Southern Nicola Project: Whipsaw Creek–Eastgate–Wolfe Creek Area, Southern British Columbia (NTS 092H/01W, 02E, 07E, 08W)

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KEYWORDS: Nicola Group, Eagle pluton, Eastgate-Whipsaw metamorphic belt, Princeton, Quesnellia, mineral deposits

INTRODUCTION

The Southern Nicola Project area is located on the eastern boundary of Manning Park, about 15 km southwest of the town of Princeton (Figure 1). Tectonically, the project area lies at the western edge of Quesnellia, just inboard of the bounding Pasayten fault, and includes the southernmost exposures of the Late Triassic Nicola Group.

Mapping by Rice (1947), Preto (1972) and Monger (1989) has outlined the essential distribution of Nicola Group strata in the Princeton area (NTS 092H/SE) and their relationships to younger intrusive and volcano-sedimentary sequences. To the east of the Boundary fault, rocks of the Nicola Group are assigned to the 'eastern belt' (Preto, 1979; Mortimer, 1987) and display an alkalic affinity. They host the important porphyry and skarn deposits of the Copper Mountain area (Preto, 1972). To the west, the rocks of the Nicola Group were not assigned to any of the three major belts by Monger (1989), although Mortimer (1987) included them in the calcalkaline 'western belt'.

Adjacent to the Eagle Plutonic Complex in the west, rocks correlated with the Nicola by Rice (1947) and Monger (1989) are remarkable for being more highly deformed and metamorphosed. This belt also shows significant lithological differences to the immediately adjacent Nicola volcanic rocks, and is the host to volcanogenic massive sulphide (VMS) deposits (e.g., Red Star and S and M properties). These dissimilarities in rock type and the presence of VMS deposits cast some doubt on the correlation with the Nicola Group. The belt may be equivalent to the Late Permian to Early Triassic Sitlika-Kutcho sequences, including volcanic rocks and intrusions from the Ashcroft area (Childe et al., 1997), about 150 km north-northwest of Princeton.

Mapping in 2008 focused in the area to the southwest of Princeton (Figure 1). The map area stretches from the Wolfe Creek area and Copper Mountain southwest to Eastgate and the boundary of Manning Park and west to the Whipsaw Creek and Hudson Bay Meadows areas. In 2009, mapping will continue northwards from Whipsaw Creek to the Tulameen and Otter Lake areas.

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PREVIOUS WORK

The Princeton area has a mining history dating from the discovery of placer gold in the 1860s. The first geological report for the area was that of Bauerman (1885), based on work done during the Boundary Commission Expedition of 1859–1861. Regional geological studies were undertaken by Dawson (1877), who defined and described the rocks of the Nicola Group. Subsequent mapping in the Princeton and adjacent areas was undertaken by Camsell (1913), Bostock (1940a, b), Rice (1947), Preto (1972, 1979), Coates (1974), Ray and Dawson (1987) and Monger (1989). Coal-bearing units of the Princeton Group have been described by Camsell (1913), Shaw (1952a, b), Hills (1962) and McMechan (1983), while industrial minerals have been described by Read (1987, 2000). Detailed investigations of the intrusions and associated copper mineralization at Copper Mountain were reported by Dolmage (1934), Fahrni (1951), Montgomery (1967), Preto (1979) and Stanley et al. (1995). No systematic mapping of Quaternary deposits, soils or terrain features has been undertaken in the area.

GEOLOGY

The results of this summer's mapping are summarized in Figures 2 and 3.

Stratified Units

LATE TRIASSIC NICOLA GROUP

The Nicola Group contains the oldest exposed rocks in the area and is the main focus of this project. Rocks previously assigned to the group can be subdivided into three packages. To the east, from Wolfe Creek to the Pasayten River, the Nicola Group sedimentary and volcanic rocks have been assigned to the eastern belt (Preto, 1979; Mortimer, 1987). Rocks to the west, in the Whipsaw–Hudson Bay Meadows area, are presently unassigned to any of the Nicola Group belts. The higher grade metamorphic rocks at the western edge of the map area are herein renamed the 'Eastgate-Whipsaw metamorphic belt'. As outlined above, their correlation with the Nicola Group is equivocal. The metamorphic belt is in fault contact with the Nicola Group proper (Figure 2).

Eastern Part of Map Area

Within the map area, the eastern Nicola Group comprises an unnamed lower sequence of clastic sedimentary rocks, overlain by a mixed volcanic and volcanic sediment package, called the Wolfe Creek Formation by Preto (1972).

Lower Unnamed Sedimentary Rocks

The lower sedimentary sequence is dominated by interbedded black argillite, grey siltstone and sandstone. Finer grained beds are laminated and may have a limy or siliceous matrix. Coarser beds can be graded, laminated or crossbedded, and show bottom structures such as load structures. Beds vary from millimetres to several centimetres thick. Matrix-supported, polymictic pebble to cobble conglomerate layers are intercalated with the finer sedimentary rocks. The clasts are dominantly clastic sedimentary, although sometimes include rare limestone and volcanic material. Limestone beds were not observed but have been reported by Preto (1972).

Grey, orange-weathering crystal and lapilli tuffs are seen bedded in the argillite and siltstone along Placer Mountain Forest Service road. Lapilli are pyroxene-feldspar porphyry, occasionally vesicular and angular in shape. The matrix is chloritic with a fine- to medium-grained calcareous cement that appears to be altered in places to skarn, with minor disseminated pyrite, chalcopyrite and arsenopyrite.

In the southern reaches of Placer Creek, east of the Boundary fault, the sedimentary rocks take on a pronounced phyllitic character. This phyllite is fine grained and dark grey to black with a silvery sheen to the foliation. Beds vary in thickness, reaching up to 10 cm, and have undergone polyphase folding in many areas. Sandy beds tend to lighter grey feldspar-sericite schist. Conglomerate is weakly foliated.

Wolfe Creek Formation

Rocks of the Wolfe Creek Formation are primarily volcanic in origin. Within the map area, they consist of units of volcanic breccia and lapilli tuff, as well as tuffaceous sand-

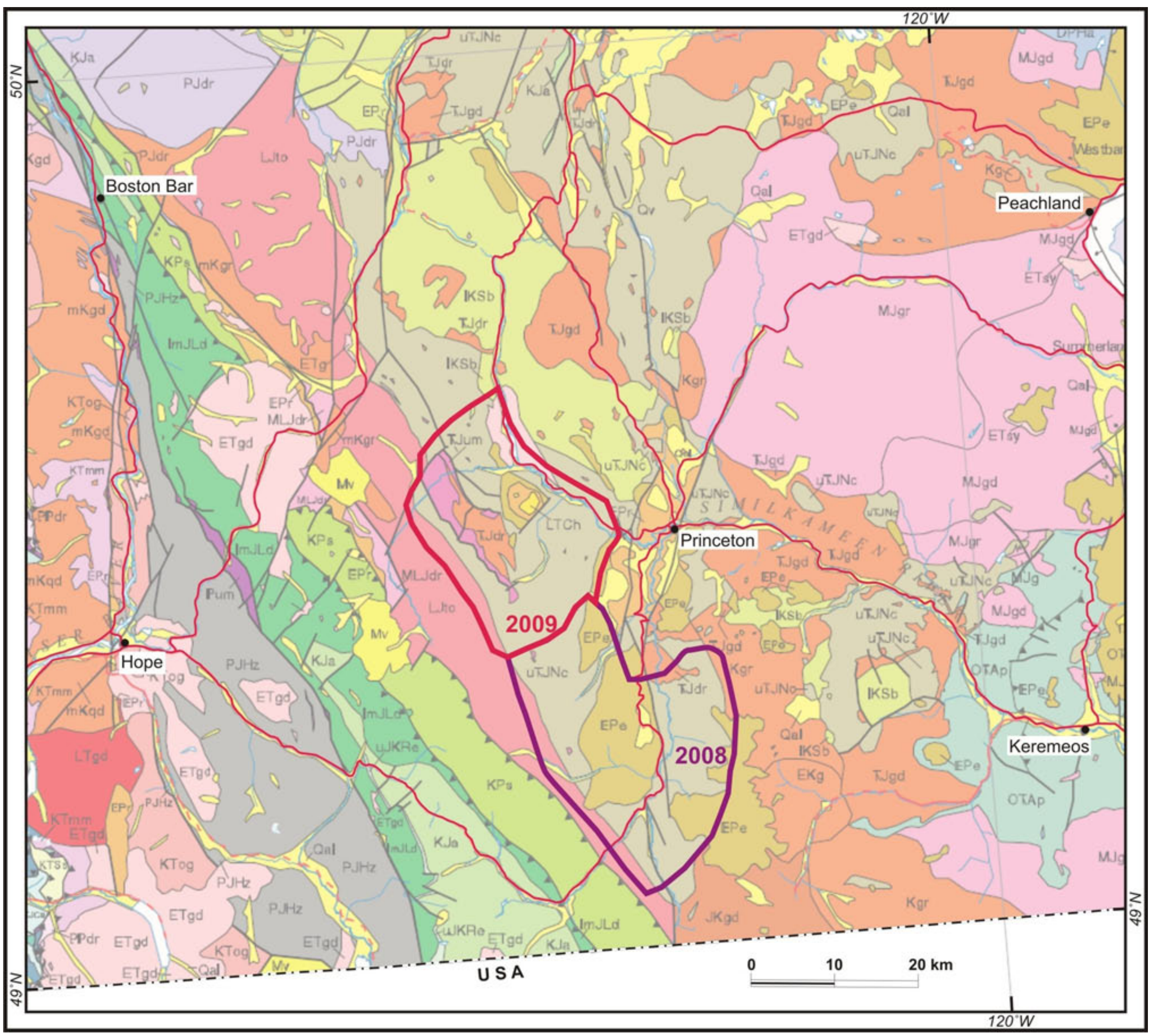

Figure 1. Location of the Southern Nicola Project. Geology base map derived from Massey et al. (2005). Boxes outline the area mapped in 2008 and proposed for 2009. Rocks of the Nicola Group are labelled uTJNc. For other units see Massey et al. (2005).

stone and siltstone. These units are intermixed, but no consistent stratigraphic sequence was determinable.

