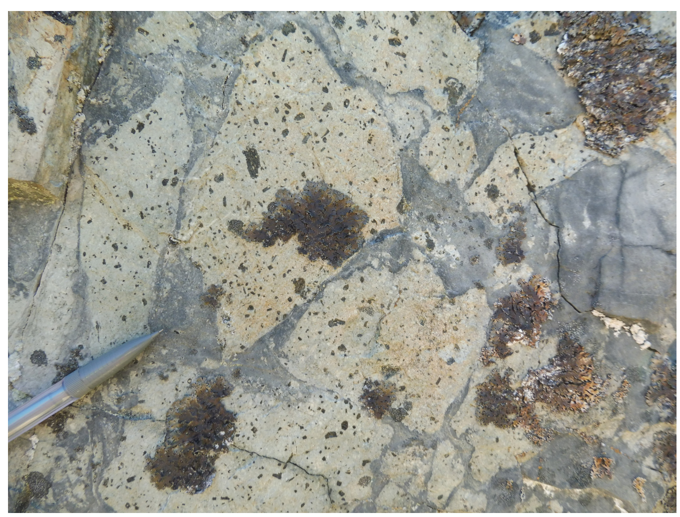


Fig. 17. Peperite breccia from contact between coherent pyroxene-hornblende-plagioclase porphyry and pebbly sandstone, polymictic conglomerate unit of the Nicola Group, 5 km west of Salmon Lake.

3.4. Jurassic intrusive rocks

Light grey, medium- to coarse-grained, isotropic, equigranular biotite-hornblende granodiorite, which cuts the Nicola volcanic sandstone unit south and southwest of Dardanelles Lake, represents the south margin of the Wildhorse batholith (Monger and McMillan, 1989). A small plug of the same composition cuts the volcanic sandstone unit 2 km southwest of the batholith, and a plug of hornblende-biotite tonalite occurs along the south margin of the study area at Salmon Lake (Fig. 3). A sample collected from the Wildhorse batholith southwest of Dardanelles Lake yielded K/Ar ages of 161.8 ±2.4 Ma on biotite, and 169.3 ±2.6 Ma on hornblende (Hunt and Roddick, 1987), whereas a U-Pb zircon crystallization age of 196 ±1 Ma was obtained from the central part of the batholith, about 20 km farther north (Parrish and Monger, 1992). This batholith is near the centre of a 300-km-long belt of Early Jurassic calcalkaline plutons, including the Thuya and Takomkane batholiths to the north, and the Pennask and Bromley batholiths to the south, which forms a prominent component of Quesnel terrane in southern British Columbia (Schiarizza, 2014).

A diorite unit cuts the Nicola volcanic sandstone unit along the north margin of the study area, about 7 km east-southeast of Dardanelles Lake (Fig. 3; Monger and McMillan, 1989). These rocks are undated, but may form part of a border phase to the Wildhorse batholith. The parts of this unit examined in 2016 comprise grey, medium-grained, equigranular to weakly porphyritic diorite containing 65% plagioclase, 30% hornblende and 5% pyroxene. A different diorite unit forms a small plug 4 km east of Stump Lake, where it cuts the volcanic sandstone unit near its contact with the overlying pyroxene basalt unit. The fine- to medium-grained equigranular diorite of this unit consists of plagioclase, lesser amounts of hornblende and biotite, and traces of quartz.

3.5. Kamloops Group

The Kamloops Group, a widespread assemblage of Eocene volcanic and sedimentary rocks (Ewing, 1981), is represented by volcanic rocks that unconformably overlie Mesozoic and Paleozoic rocks at scattered localities in the northern and western parts of the Stump Lake – Salmon River map area. These include fine-grained purple tuff that overlies the Nicola volcanic sandstone unit northeast of Stump Lake, and pale grey plagioclase-quartz-hornblende-biotite-phyric dacite that overlaps the unconformity between the Chapperon Group and Salmon Lake succession near the southeast corner of the map area. The other Eocene outliers were not examined, and are shown on Fig. 3 after Monger and McMillan (1989) and Daughtry and Thompson (2004). The Eocene may also be represented by relatively fresh dikes, including plagioclase porphyry, hornblende-plagioclase porphyry, and hornblende porphyry, that cut the Nicola Group and Salmon River unit at numerous localities within the map area.

