Geology and Mineral Occurrences of the Quesnel River Map Area, central British Columbia (NTS 093B/16)

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KEYWORDS: Quesnel River, Quesnel terrane, Cache Creek terrane, Mesozoic copper-gold metallogeny, Nicola Group stratigraphy, Dragon Lake limestone, alkalic Cu-Au porphyry mineralization, copper, gold

INTRODUCTION

Regional mapping in the Quesnel area was initiated by the British Columbia Geological Survey in 2006 and continued in 2008 as part of a multiyear program designed to study and promote exploration of BC porphyry deposits in Quesnellia. The 2007–2008 fieldwork was a continuation of regional mapping and mineral deposits studies initiated in the area around Mount Polley (Logan and Mihalynuk, 2005; Logan et al., 2007a, b), and extended coverage northwestward to the area north and east of Quesnel. The 2008 project area covers the 1:50 000 scale Quesnel River map area (NTS 093B/16; Figure 1) and ties in with 1:50 000 scale mapping carried out last year in the Cottonwood River map area (Logan, 2008) to the north.

The project objectives are to

determine the arc history and tectonics of the Quesnel terrane to understand the evolution of magmatism and porphyry mineralization over the life of the arc (ca. 230–185 Ma); and

update the mineral potential knowledge base of the area.

The Quesnel River map area is bounded on the west by the Fraser fault system and bisected diagonally from northwest to southeast by the Pinchi fault system, which marks the boundary between the Cache Creek and Quesnel terranes. West of the Quesnel River, Jurassic sedimentary rocks, derived in part from the Quesnel terrane and correlative with the Ashcroft Formation (Travers, 1978) in southern BC, overlie Cache Creek rocks and mask the terrane boundary with Quesnellia. Triassic to Jurassic volcanic and plutonic arc rocks and associated sedimentary rocks that form the Quesnel terrane crop out east of the Quesnel River. Basement to the Quesnel terrane in southern BC is the Harper Ranch Group (Devonian–Permian arc). Basement to the Quesnel terrane in central BC is unknown, but late Early Cambrian limestone is reported from a single location along its western margin (Struik, 1984). This small isolated exposure of recrystallized limestone, reported to contain archaeocyathids (52.936 N, 122.355 W), was visited and sampled, along with Mesozoic limestone occurrences, during current fieldwork.

Figure 1. Location of the Quesnel River (NTS 093B/16) map area, marked with a red box. The Quesnel terrane is shown in green, and the Cache Creek terrane in grey. The locations of Cu-Au-Ag±PGE alkaline porphyry deposits are also shown.

REGIONAL GEOLOGY

The study area lies along the eastern margin of the Intermontane Belt close to its boundary with the Omineca Belt, in south-central British Columbia (Figure 1).

The Quesnel terrane represents an extensive (>2000 km), west-facing, calcalkaline to alkaline, Late Triassic to Middle Jurassic arc that developed marginal to the western margin of North America (Mortimer, 1987; Mihalynuk et al., 1994). It is characterized by Mesozoic arc volcanic and sedimentary rocks of the Nicola, Takla and Stuhini groups, and coeval plutonic rocks that intrude and inflate the sequence.

At the latitude of the study area, the Intermontane Belt is underlain mainly by Late Paleozoic to Early Mesozoic arc volcanic, plutonic and sedimentary rocks of the Quesnel terrane and coeval rocks of the oceanic Cache Creek terrane. The southern Quesnel terrane consists of a geochemically and isotopically primitive, Late Triassic to Early Jurassic magmatic-arc complex that formed above an east-dipping subduction zone (Mortimer, 1987). The Cache Creek terrane, with its Late Triassic (Patterson and Harakal, 1974; Ghent et al., 1996) blueschist-facies rocks,

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represents the remnants of this subduction-accretionary complex (Travers, 1978; Mihalynuk et al., 2004).