The fragmental volcanic beds include the interbedded pyroxene-feldspar tuff, lapilli tuff, breccia and agglomerate that are characteristic of the Nicola Group in other areas. They are light grey in colour, weathering to green-grey with orange-stained fracture surfaces. Lithic clasts vary from angular to subrounded and are typically 3–5 cm across, ranging up to 20–25 cm in breccia and agglomerate. They are dominantly pyroxene-feldspar–porphyritic basalt and basaltic andesite, showing a wide variation in proportions and sizes of phenocrysts. Aphyric basalt can also be seen. The clasts are usually matrix supported. The matrix is medium to coarse sand sized, containing feldspar and pyroxene crystals as well as small lithic clasts and chlorite. Epidote, chlorite and calcite occur as alteration minerals in clasts and matrix, and also in veins. Quartz veins are also common. Development of hornfels is common adjacent to the Copper Mountain intrusions, rendering original fabrics cryptic.

Tuffaceous sedimentary rocks comprise well-bedded siltstone, sandstone and conglomerate, and minor cherty argillite. Sandstone units are medium to coarse grained and grey on fresh surfaces, weathering to grey or orange-brown. They are generally massive but may show some grading. They contain abundant subhedral to broken feldspar, pyroxene and lithic fragments in a chlorite matrix. Conglomerate units are polylithic with a variety of rounded to angular clasts. Volcanic clasts are usually pyroxene or pyroxene-feldspar porphyry, but one cobble to boulder conglomerate on the Wolfe-Belgie Branch 1 road contained large boulders of spherulitic obsidian, quartz-eye rhyolite and chert. These are the only felsic rocks observed in the Wolfe Creek Formation within the map area. The sedimentary rocks show pervasive chlorite alteration, veinlets and patches of epidote, and minor amounts of disseminated pyrite.

Western Part of Map Area

The Nicola Group in the western half of the map area is lithologically similar to that in the east, although differing in details of stratigraphic succession. Here, clastic sedimentary rocks—black argillite interbedded with grey to green-grey siltstone and sandstone similar to those in the east—are intercalated with feldspathic tuff, tuff breccia, tuffaceous sandstone, pebbly sandstone and fine-grained cherty siltstone. Pyroxene is rare to absent in these beds. Thin grey limestone beds occur interbedded with argillite along the Lamont Main road.

The clastic sediment and feldspathic volcaniclastic unit passes westwards, and probably upwards, into typical Nicola pyroxene-feldspar tuff, lapilli tuff and breccia. However, in contrast to the eastern part of the map area, most of the exposed volcanic rocks are deformed and schistose. The change from massive to schistose rocks is transitional and gradual from east to west. Initially, the tuff and lapilli tuff look massive in outcrop but display a weak foliation on broken surfaces. This foliation becomes progressively more penetrative to the west. Finer grained tuff produces bluish green-grey chlorite schist. Relict pyroxene is chloritized and varies from euhedral shapes (Figure 4a) to being smeared along the schistosity. Clasts in lapilli tuff and breccia are undeformed to slightly flattened (Figure 4b). Chloritic rims may develop around the clasts, with feathering of their terminations occurring along the foliation.

Eastgate-Whipsaw Metamorphic Belt

Rocks of the Eastgate-Whipsaw metamorphic belt are quite distinct from those of the Nicola Group in either the eastern or western parts of the map area. They are quite heterogeneous but can be divided into three northwest-trending lithological assemblages that show increasing metamorphic grade from greenschist in the east to amphibolite in the west. Foliation and bedding dip to the west, but the stratigraphic significance, or even the stratigraphic integrity, of the three divisions remains unclear. Mineral exploration activity in the S and M camp suggests significant faulting within the package (*see* below), although none was directly observed during the course of mapping.

Amphibolite

Amphibolite forms the western unit of the metamorphic belt and is intruded by the Eagle pluton along its western margin. The amphibolite is overall dark grey to black in colour and typically medium to coarse grained and well foliated, and consists of alternating mafic- and felsic-rich layers (Figure 5a). It comprises black to greenish black amphibole, white feldspar, quartz and minor biotite and magnetite. The elongate amphiboles are usually larger than the subhedral feldspar and quartz, and show marked alignment parallel to the compositional layering, although without distinct lineation. The amphibolite is presumably of volcanic protolith, but generally no relict textures remain. However, some relict pyroxene crystals and cryptic clast outlines are observed in outcrops to the east of Huckleberry Creek (unofficial name) and in the Hudson Bay Meadows area (Figure 5b).

Quartzite–Biotite-Quartz Schist

This subunit occurs in the centre of the metamorphic belt, predominantly to the south in the Eastgate–Pasayten Creek area. It is a package of interbedded quartzite, biotite quartzite, actinolite-biotite quartzite, biotite-quartz schist and minor chlorite schist (Figure 6a) that probably derives mainly from siliceous sediments. Quartzite units are white with orange-brown oxide staining on surfaces. They are recrystallized with a medium to coarse saccharoidal texture. They can be massive but often contain disseminated biotite flakes or thin sericite or biotite layers that impart a foliation to the rock. Distinctive actinolite±biotite quartzite contains black to green actinolite needles that vary from 0.1 to 3 cm in size (Figure 6b). The needles form randomly oriented single crystals, clots and sheaves that lie along the foliation surfaces. Subrounded, blue-black magnetite is also found in some quartzite beds.

Biotite-quartz schist is made up of 50–60% black biotite plates that range up to 3–5 mm in size and define good foliations. Sugary quartz is finer grained and interstitial to the biotite. Contacts between quartzite and biotite schist vary from sharp to gradational. Grey marble occurs as rare thin interbeds within biotite schist in the Pasayten River area. Marble is also reported in trenches and drillcore on the S and M property (*see* below).

Mixed Metavolcanic-Metasedimentary Schist

This is a very heterogeneous package of schist that lies along the eastern margin of the metamorphic belt. It includes fine- to medium-grained, dark to light grey or grey-green chlorite, chlorite-quartz and chlorite-sericite schists (Figure 7), and pale buff-orange to silvery grey sericite, sericite-quartz±feldspar and sericite-chlorite schists and paper schists (Figure 8a). Red and blue rounded quartz eyes are common in some sericite schist. Biotite and magnetite may be minor phases in some chlorite schist. Quartz veins are common, often boudinaged or tightly folded.

The schists appear to be derived from fine-grained laminated sediments or volcanic tuffs and tuffaceous sediments. Original volcanic fabrics are not preserved, although relict chloritized pyroxene is seen in chlorite schist in the Whipsaw Creek area.

Pale grey to red and blue banded, fine-grained saccharoidal quartzite occurs near the Redstar showing and is prob-