4. Structural geology

The oldest structures recognized in the Stump Lake – Salmon River area are a well-developed schistosity (or phyllitic cleavage) and subparallel transposed lithologic contacts in the Chapperon Group. The schistosity is locally re-oriented by younger structures, but typically dips steeply to the south-southeast or north-northwest in the northern part of the area, and steeply to the east or west in the southern part. Folds related to this fabric were not observed, but Read and Okulitch (1977) reported that the schistosity is axial planar to tight mesoscopic folds that plunge gently northeast or southwest. These structures are pre-Late Triassic, because the schistosity and lithologic contacts are truncated by the unconformity at the base of the Salmon River succession (Jones, 1959; Preto, 1964), and variably oriented schistose fragments from the Chapperon Group are in the basal conglomerate of the Salmon River succession (Read and Okulitch, 1977). A Permo-Triassic age is inferred by Read and Okulitch (1977) because similar structures deform Permian rocks that overlie the Chapperon Group to the south, near Dome Mountain.

The lower part of the Salmon River succession, and the unconformity at its base, dip at moderate angles to the west. Higher stratigraphic levels, in the central and western part of the Salmon River belt, are not well exposed, but dips are generally steeper, and dip direction is variable, but typically to the west or north. Mesoscopic folds were observed at scattered localities throughout the Salmon River succession, and have a uniform westward plunge, of 20 to 40° (Fig. 18). The folds typically verge to the south, and the folded rocks locally display a weak axial planar cleavage that dips at moderate to steep angles to the north. North-dipping cleavage is sporadically developed elsewhere in the Salmon River succession, including one exposure in the northeastern part of the belt, one kilometre west of the unconformity, where well-cleaved conglomerate contains moderately flattened clasts with a weak down-dip stretching lineation. Deformation associated with the west-plunging folds is presumed responsible for the variable bedding orientations

Fig. 18. Interbedded limestone and calcarenite of the Salmon River succession, deformed by west-plunging mesoscopic fold, northwest side of the Salmon River, 7.4 km north-northeast of Salmon Lake.

in the upper part of the Salmon River succession, and also for local warping of the unconformity at the base of the succession. Southeast-plunging folds that were observed to deform the schistosity within the Chapperon Group, at one locality a short distance beneath the unconformity, may be the same age. Hints of younger deformation are provided by a siltstone exposure in the southeastern part of the Salmon River succession, where the north-dipping slaty cleavage is cut by a weak crenulation cleavage that dips steeply east.

At the outcrop scale, the Nicola Group displays brittle faults and fractures of variable orientations. A weak cleavage is observed locally, but is well developed only in the western part of the pyroxene basalt unit, east of southern Stump Lake, where it dips at gentle to moderate angles to the west. Mesoscopic folds of bedding were observed at only a few scattered localities in the volcanic sandstone unit. These plunge steeply to the northwest or southeast, and do not have an associated axial planar foliation.

At the map scale, the most prominent structure in the Nicola Group is an anticline-syncline pair that is defined by opposing dips and younging directions in the volcanic sandstone unit, and the distribution of the pyroxene basalt and polymictic conglomerate units (Fig. 3). West-dipping and younging rocks of the volcanic sandstone unit, which form the easternmost Nicola exposures, are overlain, to the west, by the polymictic conglomerate unit, which is apparently preserved in the core of a NNW-trending syncline. East-dipping and younging rocks of the volcanic sandstone unit on the west limb of this syncline pass through a poorly-defined anticlinal fold hinge farther west, to form a wide panel of west-dipping and younging rocks that, 7 km west of the anticlinal hinge, is overlain by the pyroxene basalt unit. The anticlinal hinge in the southern part of the map area trends north-northwest, parallel to the adjacent synclinal hinge, but apparently bends to the west to attain an east-west trend in the northwest part of the map area. This east-west trending anticlinal segment is well defined by opposing dip directions in the volcanic sandstone unit, and the distribution of the overlying pyroxene basalt unit on both north and south limbs. It is less certain whether the east-west and north-northwest trending segments are actually parts of a single fold, or are two separate folds, possibly of different ages.