The chemical and facies architecture of the Nicola Group rocks records an eastward shift in magmatism from calcalkaline in the fore-arc volcaniclastic-dominated successions to alkalic across the arc into back-arc Middle to Late Triassic, fine-grained clastic rocks (the black phyllite unit of Rees, 1987). The eastern boundary of the Quesnel terrane is marked by the Eureka thrust (Struik, 1988), an easterly-verging fault zone interpreted to have formed during accretion of Quesnellia to North America. The variably sheared mafic and ultramafic rocks of the Crooked amphibolite that occupy this boundary are assigned to the Slide Mountain terrane, a Late Paleozoic marginal-basin assemblage (Schiarizza, 1989; Roback et al., 1994) of oceanic basalt and chert that separated Quesnellia from North America until its closure, beginning in the Late Paleozoic (Klepacki and Wheeler, 1985), and final collapse in the Early Jurassic (Nixon et al., 1993). The footwall to the Eureka thrust comprises the Proterozoic to Paleozoic Snowshoe Group rocks of the Barkerville subterrane (Struik, 1986), a northern extension of the Kootenay terrane (Monger and Berg, 1984), which are pericratonic and likely represent distal sedimentation of ancestral North America (Colpron and Price, 1995). By Middle Jurassic time, Stikinia had collided with Quesnellia, resulting in demise of the Cache Creek subduction zone (173 Ma) and stitching of the boundary in the northern Cordillera by ca. 172 Ma plutons (Mihalynuk et al., 2004). At the same time, the Quesnel terrane, Slide Mountain terrane, and Barkerville and Cariboo subterranes were imbricated and thrust eastward onto the North American craton (Nixon et al., 1993).

The tectonic boundary between the Kootenay and Quesnel terranes is intruded by the Cretaceous Naver pluton north of the study area (Struik et al., 1992: Moynihan and Logan, 2009). Tertiary volcanic rocks and feeder dikes of the Eocene Endako Group, Oligocene to Miocene sedimentary rocks and Miocene flood basalt of the Chilcotin Group are the youngest rocks in the region (Rouse and Mathews, 1979; Mathews, 1989).

Quesnel arc magmatism and associated porphyry mineralization migrated eastward with time, beginning in the west ca. 215–210 Ma with emplacement of plutons and development of calcalkaline Cu-Mo±Au deposits at Highland Valley and Gibraltar. New data suggest that mineralization at Highland Valley postdates intrusion of the Guichon batholith by up to 4 Ma (Ash et al., 2007). To the east, at Mount Polley in the central axis of the arc, alkaline magmatism and Cu-Au mineralization took place ca. 205 Ma. A chain of similar deposits extends the length of the Intermontane Belt (Barr et al., 1976; Figure 1). In the south, they are associated with the Iron Mask batholith (Afton, Ajax and Crescent) and Copper Mountain intrusions (Copper Mountain, Ingerbelle) and, to the north, with the Hogem batholith (Kwanika). Uplift and erosion of the fore arc produced sub-Jurassic unconformities as magmatism shifted east and culminated with intrusion of calcalkaline composite plutons, consisting of quartz monzodiorite (ca. 202 Ma) and granodiorite (195–193 Ma) phases (Schiarizza and Macauley, 2007) in the south (Takomkane, Thuya, Wild Horse and Pennask), and deposition of volcaniclastic and sedimentary rocks across the terrane. Copper-molybdenum mineralization is associated with the Takomkane (Woodjam) and Pennask batholiths (Brenda). A temporally unrelated, ca. 183 Ma, synaccretionary pulse of alkaline magmatism and Cu-Au mineralization is recognized at Mount Milligan, 275 km northwest of Mount Polley. Postaccretion plutons in the central Quesnel belt include the Middle Jurassic (ca. 163 Ma) Quesnel River leucogranite, with its associated Cu-Au-Mo mineralization, and the mid-Cretaceous (ca. 104 Ma) Bayonne suite of plutons, with associated Mo mineralization at the Boss Mountain deposit and the Anticlimax showing.

STRATIGRAPHY

The Quesnel River map area is underlain by the Quesnel and Cache Creek terranes, two major elements of the Intermontane Belt of the Canadian Cordillera. The contact is covered but inferred to transect the map area from northwest to southeast, following the approximate trend of the Quesnel River. This is based upon projecting Cache Creek rocks exposed north of the map area along the Fraser River at the confluence with the Cottonwood River (Struik et al., 1990) to outcrops on Beedy Creek, a tributary of Beaver Creek (Tipper, 1959, 1978) located south of the area. Cache Creek basement has been intersected in drilling east of Kersley in the southwest corner of the map area (Sproule and Associates, 1953). The terrane boundary is assumed to be a steeply dipping linear feature.