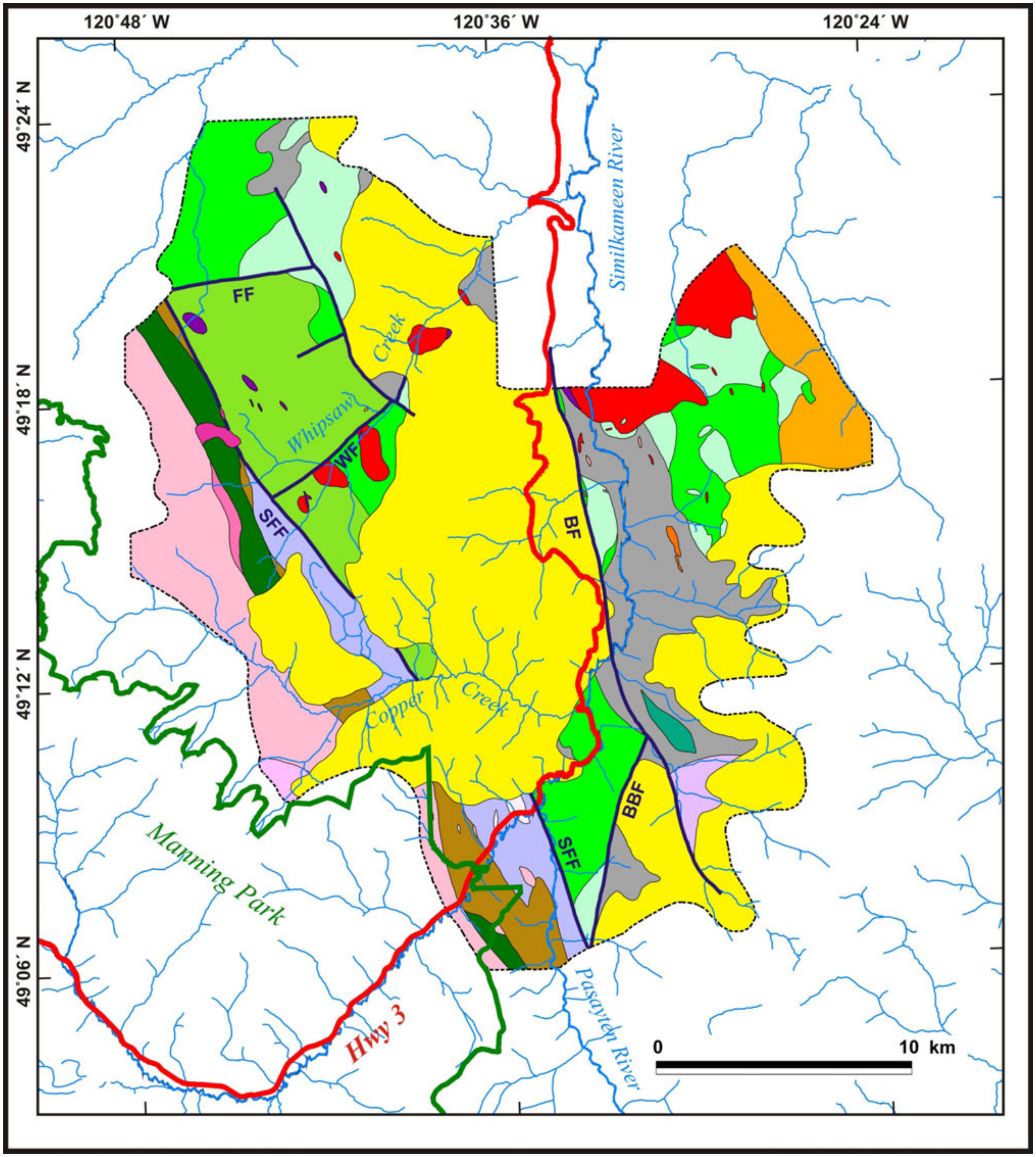

Figure 2. Geology of the 2008 map area. *See* Figure 3 for key to geological units. Abbreviations: BF, Boundary fault; BBF, Baby Buggy fault; SFF, Similkameen Falls fault; WF, Whipsaw Creek fault; FF, Frenchy Creek fault.

ably a meta-chert (Figure 8b). This is massive to weakly foliated with fine-grained sericite along cleavage planes. Other minor rock types include massive grey to grey-green metabasalt and massive to weakly cleaved, white to bluish pink, quartz-eye biotite rhyolite. Weakly foliated, white to pale buff, leucocratic quartz-feldspar porphyry forms several dikes and a small stock in the Similkameen Falls area. It is unclear if this porphyry is correlative with the schist or related to the younger Eagle pluton.

PRINCETON GROUP

Eocene rocks of the Princeton Group occur at higher elevations in the central and eastern parts of the map area (Figure 2). They lie unconformably on the Nicola Group and all older intrusive rocks. Significant paleorelief is evident on the unconformity and was estimated at more than 300 m by McMechan (1983).

Within the map area, the Princeton Group is a heterogeneous sequence of mafic to felsic, mostly subaerial, alkalic volcanic and minor clastic sedimentary rocks. Exposure is often limited and discontinuous, and stratigraphic relationships are difficult to infer. Read (2000) correlated the volcanic rocks (not designated on Figure 2) with the Cedar Formation, formerly called the ‘Lower Volcanic Formation’ (Shaw, 1952a; McMechan, 1983), and suggested a Middle Eocene age based on whole-rock K-Ar dating. He also correlated conglomerate and sandstone of the Sunday Creek area with the overlying Allenby Formation, also of Middle Eocene age.

The volcanic rocks vary widely in lithology and composition, from mafic to felsic, aphyric to porphyritic, and massive to volcaniclastic, often changing character within tens of metres. Although generally quite fresh in appearance, the volcanic rocks can show a variety of weathering colours, with pink and purple hues common but including some very distinctive blue-green shades. Zeolite was observed in some vesicles and vugs, and is reported in tuffaceous sedimentary rocks (Read, 1987).

Volcanic units of intermediate composition are most common and generally display porphyritic textures. These include varieties of feldspar-pyroxene, feldspar-hornblende and feldspar-pyroxene±hornblende andesite; megacrystic feldspar andesite; hornblende-biotite-feldspar and feldspar-hornblende±quartz dacites; and monolithic and heterolithic andesitic lapilli tuffs, pyroxene and feldspar crystal tuffs, and fine-grained dacitic tuff. Felsic units include massive, light grey to white or pink, rhyolite, quartz and feldspar crystal tuffs, and lithic rhyolite tuff. Mafic units are dark grey or brown in colour and massive, although occasionally columnar jointed or vesicular. Minor phenocrysts of olivine, pyroxene, feldspar or analcite were observed.

Interbedded with the volcanic units are volcanic breccia, conglomerate and finer clastic sedi-

Figure 4. Schistose volcanic rocks of the Nicola Group: **a)** relict pyroxene crystals in chlorite schist (field station 08JVI22-07-02; UTM Zone 10, 5459675N, 667153E, NAD83); **b)** schistose pyroxene lapilli tuff; clasts are flattened within the foliation (08NMA31-09; UTM 5465573N, 667794E).

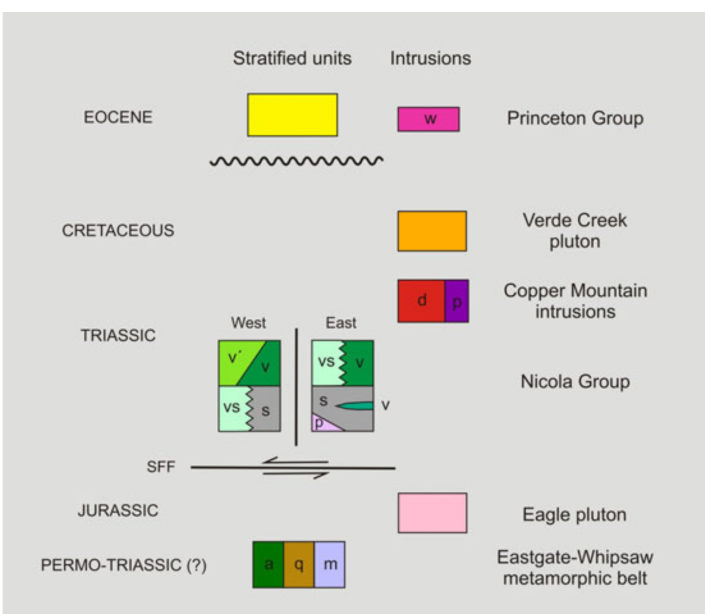

Figure 3. Geological units in the map area. Nicola Group abbreviations: s, clastic sedimentary rocks; p, phyllite; v, volcanic rocks; vs, volcaniclastic sedimentary rocks; v´, schistose volcanic rocks. Eastgate-Whipsaw metamorphic belt abbreviations: a, amphibolite; q, quartzite–biotite-quartz schist; m, mixed metavolcanic-metasedimentary unit. Intrusive units abbreviations: w, Whipsaw porphyry; d, diorite; p, pyroxenite; SFF, Similkameen Falls fault.

mentary rocks. Clasts in the breccia and conglomerate beds vary from pebble to boulder size and are polymictic, with clasts of rhyolite to basalt, beige claystone, grey siltstone and rarely granite. Other beds include black or purple argillite, light grey tuffaceous sandstone, fine- to medium-grained light grey sandstone, and light grey felsic gritstone.

Intrusive Rocks

Several phases of intrusions have been observed, mostly peripheral to the map area. These include the Late Triassic–Early Jurassic Copper Mountain intrusions, the Middle–Late Jurassic Eagle pluton and the Cretaceous Verde Creek pluton.

LATE TRIASSIC–EARLY JURASSIC INTRUSIONS

Copper Mountain Intrusions

The Copper Mountain intrusions include four main bodies (Preto, 1972), of which only two, the Copper Mountain and Voigt stocks, fall within the map area. These bodies intrude and cause hornfels alteration of the Nicola Group rocks. Uranium-lead dating of zircon and titanite from various phases of the body suggests an age of 206–200 Ma (Mortensen et al., 1995).

The Copper Mountain stock was mapped by Dolmage (1934) and Montgomery (1967) as a concentrically zoned, differentiated intrusion grading from an outer mafic diorite through monzonite into a syenite core. Only the outer mafic zone occurs within the map area. The diorite is white to grey with a pinkish colour on weathered surfaces. It is equigranular and medium to coarse grained (averaging 1–2 mm in size), and displays a typical salt-and-pepper texture. Mineralogically, the diorite has approximately equal proportions of subhedral to euhedral, creamy white K-feldspar and grey subvitreous plagioclase. Colour indices range from 30 to 35, with principal mafic minerals being pyroxene and lesser hornblende and/or biotite. The Copper Mountain diorite has a high magnetic susceptibility, with an average range of 10–50 and highs of 90–140, and easily deflects a pen magnet. Epidote and chlorite veinlets, some with potassic alteration halos, are fairly pervasive throughout the diorite. Sparse xenoliths are seen in a few outcrops, including fine-grained hornfelsed metasedimentary rocks and mafic pyroxene porphyry.