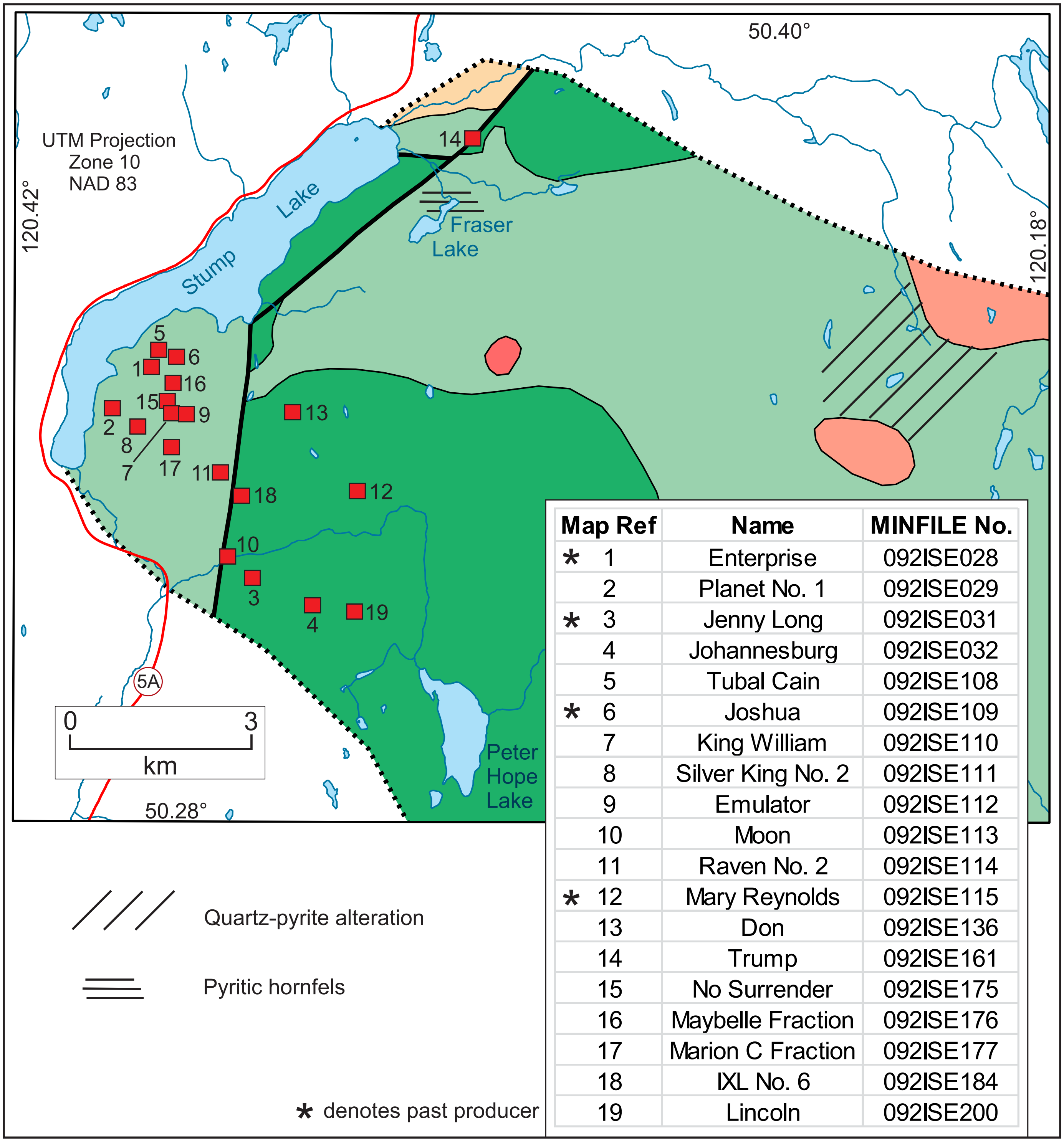
Faults mapped to the east of Stump Lake are relatively young structures, probably related to a complex system of Eocene faults in the region (Ewing, 1980; Moore et al., 1990). One of these, trending north-south, truncates the main exposure belt of the pyroxene-basalt unit, and juxtaposes it against the volcanic sandstone unit to the west. This fault trace is well defined, but the fault itself was not observed. The stratigraphic separation suggests that it has a component of east-side-down displacement. Farther north, a northeast-trending fault truncates the volcanic sandstone unit on the north limb of the map-scale anticline, and juxtaposes it against a panel of pyroxene basalt that forms the eastern shoreline of northern Stump Lake. Where observed, this fault is vertical and marked by several metres of platy ankerite-altered rock, locally cut by veins of magnesite and quartz.