The Quesnel terrane comprises two main rock packages: a Middle to Late Triassic Eastern Sedimentary succession, consisting of the Black pelite and Cottonwood River successions; and the Late Triassic Western Volcaniclastic succession, itself consisting of the Maroon Volcaniclastic and Green Volcaniclastic successions (Figures 2, 3).

The Cache Creek terrane is overlain by three main rock packages: an Early to Middle (?) Jurassic Dragon Mountain succession, an Eocene volcanic succession, and Oligocene to Miocene sedimentary rocks (Figure 3).

Unconsolidated Recent and glacial deposits are thick and cover the majority of the map area (Figure 2).

Nicola Group

EASTERN SEDIMENTARY SUCCESSION

BLACK PELITE SUCCESSION

Outcrops are scarce and varied north of the Swift River in the northeast corner of the map area. They include massive to well-bedded pyroxene-phyric volcaniclastic units; rusty weathering, very fine grained, cherty, green and black argillaceous rocks; thin, interlayered, siliceous, muscovite-bearing siltstone and phyllite; and thinly banded calcareous volcaniclastic rocks. Detrital quartz and muscovite in quartzite beds imply a continental margin rather than a fore-arc volcanic setting. The northwestern continuation of the black, fine-grained, siliceous and calcareous clastic rocks structurally overlies sheared serpentinite of the Crooked amphibolite in the Cottonwood map area (Logan, 2008). These fine-grained black clastic rocks are correlated with the Middle and Late Triassic Black phyllite unit of Rees (1987). The Black pelite succession is considered to be broadly coeval with the eastern volcaniclastic Nicola Group and may be an eastern back-arc facies onto which arc volcanic and volcaniclastic rocks were deposited (Bloodgood, 1987; Rees, 1987; Panteleyev et al., 1996).