Coarse biotite-olivine pyroxenite is associated with the diorite in the lower reaches of Friday Creek. The pyroxenite is dominantly black pyroxene with green trans-

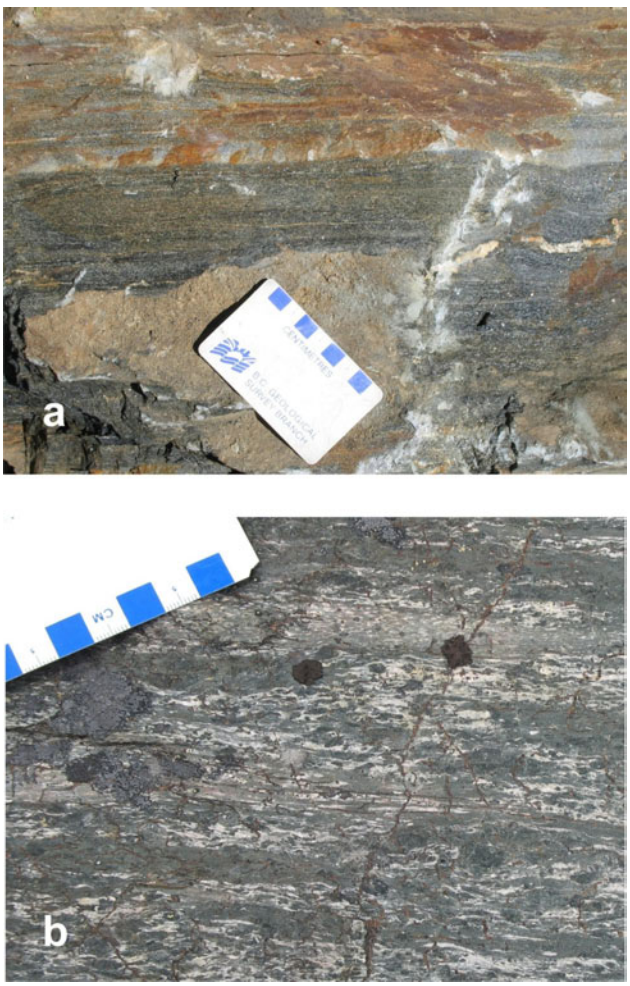

Figure 5. Amphibolites of the Eastgate-Whipsaw metamorphic belt: **a)** well-foliated medium-grained amphibolite (field station 08NMA16-04; UTM Zone 10, 5442156N, 674387E, NAD83); **b)** amphibolite with relict pyroxene crystals and cryptic clast outlines (08NMA30-09; UTM 5460351N, 664310E).

Figure 6. Quartzite–biotite-quartz schist of the Eastgate-Whipsaw metamorphic belt: **a)** interbedded quartzite, biotite quartzite and biotite-quartz schist; note schistosity is subparallel to bedding (field station 08NMA20-11; UTM Zone 10, 54448316N, 673430E, NAD83); **b)** coarse actinolite needles and sheaves in biotite quartzite (08NMA17-06; UTM 5442201N, 675785E).

lucent olivine, black magnetite and sparse white feldspar. Biotite forms very coarse grained pegmatite-like patches, as well as smaller grains scattered within the pyroxenite. It can be associated with pink K-feldspar veins and alteration patches, some of which show malachite staining, suggesting that it may result, at least in part, from potassic alteration of the original olivine pyroxenite.

Microdiorite and mafic pyroxene porphyry occur as minor intrusions associated with the Copper Mountain stock.

The Voigt stock consists of green-grey, equigranular, fine- to medium-grained diorite that weathers to a light grey colour. Feldspar is mostly white plagioclase, while mafic minerals are dominantly pyroxene with lesser biotite. A hornblende-rich phase, with minor pyroxene and biotite, was also observed. As with the Copper Mountain diorite, the Voigt stock is quite magnetic. Two types of crosscutting veinlets are found throughout the intrusion. The first, and most common, is epidote-chlorite veinlets, and the second is K-feldspar–filled veinlets. Epidote alteration patches are also commonly seen within the diorite.

Other Diorite and Pyroxenite Stocks

Several small stocks of mafic diorite and pyroxenite are found intruding Nicola Group rocks in the Whipsaw Creek area. Their correlation is uncertain, however, as they may be related to the Copper Mountain intrusions or to the Late Triassic Tulameen Complex (Nixon et al., 1997).

Figure 7. Interlaminated chlorite and sericite schists (meta-argillite-metasiltstone interbeds) in the Eastgate-Whipsaw metamorphic belt (field station 08NMA23-12-02; UTM Zone 10, 5457516N, 6660687E, NAD83).

The diorite is fine to medium grained and has typical grey salt-and-pepper fresh surfaces with brown or brick red to grey weathered surfaces. It is composed primarily of white feldspar and greenish black hornblende, with colour indices varying from 30 to 50 in most outcrops, but up to 70 in melanocratic phases. Minor minerals include rare euhedral biotite flakes, pyroxene or quartz.

Pyroxenite is dark green to black on fresh surfaces and weathers dark grey. It is coarse grained with crystals ranging from 1 to 3 cm. Pyroxene constitutes 80–90% of the rock, the rest being chlorite, magnetite and minor feldspar. Epidote-chlorite veinlets are common; serpentinite and calcite alteration is rare. The pyroxenite outcrops separately from but close to the diorite. Contacts are rarely seen but suggest that the diorite is intrusive into the pyroxenite.

JURASSIC–CRETACEOUS EAGLE PLUTONIC COMPLEX

The Eagle Plutonic Complex lies along the western margin of the map area (Figure 2), intruding and being deformed with the Eastgate-Whipsaw metamorphic belt. Greig (1992) described the complex immediately to the

Figure 8. Metavolcanic-metasedimentary rocks of the Eastgate-Whipsaw metamorphic belt: **a)** sericite-chlorite paper schist with two obliquely crosscutting schistosities (field station 08NMA19-01; UTM Zone 10, 54469396N, 674182E, NAD83); **b)** s-fold in laminated quartzite (meta-chert; 08NMA18-06-01; UTM 5447070N, 674145E).

north. Within the map area, most outcrops belong to Grieg's 'Eagle tonalite', although, in the absence of petrographic data, these were called biotite granodiorite in the field, which terminology is retained here. Greig et al. (1992) reported Middle–Late Jurassic U-Pb zircon ages for the Eagle tonalite.

The biotite granodiorite is a syntectonic intrusion with varying texture and fabrics. A range of foliate fabrics from massive to gneissic is seen in the granodiorite, particularly in the marginal portions.

Massive phases are equigranular to seriate, varying in grain size from 3–5 mm to 5–6 mm. White feldspar forms subhedral laths. Translucent grey quartz is irregular, often interstitial to feldspar and biotite, and may be smaller in grain size. Biotite is typically black and micaceous and makes up 10–25% of the rock. Minor epidote and red garnet are common. Finer grained microgranodiorite (1–2 mm grain size) is of similar mineral composition, although more melanocratic with up to 50% biotite.

Weakly foliated granodiorite is similar to the massive phase, except that biotite shows a marked alignment (Figure 9a), may cluster and may also be coarser grained. In foliated phases, biotite forms penetrative sheets, or folia, that break the granodiorite into layers 1–10 cm thick (Figure 9b). Within the layers between folia, biotite is aligned parallel to the folia. White feldspar megacrysts up to 1–2 cm can be associated with the biotite folia, giving a very distinctive spotted look to surfaces. Biotite folia may be folded into tight isoclinal folds (Figure 9c)

Biotite gneiss occurs in the Whipsaw Creek area, marginal to the intrusion (Figure 9d). Layers of biotite or biotite-feldspar alternate with leucocratic feldspar-quartz layers. The gneiss is intruded and included by massive granodiorite. The mineralogy of the gneiss contrasts with that of the amphibolite of the adjacent Eastgate-Whipsaw metamorphic belt and suggests that it may be related to the 'Eagle gneiss' unit of Greig (1992).