The contact between the Nicola Group and the Salmon River succession is in an area of very poor exposure. It is broadly constrained to trend north-south, but neither the nature of the contact, nor its orientation, are known. It is suspected to be a fault, because the west-plunging folds and associated north-dipping cleavage in the Salmon River succession were not observed in adjacent Nicola rocks, suggesting juxtaposition of two different structural domains. Working farther south, Moore (1989) suggested that the Nicola Group was thrust eastward over the Chapperon Group, and that to the north (i.e. in the current map area), this thrust zone must cut either above or below the Salmon River unconformity. One possibility, therefore, is that this thrust zone has cut upsection through the footwall and forms the contact between the Nicola Group and the Salmon River succession in the Stump Lake – Salmon River map area.

5. Mineral occurrences

Metallic mineral occurrences are known only in the western part of the Stump Lake - Salmon River map area, where they comprise epigenetic polymetallic vein systems of the historic Stump Lake mining camp (Fig. 19). Pyritic alteration zones, unrelated to the Stump Lake vein systems, were noted elsewhere in the western part of the map area, but are not known to host precious or base metal mineralization. The largest alteration zone consists of pyrite-silica-altered siltstones and sandstones of the volcanic sandstone unit, in an area extending from the southwest margin of the Wildhorse batholith to the small satellite stock to the southwest (Fig. 19). Pyritic biotite hornfels was also noted along Fraser Lake (Fig. 19), and may be related to an unidentified intrusion underlying an area of poor outcrop to the east and southeast.

The vein systems of the Stump Lake camp are described by Hedley (1937), Cockfield (1948), and Moore et al. (1990). Mineralization was first reported in the mid-1880s; modest intermittent production extended from 1889 to 1980. The vein systems, suspected to be Eocene, are on both sides of the prominent north-trending fault east of southern Stump Lake. The veins west of the fault are in volcanogenic sandstones of the volcanic sandstone unit; those to the east are in pyroxene-phyric basalts of the pyroxene basalt unit. Mineralization is in veins, lenses and stringer zones of quartz, which are controlled by fracture zones and shear zones that typically dip at moderate to steep angles to the east (Fig. 20). Metallic minerals are mainly pyrite, galena, sphalerite, tetrahedrite, chalcopyrite, bornite and scheelite, locally with arsenopyrite, pyrrhotite and native gold. Alteration adjacent to the veins is mainly Fe-Mg carbonate and pyrite, locally with green mica. Most production from the Stump Lake camp came from the Enterprise vein system, where 71,313 tonnes were mined intermittently from 1926 to 1980 (mainly 1929 to 1941), and produced 7,781,650 g Ag, 254,783 g Au, 1,040,296 kg Pb, 235,148 kg Zn, and 49,562 kg Cu (MINFILE 092ISE028 Production Report).



Map Ref	Name	MINFILE No.
* 1	Enterprise	092ISE028
2	Planet No. 1	092ISE029
* 3	Jenny Long	092ISE031
4	Johannesburg	092ISE032
5	Tubal Cain	092ISE108
* 6	Joshua	092ISE109
7	King William	092ISE110
8	Silver King No. 2	092ISE111
9	Emulator	092ISE112
10	Moon	092ISE113
11	Raven No. 2	092ISE114
* 12	Mary Reynolds	092ISE115
13	Don	092ISE136
14	Trump	092ISE161
15	No Surrender	092ISE175
16	Maybelle Fraction	092ISE176
17	Marion C Fraction	092ISE177
18	IXL No. 6	092ISE184
19	Lincoln	092ISE200

Fig. 19. Mineral occurrences of the Stump Lake mining camp, and pyritic alteration zones in the western part of the Stump Lake – Salmon River map area.

Fig. 20. East dipping quartz vein and fracture zone exposed at top of old shaft at the Joshua occurrence. View is south.