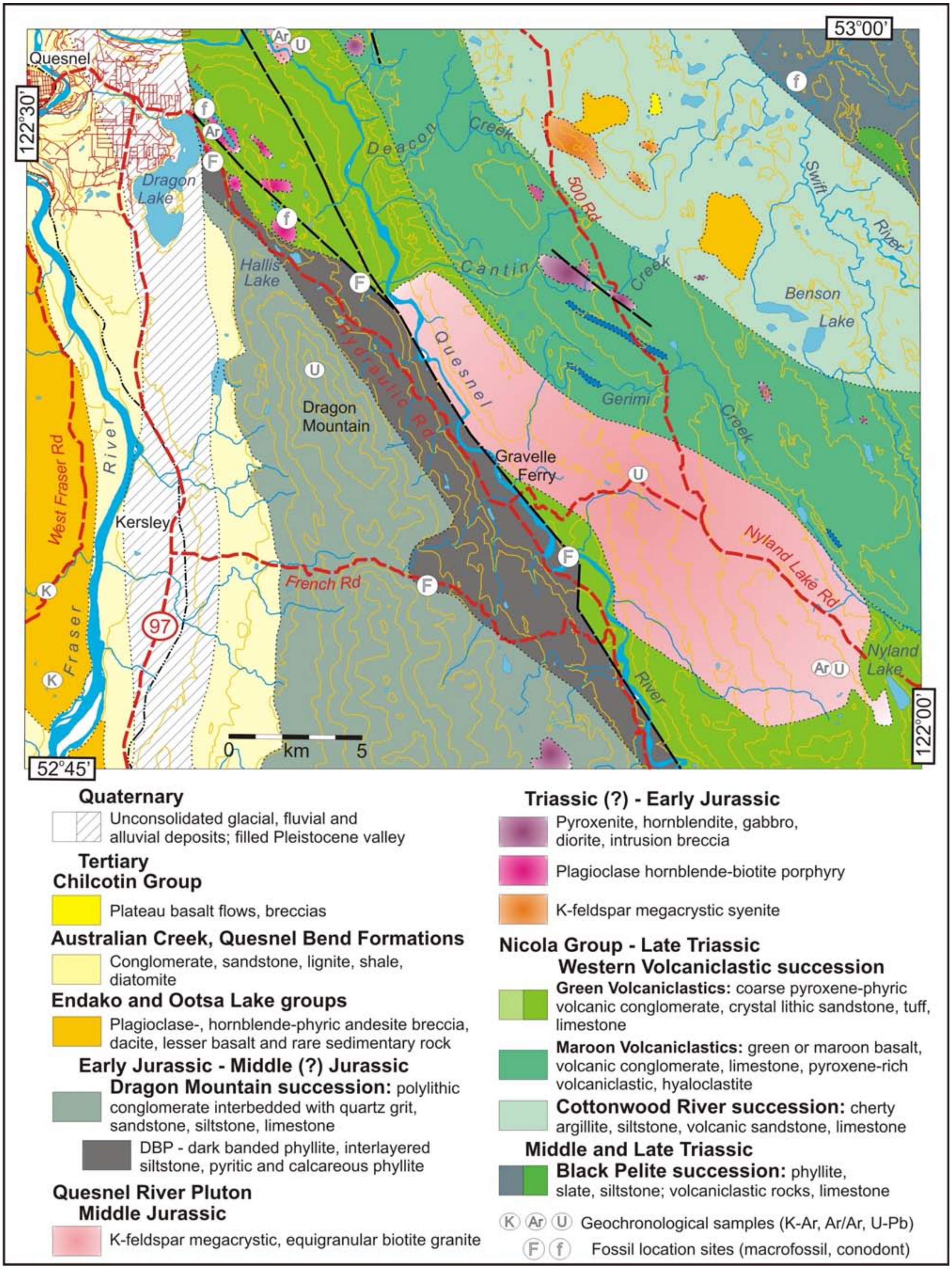

Figure 2. Generalized geology of the Quesnel River map area, based on 2008 fieldwork and interpretation of airborne geophysical data (Carson et al., 2006). The map shows the location of geochronological, microfossil and macrofossil samples.