Coarse quartz-feldspar-biotite pegmatite and leucocratic feldspar-quartz aplite intrude all phases of the granodiorite, massive or foliated. Rare muscovite granite, probably related to muscovite granite in the mid-Cretaceous Fallslake Plutonic Suite (Greig, 1992; Greig et al., 1992), occurs as a minor phase in the southern Copper Creek area, as well as occasional thin dikes. The granite contains both pink and white feldspars, quartz, muscovite,

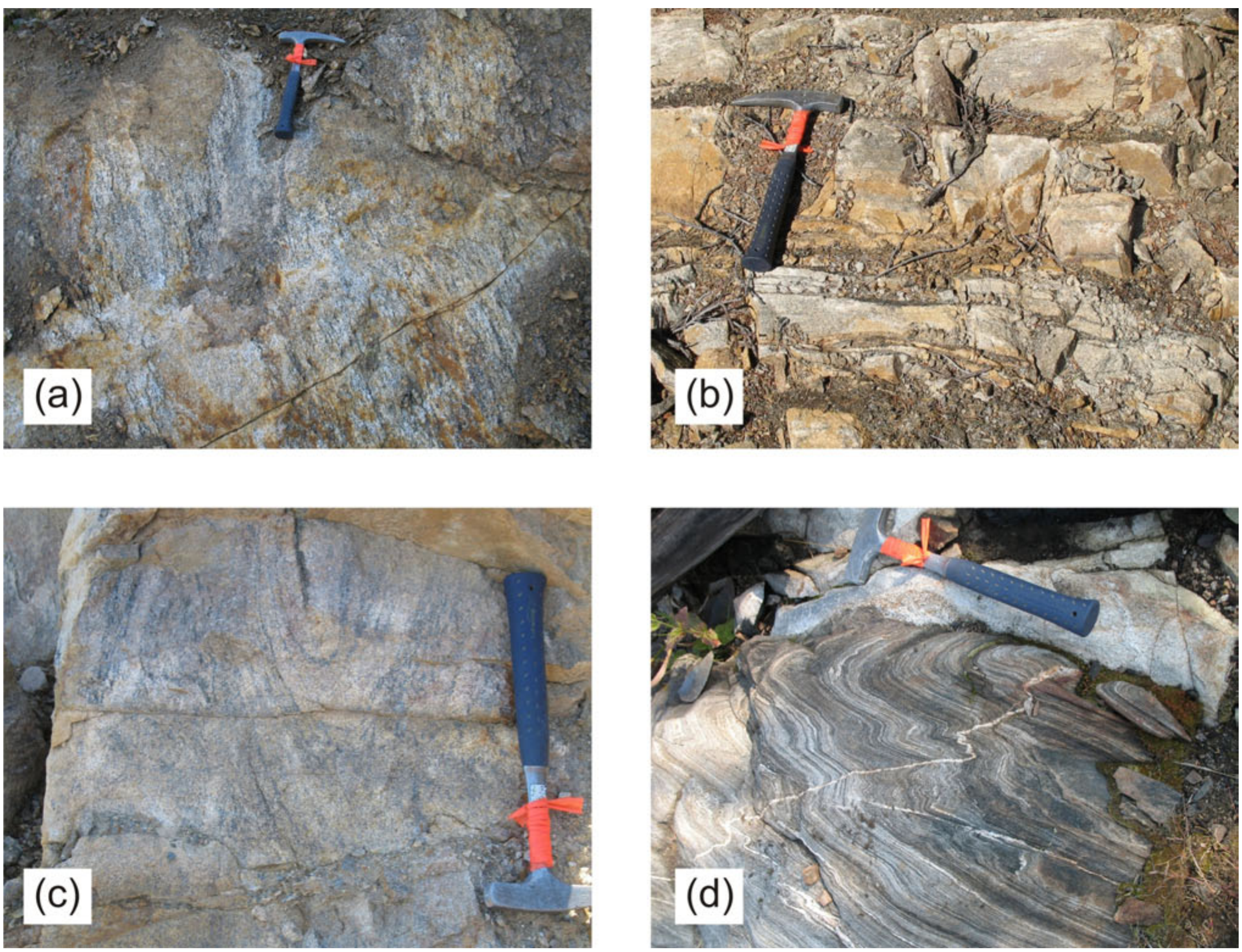

Figure 9. Foliated rocks of the Eagle Plutonic Complex: **a)** weakly foliated biotite granodiorite (field station 08NMA24-05; UTM Zone 10, 5457745N, 663754E, NAD83); **b)** biotite folia between layers of weakly foliated biotite granodiorite (08NMA24-06; UTM 5457773N, 663966E); **c)** folded foliation in gneissic granodiorite (08NMA25-07; UTM 5456645N, 661853E); **d)** biotite gneiss intruded by massive biotite granodiorite (08NMA27-02; UTM 5459801N, 663688E).

biotite and minor red garnet. Pink K-feldspar may form megacrysts up to 2 cm in size.

CRETACEOUS VERDE CREEK QUARTZ MONZONITE

Quartz monzonite of the Verde Creek stock is variable in texture from medium to coarse grained, and from equigranular to porphyritic. It is generally pinkish grey to grey in colour, weathering buff to orange with dark iron and manganese staining on fracture surfaces. The quartz monzonite is leucocratic, with white plagioclase, pinkish K-feldspar and clear quartz. Myrmekitic intergrowths of quartz and feldspar are common. Quartz contents are commonly about 10–15% but range up to 25% in more granitic phases. Mafic minerals range from 2 to 7%, with hornblende usually more common than biotite. Miarolitic vugs, lined with brown-red–stained quartz crystals, are common. The vugs are usually elongate and can be as long as 7 cm. Minor intrusive phases include a distinctive needle hornblende porphyry, characterized by long, thin laths of hornblende up to 2.5 cm long. Contacts with the quartz monzonite are equivocal and perhaps transitional. Pink feldspar porphyry, possibly a chill phase of the quartz monzonite, is occasionally seen as xenoliths within the margin of the quartz monzonite stock.

Rice (1947) correlated the Verde Creek stock with the Otter granite and assigned it an “Upper Cretaceous or later” age. Preto reported two K-Ar ages of 101 ±4 Ma and 98 ±4 Ma (recalculated to 102 ±8 Ma and 100 ±8 Ma, respectively, by Breitspecher and Mortensen [2004]) from biotite of the Verde Creek stock, which suggest a late Early Cretaceous age.

TERTIARY (?) INTRUSIONS

Many minor intrusions occur through out the map area. A bimodal suite of dikes in the area around and to the east of Copper Mountain has been called the ‘Mine Dykes’ in the older literature (Preto, 1972). These are dominated by buff to cream, quartz and pink feldspar porphyries and aphyric fine-grained felsite. They demonstrate characteristic Liesegang rings or ‘picture rock’ alteration. Minor brown-weathering, black, aphyric mafic dikes are also found. The age of the ‘Mine Dykes’ is uncertain. They may be comagmatic with the Eocene Princeton Group volcanic rocks, although Preto (1972) suggested a Late Cretaceous to Early Tertiary age.

Intermediate to felsic dikes of more certain correlation with the Princeton Group are ubiquitous in the map area. They include feldspar basalt; pyroxene, pyroxene-feldspar and hornblende±feldspar andesite porphyries; hornblende-feldspar, feldspar and aphyric dacites; and rare rhyolite.

The Whipsaw porphyry forms a small stock and associated dikes in the Fortyfive Mile Creek area, north of Whipsaw Creek. This grey to pink porphyry is marked by abundant (20–30%) white to pink feldspar laths, up to 5–8 mm in size. Quartz is less abundant (1–5%) and forms smaller (1–3 mm) rounded crystals. Hornblende and biotite phenocrysts are tabular, greenish black and often altered to epidote, making identification difficult. Disseminated sulphides and malachite staining are observed in some outcrops. The age of the Whipsaw porphyry is unknown. It intrudes the Eagle pluton and may be correlated with porphyries of the Late Cretaceous Otter Lake suite in the Tulameen area to the north. Alternatively, it may be comagmatic with the Princeton Group.

STRUCTURE

Folds

Coarse clastic sedimentary rocks of the Princeton Group in the Sunday Creek area have been correlated by Read (1987) with the Allenby Formation, which overlies the older volcanic rocks of the Cedar Formation in the core of the Kennedy Lake syncline. This runs north-south, subparallel and adjacent to the Boundary fault. Limited outcrop and scarcity of structural information preclude identification of other major folds within the Princeton Group in the map area.

In the eastern half of the map area, lack of regional markers and suspected facies changes within the volcanic and volcaniclastic rocks of the Nicola Group render the identification of major folds difficult. Observed bedding attitudes generally strike north-northwesterly in the north and become more northwesterly to the south. Dips are steep, 60–80 to both the northeast and the southwest, perhaps suggesting some upright isoclinal folding. Shallower east-northeasterly dips, about 45 , occur in the Wolfe Creek area, south of Copper Mountain.

Schistosities in the western part of the Nicola Group are subparallel to bedding where both are observed, and to bedding in nonfoliated units. They strike north-northwesterly with shallow to moderate (20–45) westerly dips. Dips steepen in the west to 60–70 , closer to the Similkameen Falls fault. East-northeasterly-striking schistosity is found to the south of the Frenchy Creek fault and also adjacent to the Whipsaw Creek fault. The age of deformation within the Nicola Group rocks is unknown.

The metamorphic rocks of the Eastgate-Whipsaw metamorphic belt and Middle–Late Jurassic, syntectonic granodiorite of the Eagle pluton show variable, moderate to steep (60–90) westerly dipping schistosity that parallels the belt orientation. Two schistosities are discernible in some outcrops crosscutting at an acute angle (Figure 8a). It is often difficult to determine the relative order of formation of these schistosities, which may have resulted from progressive deformation rather than two separate events. Minor S- and Z-folds of the foliations, intrafolial quartz pods or granodiorite bands (Figure 9c) show variable plunges from steep to shallow and trending to either the northwest or the southeast. Anomalous northeast- and north-northeast-striking schistosity and bedding attitudes are found just west of the Pasayten River. The westerly-dipping structures within the Eastgate-Whipsaw metamorphic belt match those reported by Greig (1992) farther to the north.

Major Faults

The majority of Princeton Group volcanic and sedimentary units in the central part of the map area accumulated within a half-graben bounded on its eastern side by the Boundary fault (Figure 2). This subvertical normal fault was first identified by Preto (1972), and confirmed by Read (1987) in an area to the north. Present mapping continues the trace of the fault to the south, where it curves into the valley of Placer Creek. A smaller Tertiary graben is indicated to the west of Placer Creek, bounded by the Boundary and Baby Buggy faults. Despite considerable movement during the Eocene, the Boundary fault is part of a larger system extending to the north and suspected by Preto (1979) to have been established early in the geological history of the region, controlling the facies distributions and pluton emplacement within the Nicola Arc.