6. Discussion

6.1. Comparison of Nicola subunits in the Stump Lake – Salmon River area to those in the Bridge Lake – Quesnel River area

The Nicola Group in the Stump Lake – Salmon River area consists of three subunits. The volcanic sandstone unit is predominant, and is stratigraphically overlain by the pyroxene basalt unit in the western part of the map area. The polymictic conglomerate unit apparently overlies the volcanic sandstone unit in the central part of the area, where it is inferred to occupy the core of a northerly-trending syncline. The omission of the pyroxene basalt unit in this area, and suspected relationships of correlative rocks to the north, suggest that the polymictic conglomerate unit was deposited above an unconformity (Fig. 21).

The volcanic sandstone unit consists mainly of plagioclase and pyroxene-rich sandstones that were derived from mafic volcanic rocks. Similar sandstones are the predominant component of assemblage two in the Bridge Lake – Quesnel River area (Schiarizza, 2016). Assemblage two, mainly Carnian and lower Norian, also includes basalt flows and breccias, and may comprise volcanic rocks from numerous local centres, distributed across most of the width of the arc, together with epiclastic deposits derived from them. The lack of coherent volcanic rocks in the volcanic sandstone unit in the Stump Lake – Salmon River area may reflect a position east of most volcanic centres, or a restricted age range for the rocks in this area.

The pyroxene basalt unit is a thick, uniform succession of pyroxene-phyric basalt flows and related breccias that rests stratigraphically above the volcanic sandstone unit. It is identical, in predominant lithology and stratigraphic position, to assemblage three of the Bridge Lake – Quesnel River area, which is inferred to represent a major Norian constructional phase in the Nicola arc (Schiarizza, 2016). Data to establish regional thicknesses, areal extent, and stratigraphic relationships from farther west are required to test this correlation.

The polymictic conglomerate unit contains conglomerates with a distinctive clast population that includes abundant hypabyssal and mafic plutonic rocks. These rocks are identical to conglomerates that predominate in assemblage four of the Bridge Lake – Quesnel River area (Schiarizza, 2016), with which they are correlated. Assemblage four reflects significant

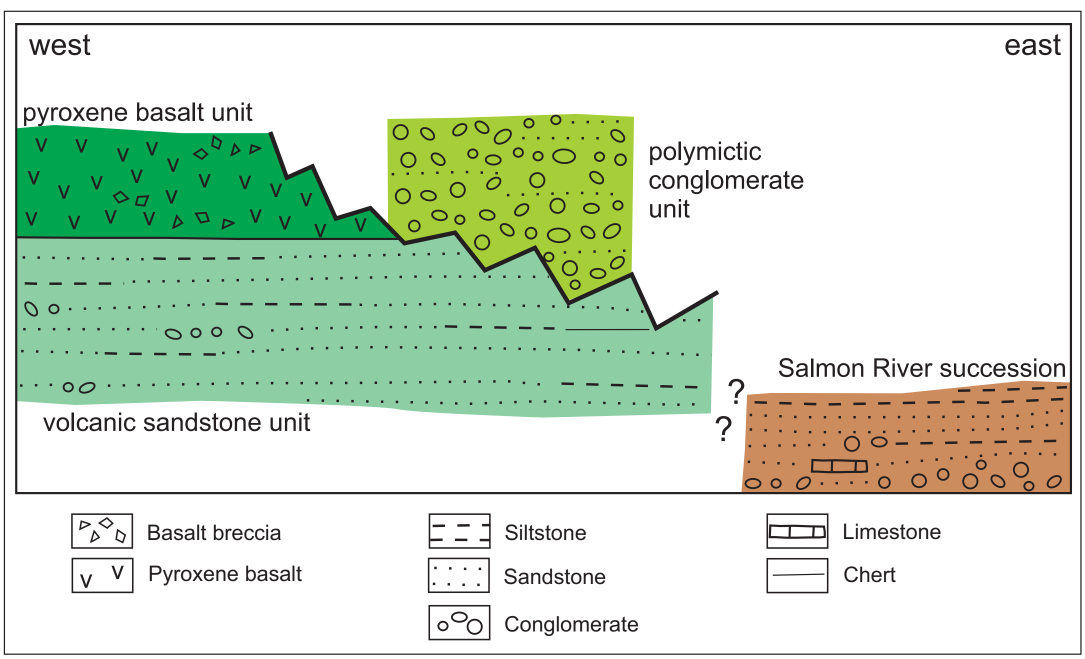


Fig. 21. Schematic summary of stratigraphic relations among Triassic rocks of the Nicola Group and Salmon River succession in the Stump Lake – Salmon River map area.