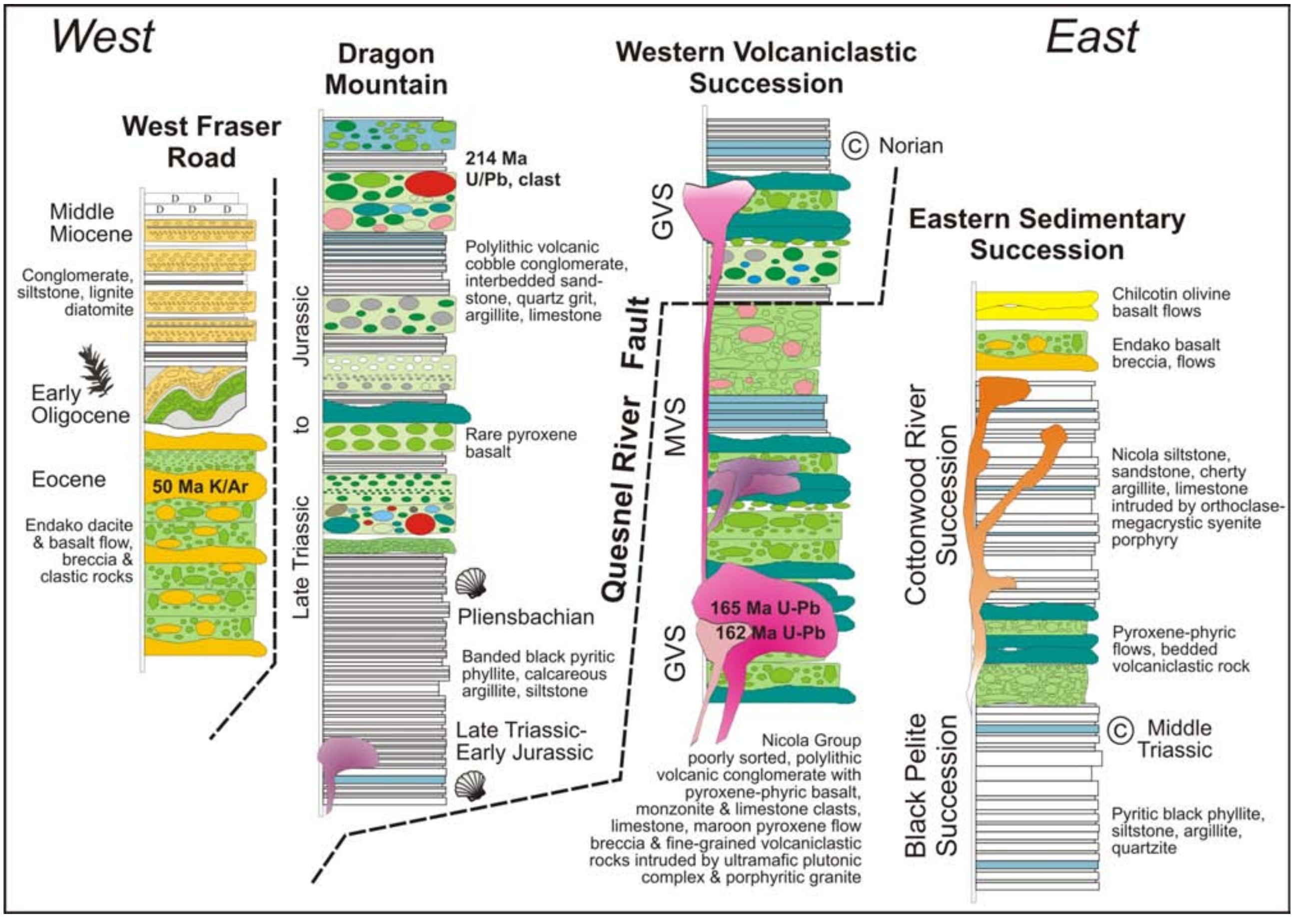

Figure 3. Schematic stratigraphic sections for Nicola Group volcanic and sedimentary successions, the Dragon Mountain sedimentary succession, and Tertiary Endako volcanic and younger sedimentary rocks in the Swift River, Cantin Creek-Quesnel River, Dragon Mountain and Fraser River portions of the Quesnel River map area. Abbreviations: GVS, Green Volcaniclastic succession; MVS, Maroon Volcaniclastic succession.

Middle Triassic conodonts have been identified by M. Orchard (pers comm, 2008) from limestone interbedded with fine-grained volcaniclastic rocks and siltstone of the Eastern Sedimentary succession exposed in the Swift River (Figure 3).

COTTONWOOD RIVER SUCCESSION

The Cottonwood River succession is dominated by fine-grained, volcanic-derived clastic sedimentary rocks that are best exposed along the length of the Cottonwood River in NTS 093G/01 (Logan, 2008). It forms a continuous belt extending south from the Naver pluton, through and beyond the current map area, and has similarities with the Gavin Lake succession in the Mount Polley area (Logan and Bath, 2006).

In the Quesnel River map area, the Cottonwood River succession is dominated by thin, wavy-laminated, cryptic-bedded, grey, green, buff and black cherty argillite, volcanic siltstone, slate and grey or buff limestone that form a belt of rocks approximately 9 km wide between the 500 Road and the Swift River (Figures 2, 3). The succession consists mainly of dark, rusty-weathering cherty argillite and fine-grained, parallel-laminated volcanic siltstone. Bedding is difficult to recognize in outcrop, specifically in the massive, conchoidally fractured siliceous argillite. Well-bedded intervals of green- or orange-weathering, normally graded crystal and lithic sandstone and rare conglomeratic beds are found throughout the belt. Another distinctive unit recognized along the length of the belt is thickly bedded to massive, green volcanic sandstone characterized by centimetre-scale, angular rip-up clasts of grey cherty argillite. In addition, centimetre-thick grey limestone beds occur interlayered with the cherty argillite sequence or rarely as thicker, buff-coloured silty limestone interbedded with the phyllite. Relatively minor amounts of dark green, coarse, pyroxene-phyric volcaniclastic units occur interbedded with other sedimentary rocks along the eastern margin of the belt.