Three northeast- to east-northeast-trending faults are interpreted within the western Nicola Group volcanic rocks (Figure 2). Massive, nonschistose, feldspathic volcaniclastic rocks and pyroxene lapilli tuffs and breccias occur on the south side of Whipsaw Creek valley, intruded by massive diorite and pyroxenite. In marked contrast, north-northwesterly-trending schistose pyroxene-phyric volcanic rocks occur on the north side of the valley. Similarly, the Frenchy Creek fault separates nonfoliated rocks to the north from schistose volcanic rocks to the south. The age of this faulting is unknown, but postdates schistosity generation in the volcanic rocks.

The Eastgate-Whipsaw metamorphic belt is separated from Nicola Group volcanic rocks by the northwest-trending Similkameen Falls fault. This is best seen along Highway 3 about 1 km south of Similkameen Falls (Figure 10). Here the fault places northeast-trending interbedded sericite and chlorite schists against massive pyroxene lapilli tuff of the Nicola Group. The fault trace appears to be linear, continuing to the southeast along the Pasayten River and to the northwest into the Hudson Bay Meadows area, and is therefore interpreted to be steep. The age of the fault is unknown. It terminates the easterly-trending faults in the western belt of the Nicola Group. It also appears to acutely crosscut the three lithological assemblages of the Eastgate-Whipsaw metamorphic belt, suggesting that it postdates the Middle–Late Jurassic deformation. The fault trace is sealed by the Whipsaw porphyry and overlain by Princeton Group strata. Motion must have therefore concluded before the Eocene.

MINERALIZATION

Some 38 mineral occurrences are reported for the map area in the MINFILE database (Table 1; MINFILE, 2008). Sixteen of these occurrences lie in the northeast corner of the map area (Figure 11) and are related to the Copper Mountain alkalic porphyry Cu-Au system, which has been described in detail by several authors, including Dolmage (1934), Fahrni (1951), Montgomery (1967) and Preto (1979). Within the map area, showings display a variety of styles, including veins, stockworks, shear zones or disseminated chalcopyrite-bornite-pyrite mineralization hosted in Copper Mountain diorite, Voigt diorite or Nicola Group volcanic and sedimentary rocks. Platinum and palladium minerals are found in faults and shears in Copper Mountain pyroxenite and diorite.

Both the Red Star and S and M massive sulphide camps occur in rocks of the Eastgate-Whipsaw metamorphic belt. At the Red Star, mineralization is hosted by a wide zone of strongly sheared, strongly schistose quartz-sericite-pyrite schist, sericite schist and chlorite schist of the metavolcanic-metasedimentary subunit. Intense sericitization is characteristic over the entire Red Star horizon; silicification and pyritization are also common. Several styles of mineralization have been identified, including pyritized silicified schist; white sugary quartz-carrying pyrite, sphalerite, chalcopyrite and galena; and glassy quartz with patches or blebs of pyrite, chalcopyrite and rarely bornite with chalcocite. Pyrrhotite, tetrahedrite, Au and tellurides have also been reported. The best mineralization is associated with the Main zone, which extends north-south for 480 m and generally consists of disseminated sphalerite and chalcopyrite in quartz veins and sweats within highly sheared, sericitic schist. Significant sphalerite, chalcopyrite with galena, Ag and Au mineralization was reported from the underground workings, which have since caved in. A lens of massive, coarse-grained sphalerite, pyrite and chalcopyrite occurs within the Main zone. Minor bornite, galena, molybdenite and pyrrhotite are also present. Gangue minerals include quartz, barite, kaolinite and sericite.

In the S and M camp, mineralization is hosted in a north-trending fault zone that cuts schist of the metavolcanic-metasedimentary subunit and amphibolite. The brecciated fault zone varies from 5 m to greater than 10 m in width and extends for about 1.5 km. The breccia contains 2.5–25 cm fragments in a matrix of sheared clayey rock and fault gouge that may be cemented by ankerite, dolomite or calcite. Many of the breccia fragments consist of massive to semimassive sulphides, comprising sphalerite, galena, pyrite, chalcopyrite and argentite with carbonate. Pyrite,

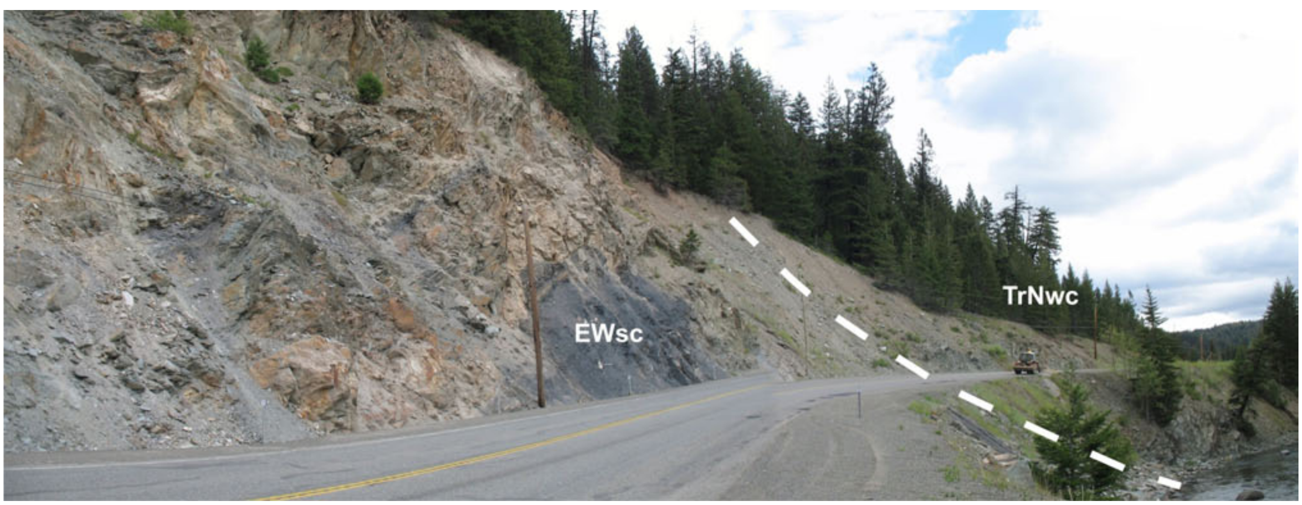

Figure 10. Similkameen Falls fault, separating chlorite and sericite schists of the Eastgate-Whipsaw metamorphic belt (EWsc) from massive pyroxene lapilli tuff of the Nicola Wolfe Creek Formation (TrNwc; station 08NMA21-02; UTM Zone 10, 5447430N, 675927E, NAD83).

Table 1: Mineral occurrences in the map area (*from* MINFILE, 2008). Note that only the principal name is shown for each occurrence for brevity. Deposit type codes: C01, surficial placer; D01, open-system zeolite; D03, volcanic redbed Cu; G04, Besshi massive sulphide; G06, Noranda/Kuroko massive sulphide; I01, A-quartz vein; I05, Ag-Pb-Zn±Au polymetallic veins; I06, Cu±Au veins; K01, Cu skarn; K02, Pb-Zn skarn; L01, subvolcanic Cu-Ag-Au (As-Sb); L03, alkalic porphyry Cu-Au; L04, porphyry Cu±Mo±Au.