unroofing of the arc, and is suspected to rest above other units of the Nicola Group across an unconformity. An unconformity beneath the polymictic conglomerate unit is likewise invoked to explain stratigraphic relationships in the Stump Lake – Salmon River area (Fig. 21). Schiarizza (2016) questioned if assemblage four might have accumulated in one or more intra-arc rifts. Although mapped as a simple syncline, it is possible that one or both contacts of the polymictic conglomerate unit are faults, consistent with such an interpretation.

6.2. Correlation of the Salmon River succession

Upper Triassic sedimentary rocks of the Salmon River succession are excluded from the Nicola Group because they do not include volcanic or volcaniclastic rocks typical of age-equivalent Nicola rocks, and lack stratigraphic ties to rocks of the Nicola Group. They are considered part of the Slocan Group, following Daughtry and Thompson (2004) and Thompson et al. (2006). Upper Triassic sedimentary rocks that unconformably overlie the Old Tom and Shoemaker formations near Olalla, 55 km east-southeast of Princeton (Read and Okulitch, 1977; Fig. 2), are probably correlative and are likewise considered an outlier of the Slocan Group.

The Slocan Group and related rocks represent a Triassic sedimentary basin that formed east of, but coeval with, Nicola Group deposition. Stratigraphic ties between the upper parts of the two groups are suggested by local occurrences of volcanic rock, mapped as Nicola Group, that overlie the Slocan Group east and northeast of Kamloops, and near the north end of Okanagan Lake (Thompson et al., 2006; Fig. 2). However, these volcanic units are undated, and they might actually be Lower Jurassic and part of the Rossland Group (Daughtry and Thompson, 2004; Thompson and Beatty, 2004; Thompson and Unterschutz, 2004). The Rossland Group is a prominent component of Mesozoic Quesnel terrane 150 km east of southern Okanagan Lake, and also unconformably overlies the Harper Ranch Group 20 km east of Kamloops (Beatty et al., 2006; Fig. 2). A better understanding of the mutual relationships between the Nicola, Slocan and Rossland groups in the Kamloops – Okanagan Lake area requires further study.

7. Conclusions

The Nicola Group (Triassic) in the Stump Lake – Salmon River area consists of three subdivisions, referred to as the volcanic sandstone unit, the pyroxene basalt unit, and the polymictic conglomerate unit. The volcanic sandstone unit, consisting of pyroxene-feldspar sandstone with intercalations of volcanic conglomerate and siltstone, is predominant. It resembles volcanic-derived sedimentary intervals that are a major component of assemblage two in the Bridge Lake – Quesnel River area (Schiarizza, 2016). The pyroxene basalt unit, a uniform succession of pyroxene-phyric basalt flows and related breccias, overlies the volcanic sandstone unit in the western part of the area. It is similar, in lithology and stratigraphic position, to assemblage three of the Bridge Lake – Quesnel River area. The polymictic conglomerate unit, comprising conglomerates with a distinctive clast population that includes abundant mafic plutonic rocks, overlies the volcanic sandstone unit in the central part of the map area. It is correlated with assemblage four of the Bridge Lake – Quesnel River area, and is suspected to rest unconformably above older units of the Nicola Group.

The Salmon River succession contains Triassic sedimentary rocks, including calcareous sandstone, conglomerate, limestone, and siltstone, which crop out east of the Nicola Group, across a suspected fault contact. These rocks rest unconformably above Paleozoic metamorphic rocks of the Chapperon Group. They are part of a Triassic basin, represented mainly by the Slocan Group, which formed east of the Nicola Group. Relationships between this basin and the coeval accumulation of volcanic and volcaniclastic rocks represented by the Nicola Group are unknown.

Acknowledgments

I thank Isato Wada, who assisted with fieldwork for most of the summer, Lori Kennedy, who provided excellent assistance for one week in August, and Jim Britton, who helped with logistics and shared information on regional geology and mineralization. I also thank the Stump Lake Ranch (in particular, Dan Fremlin), and the Douglas Lake Ranch, for granting access to their properties. Lawrence Aspler provided a thorough review that improved the paper.

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