In a series of outcrops close to the eastern boundary of the Cotton River succession, an intraclastic mélange-type fabric is visible on highly weathered surfaces. Clasts of relatively intact rock are wrapped by a matrix fabric that is defined by compositional layering and contains numerous tight-isoclinal folds. As these fabrics have highly variable orientations and cleavage is not visible in the outcrops, this deformation probably occurred before full lithification of the rock. These textures are only visible on highly weathered surfaces; elsewhere, the rock appears massive. Bedding was not identified in this area, and the full extent and significance of this disrupted zone is not known.

The upper contact with the Western Volcaniclastic succession is not well established but inferred from the vertical-gradient aeromagnetic map. Samples of limestone and calcareous black siltstone from the Cottonwood River succession have been submitted to the Geological Survey of Canada micropaleontology laboratory in Vancouver.

WESTERN VOLCANICLASTIC SUCCESSION

The Western Volcaniclastic succession of the Nicola Group forms a northwest-trending, 10–12 km wide belt of subaqueous and subordinate subaerial volcanic rocks that defines the western part of the Quesnel terrane in the Cottonwood River and Quesnel River map areas. It extends southeastward into the Mount Polley area, where it occupies a medial position between the Black phyllite and Gavin Lake sedimentary successions (Logan and Bath, 2006). The pyroxene crystal–rich sandstone, volcaniclastic breccia and conglomerate horizons contain abundant detrital magnetite and a relatively high magnetic susceptibility, which is evident on the airborne magnetic maps. The stratigraphy of the Western Volcaniclastic succession (Bailey, 1989; Lu, 1989) is similar to that described in the Hydraulic map area (Bailey, 1988, Panteleyev et al., 1996; Logan and Mihalynuk, 2005). It comprises pyroxene-phyric basalt breccia, limestone, heterolithic volcanic conglomerate, crystal-lithic sandstone and fine-grained heterolithic volcaniclastic rocks of Late Triassic age (Orchard, 2007b), and rare quartz-bearing tuff and tuffaceous sedimentary rocks of Early Jurassic age (Figures 2, 3).

In the Quesnel River map area, the Western Volcaniclastic succession is divisible into two age-equivalent units: the Maroon Volcaniclastic succession (MVS) in the east and the Green Volcaniclastic succession (GVS) in the west. Contact relationships between these two and with the fine clastic rocks of the Cottonwood River succession are not well constrained. Along most of its length, the western boundary of the Western Volcaniclastic succession is marked by the Quesnel River fault (Figures 2, 3).

The majority of outcrops in the Maroon Volcaniclastic unit consist of massive, green and/or maroon, pyroxene-phyric and aphyric basalt; monomictic basalt breccia flows; hyaloclastite; and associated volcaniclastic rocks. Basalt flows are approximately 5 m thick and characterized by brecciated margins. Flows vary from coarse, crowded pyroxene porphyry to sparse and aphyric, commonly highly vesicular varieties. Overlying and interbedded with fine maroon volcaniclastic material are fine-grained grey, green and maroon argillite and siltstone with discontinuous decimetre-thick beds of dolomitic limestone. Late Triassic (Norian) conodonts have been identified by M. Orchard (pers comm, 2008) from equivalent limestone exposed in the Cottonwood River, north of Ten Mile Lake (093G/01). Green and maroon polymictic volcanic and plutonic-dominated volcaniclastic and conglomeratic units form the uppermost strata in the belt. They are chaotic to well-sorted, boulder- to granule-size clastic units dominated by coarse pyroxene-phyric basalt and plagioclase-phyric basaltic andesite. Minor amounts of pink-weathering porphyritic monzonite are also present. Clasts are supported by a matrix of coarse lithic and crystal sand; bedding is rarely observed (Figure 4). Rocks are variably green and/or maroon and hematitic, suggesting marine and subaerial deposition, and diagenetic and/or metamorphic alteration.