MINFILE number	Name	Status	Commodities	Latitude	Longitude	Deposit type	Zone	Easting	Northing
Copper Mountain camp									
092HSE021	Falum	Showing	Cu, Au	49.338050	-120.471100	L03	10	683705	5468113
092HSE022	Azurite	Showing	Cu	49.330280	-120.480000	L03	10	683089	5467227
092HSE027	Jennie Silkman	Prospect	Cu, Au	49.312780	-120.508100	L03	10	681115	5465214
092HSE029	Marquis of Lorne	Prospect	Cu, Ag	49.291940	-120.513900	L03, K01	10	680767	5462884
092HSE031	Johnston	Showing	Cu	49.291390	-120.533100	L03	10	679375	5462777
092HSE033	Friday Creek	Prospect	Cu, Au, Ag, Pd, Pt	49.300000	-120.560600	L03	10	677345	5463669
092HSE044	St. Louis Fraction	Showing	Cu, Ag	49.284720	-120.536400	L03	10	679157	5462028
092HSE092	Skagit 1 Fraction	Prospect	Cu, Ag	49.291940	-120.506400		10	681312	5462902
092HSE109	OX	Showing	Cu	49.268610	-120.521100	L03	10	680327	5460274
092HSE114	Reco	Prospect	Cu, Au, Ag	49.285280	-120.545300	L03, L01	10	678509	5462069
092HSE121	Enterprise	Showing	Cu	49.290550	-120.540800	L03	10	678813	5462666
092HSE132	TAS	Showing	Cu	49.279450	-120.449700	D03, L03, L01	10	685479	5461651
092HSE192	Y	Showing	Cu	49.284440	-120.487500	L01, G04	10	682713	5462114
092HSE193	Y 46	Showing	Cu	49.295280	-120.467800	L01, G04	10	684107	5463366
092HSE194	Elk No. 1 Fraction	Showing	Cu	49.290000	-120.546700	L03	10	678391	5462590
092HSE195	Ilk	Prospect	Cu, Au, Ag, Pd	49.293890	-120.555600	L03	10	677731	5463002
Red Star camp									
092HSE067	Red Star	Past Producer	Zn, Cu, Ag, Au, Pb, Mo	49.149720	-120.610000	G06, I05	10	674279	5446850
092HSE068	Pasayten	Prospect	Cu, Au, Ag, Pb	49.156390	-120.591100	G06, I05	10	675632	5447635
092HSE069	Knob Hill	Prospect	Cu, Ag, Zn, Au	49.146670	-120.626700	G06, I05	10	673074	5446472
092HSE093	Paw	Showing	Cu, Au, Ag	49.154450	-120.621100	I06	10	673452	5447350
092HSE191	Golden Crown	Showing	Cu, Au, Ag	49.153340	-120.586100	L01, G06	10	676008	5447307
S and M camp									
092HSE072	Knight and Day	Prospect	Zn, Pb, Au, Ag, Cu	49.262780	-120.732800	I05, G04	10	664950	5459142
092HSE073	S and M	Past Producer	Pb, Zn, Cu, Ag, Au	49.275550	-120.736100	I05, G04	10	664665	5460555
092HSE097	Metestoffer	Prospect	Zn, Au, Ag, Cu, Pb	49.261390	-120.746100	I05, G04, I06	10	663984	5458958
092HSE098	Five Fissures	Prospect	Pb, Zn, Ag, Cu, Au	49.267780	-120.733600	I05, G04, I06	10	664873	5459696
092HSE206	T.G.S.	Showing	Zn, Cu	49.282500	-120.746100	G04	10	663915	5461305
092HSE207	BZ	Prospect	Zn, Cu, Ag, Au, Mo, Pb	49.277500	-120.745600	G04	10	663971	5460750
Whipsaw camp									
092HSE102	Whipsaw	Prospect	Cu, Mo, Ag	49.293330	-120.759400	L04	10	662909	5462480
092HSE074	Marian	Prospect	Zn, Cu, Au, Ag, Pb, Mo	49.277500	-120.757500	I05, G04, K01, K02	10	663103	5460724
Others									
092HSE042	Wilmac	Showing	Cu	49.375550	-120.679700		10	668424	5471795
092HSE071	Silver Moon	Prospect	Au, Ag, Zn, Cu, Pb	49.196950	-120.553900	I01	10	678200	5452230
092HSE077	Riv	Showing	Au, Ag	49.355000	-120.601400	I01, L01	10	674183	5469688
092HSE081	Mazie	Prospect	Pb, Ag	49.274720	-120.700000	G06, I05	10	667294	5460541
092HSE105	Ski	Showing	Cu	49.348610	-120.604700		10	673963	5468970
092HSE112	Nev	Showing	Cu	49.292500	-120.658100	L04, K01	10	670283	5462611
092HSE124	Goldroop	Past Producer	Zn, Cu, Pb, Au, Ag	49.335560	-120.626900	G06, I05	10	672395	5467468
092HSE168	Sunday Creek	Prospect	Zeolite	49.248610	-120.584200	D01	10	675811	5457902
092HSE236	Whipsaw Creek Placer	Past Producer	Au, Pt	49.306390	-120.649700	C01	10	670841	5464174

sphalerite, galena and chalcopyrite also occur as disseminations and blebs in quartz-carbonate veinlets ranging from a few millimetres to 40 cm wide, and in quartz veins that are generally up to 15 cm in width.

Porphyry Cu-Mo mineralization is associated with the Whipsaw porphyry and its hostrocks of the Eagle Plutonic Complex and the Eastgate-Whipsaw metamorphic belt. It may also partially overprint the massive sulphide mineralization in the adjacent S and M camp. Sulphide mineralization is developed over a widespread area, as disseminations and fracture fillings, and in quartz and calcite veins. Pyrite is most abundant, ranging from 2 to 10%, particularly within altered porphyry. Trace amounts of chalcopyrite, molybdenite, bornite, chalcocite and covellite occur with up to 10% magnetite, primarily in the Eastgate-Whipsaw metamorphic belt and Eagle Plutonic Complex hostrocks flanking the stock, and in feldspar porphyry dikes and sills. The chalcopyrite is closely associated with pyrite and occurs as disseminations in the porphyry and schist, as fracture fillings and in quartz-carbonate veins in schist. Molybdenite forms fine-grained coatings along fractures and along margins of quartz and quartz-carbonate veins in the porphyry and surrounding hostrocks. Bornite is closely associated with pyrite and occurs as fine disseminations in the porphyry. Thin blebs and rounded coatings of chalcocite and covellite are present in porphyry dikes to the south. Epidote and chlorite are the most common alteration minerals. Argillic alteration is best developed in the margins of the stock. The porphyry also exhibits quartz-sericite alteration, which appears to be associated with the argillic alteration. Feldspars are replaced by kaolinite and minor epidote and sericite in the more altered sections of the stock. The main mineralization occurs along the stock's northern contact and near the southern contact, where a southeastward-trending apophysis extends from the main body. Sphalerite, pyrite, pyrrhotite and chalcopyrite with minor galena and molybdenite in garnet-epidote-diopside or quartz-epidote skarn on the Marian showing is peripheral to, and possibly related to, the Whipsaw porphyry Cu-Mo mineralization.

Other mineral showings in the map area include a variety of quartz veins with either gold or sulphides; zeolite in Eocene volcaniclastic sedimentary rocks; and placer Au and Pt.

Table 2 reports the results of analyses of various mineralized grab samples from the map area. These form three

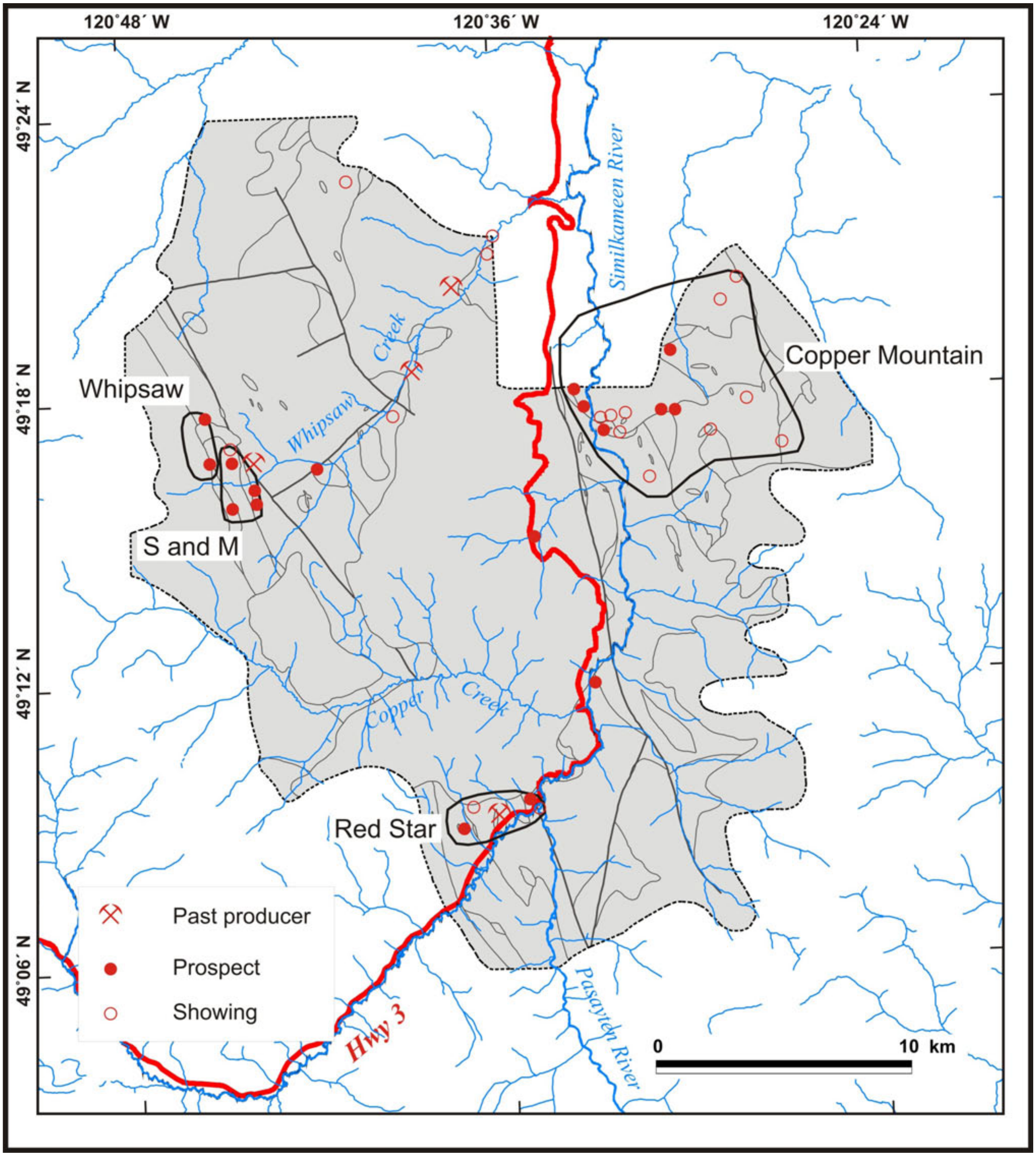

Figure 11: Locations of mineral occurrences in the map area. Important camps are outlined and labelled. Geological contacts and faults in the grey map area are as in Figure 2.

Table 2. Analyses for selected elements on mineralized grab samples collected in the map area in 2008. Samples crushed and milled in a Cr steel mill. Analyses by ACME Analytical Laboratories Ltd. (Vancouver) using inductively coupled plasma–mass spectrometry after HCl-HNO_3 digestion.

Sample No	Latitude	Longitude	Zone	Northing	Easting	Lab No.	Mo (ppm)	Cu (ppm)	Pb (ppm)	Zn (ppm)	Ag (ppb)	Au (ppb)	As (ppm)	Sb (ppm)	S (%)
a) Sulphide mineralization asociated with the Whipsaw porphyry															
08NMA28-01	49.289038	-120.765018	10	5461990	662519	61556	50.31	456.75	1.24	34.9	541	2.9	1.1	0.03	0.89
08SOL18-13A	49.298642	-120.759313	10	5463070	662902	61548	0.49	722.35	0.78	139.7	651	1.6	0.5	0.07	1.49
08SOL18-13B	49.298642	-120.759313	10	5463070	662902	61550	4.61	595.70	0.74	106.8	710	1.7	0.7	0.07	0.70
08SOL18-14A	49.297318	-120.762781	10	5462915	662655	61546	1.12	238.52	1.09	69.2	177	1.7	0.8	0.02	0.92
08SOL18-14B	49.297318	-120.762781	10	5462915	662655	61547	0.93	665.15	1.33	55.0	582	3.9	1.6	0.03	1.90
b) Calcareous tuffs, partially skarned															
08NMA12-03-01	49.182849	-120.510861	10	5450765	681387	61564	0.87	46.86	3.55	29.9	60	1.5	-0.1	0.22	1.45
08NMA12-03-02	49.183064	-120.511271	10	5450788	681357	61719	0.76	22.76	4.70	45.7	133	3.2	1.8	0.24	1.53
08NMA12-03-03	49.183655	-120.512382	10	5450851	681274	61562	0.73	76.91	1.78	35.4	31	4.7	3.9	0.20	1.03
08NMA12-05-01	49.184253	-120.515249	10	5450910	681063	61563	1.39	101.73	1.91	56.7	47	1.3	1.3	0.15	1.64
c) Iron carbonate–silica alteration zones															
08NMA29-07A	49.311243	-120.687187	10	5464629	668103	61554	0.24	23.70	2.07	22.5	59	1.5	0.5	0.03	-0.02
08NMA29-07B	49.311243	-120.687187	10	5464629	668103	61555	0.13	196.37	1.86	57.8	91	23.2	0.4	-0.02	-0.02
08NMA32-07A	49.347796	-120.686680	10	5468693	668015	61551	0.44	79.31	1.14	64.4	143	0.9	105.9	0.15	0.20
08NMA32-07B	49.347796	-120.686680	10	5468693	668015	61552	0.47	75.46	1.68	52.3	85	1.8	78.5	0.10	0.11
08NMA32-07C	49.347796	-120.686680	10	5468693	668015	61553	0.28	122.23	0.78	60.6	238	2.6	152.2	0.13	0.23
08NMA32-07C-Rep	49.347796	-120.686680	10	5468693	668015	61565	0.31	133.05	0.98	64.3	267	3.5	155.6	0.14	0.23
08NMA32-08	49.347328	-120.687886	10	5468638	667929	61560	1.83	66.79	3.94	49.4	172	2.6	136.0	0.28	-0.02
08NMA32-10	49.348220	-120.680290	10	5468754	668478	61561	0.19	7.60	0.58	35.6	16	12.1	63.4	0.07	-0.02
08NMA32-13	49.339153	-120.681716	10	5467743	668405	61557	0.76	94.71	1.16	51.4	242	4.9	122.5	0.09	0.05
08NMA32-14	49.335878	-120.682731	10	5467377	668343	61558	17.79	87.18	3.10	222.3	236	4.5	76.1	0.22	0.02
08NMA33-06	49.311319	-120.653013	10	5464714	670586	61559	0.18	65.40	0.45	55.9	88	13.7	28.7	0.07	0.45
08SOL21-04	49.365024	-120.669913	10	5470646	669174	61549	0.99	56.02	2.88	64.2	293	2.9	3.8	0.43	0.04

groupings (Figure 12). Assays of grab samples northwest of the Whipsaw property show reasonably anomalous Cu, Mo and Ag values, suggesting that the Whipsaw porphyry Cu system could be extended.

The calcareous matrix of volcanic rocks within the lower Nicola sedimentary sequence is variably altered to skarn with some visible sulphides. Analyses of grab samples, however, proved to be unremarkable.

Several grab samples were collected in the northwestern part of the map area, where several areas of orange-brown iron carbonate–silica alteration occur in Nicola volcanic rocks and possibly the Princeton Group. The samples

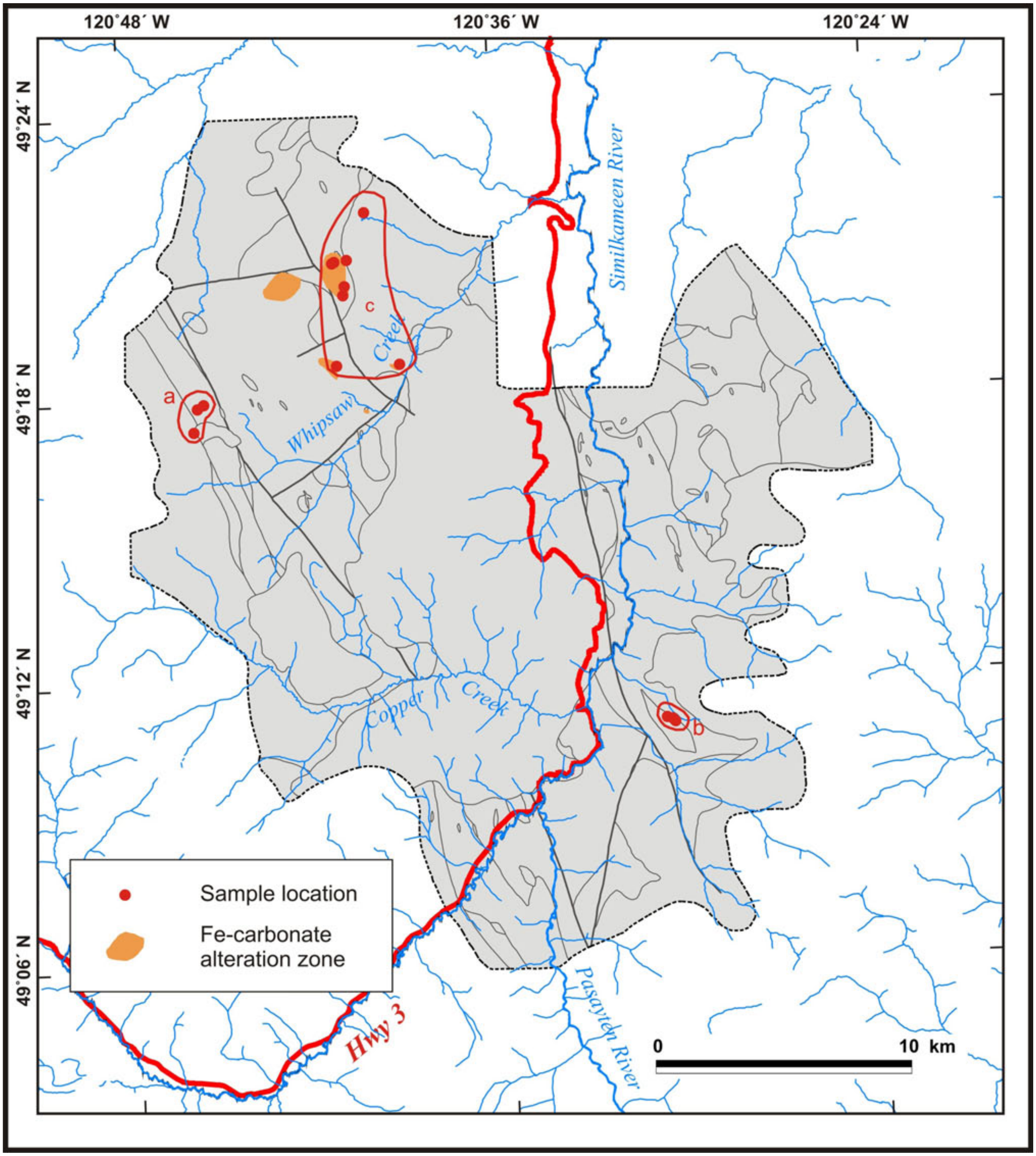

Figure 12. Locations of assay samples (*see* Table 2 for analyses and identification of groupings). Geological contacts and faults in the grey map area are as in Figure 2.

are somewhat variable but do show some elevated As and Ag values and moderate Au and Cu. The full extent and continuity of this alteration is unknown. No MINFILE occurrences are reported in this area and there is little recorded work in assessment reports.

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