The Green Volcaniclastic succession is best exposed in the area between Dragon Lake and the Quesnel River, where it extends south to the Quesnel River pluton as a 5 km wide belt of pyroxene-phyric breccia; maroon and green,

Figure 4. Coarse, pyroxene-phyric, basalt-dominated, chaotic, matrix-supported boulder and granule conglomerate beds of the Late Triassic Western Volcaniclastic succession. Outcrop located midway between Nyland and Benson lakes.

pyroxene- and plagioclase-phyric volcaniclastic and massive polylithic conglomerate; green tuffaceous rocks; and limestone (Figures 2, 3). The relationship between rock types is complicated by faults and the intrusion of numerous small, Early Jurassic, high-level stocks and dikes, including acicular hornblende diorite, plagioclase porphyry and Middle Jurassic equigranular granite. Narrow discrete mylonite zones cut the intrusive rocks. Struik (1984) established a stratigraphy for the Triassic Dragon Lake rocks that included, from oldest to youngest, conglomerate, volcaniclastic greywacke, shale, tuff, limestone, calcareous shale and pyroxene-phyric flows. He also distinguished a Jurassic sequence consisting of aphyric basalt, sandstone, micritic nonfossiliferous limestone, andesite and shale. Our regional-scale mapping did not distinguish a separate Jurassic volcanic and sedimentary sequence. It is from this area that an isolated outcrop of Early Cambrian limestone (archaeocyathid-bearing) was reported (Tipper, 1978; Struik, 1984).

Re-examination of this limestone was undertaken after samples collected in 2005 returned a single Late Triassic (Early Norian) conodont identification (Orchard, 2007a). Contact relationships with the country rock are not exposed (Struik, 1984; this study). The limestone is flanked on the west and east by purple- and pale green–mottled, phyllitic volcaniclastic rocks consisting of plagioclase and pyroxene breccia, crystal-rich lapillistone, sandstone and thin-laminated siltstone beds locally characterized by 0.5–1 mm black calcite crystals. The southern boundary is masked by medium-grained, weakly trachytic, acicular hornblende porphyry diorite. The limestone unit consists of white-, grey- and buff-weathering, fine phyllitic micrite and yellow-weathering, medium- to coarse-grained, crinoid ossicle–rich grainstone (B. Pratt, pers comm, 2007). The latter contains numerous spherical and elliptical crinoid stems, a few of which possess a central void core or circular outer wall with radial partitions. No archaeocyathids are present.

The uppermost stratigraphy of the Green Volcaniclastic succession is exposed around the Hydraulic Road, east of Dragon Lake, where it generally fines upward from coarse, polymictic volcanic conglomerate and clastic rocks through limestone with or without pyroxene-phyric flows to dark banded phyllite. The same tripartite stratigraphic relationship—pyroxene-phyric volcaniclastic rocks, limestone and dark banded phyllite—that occurs east of Dragon Lake is also present at the southern boundary of the map area south of the Quesnel River pluton. Here however, the pyroxene-phyric volcaniclastic rocks are more extensively recrystallized (Figures 5, 6) and the limestone has been converted to a marble.

Interbedded with the volcaniclastic rocks along the Quesnel River are well-sorted, planar-laminated argillite and siltstone units and metre-thick chaotic slump deposits of sedimentary- and volcanic-derived material. These coarse-grained intervals consist of angular boulder- to granule-size volcanic clasts and centimetre-size rip-up clasts of cherty argillite supported within a matrix of pyroxene- and plagioclase-rich sand. The grain-flow deposits are dominated by clasts of pyroxene-phyric basalt.

At Hallis Lake, the Nicola Group is fossiliferous (Struik, 1984) and Norian in age; however, along strike and upsection (Hydraulic and French roads) are similar, fine-grained black siltstone and phyllite that contain Sinemurian fossils (Tipper, 1978; Petersen et al., 2004). The upward fining of volcaniclastic rocks and the presence of black, fine-grained calcareous rocks at the top of the Triassic GVS are similar to lower parts of the Sinemurian phyllite and siltstone interbedded with volcanic conglomerate of the Dragon Mountain succession.

Dragon Mountain Succession

A thick (>500 m) package of alternating coarse- and fine-grained, arc-derived sedimentary rocks defines a north-tapering wedge-shaped area extending 45 km north from the Gibraltar mine to Dragon Lake. The resistant, massive, coarse conglomerate that dominates this sequence underlies Dragon Mountain and the south-trending highlands that separate the southward-flowing Fraser River and

Figure 5. Foliated and metamorphosed pyroxene-phyric basalt and limestone-dominated volcaniclastic rocks of the Green Volcaniclastic succession, exposed in the Quesnel River at the southern boundary of the map area.

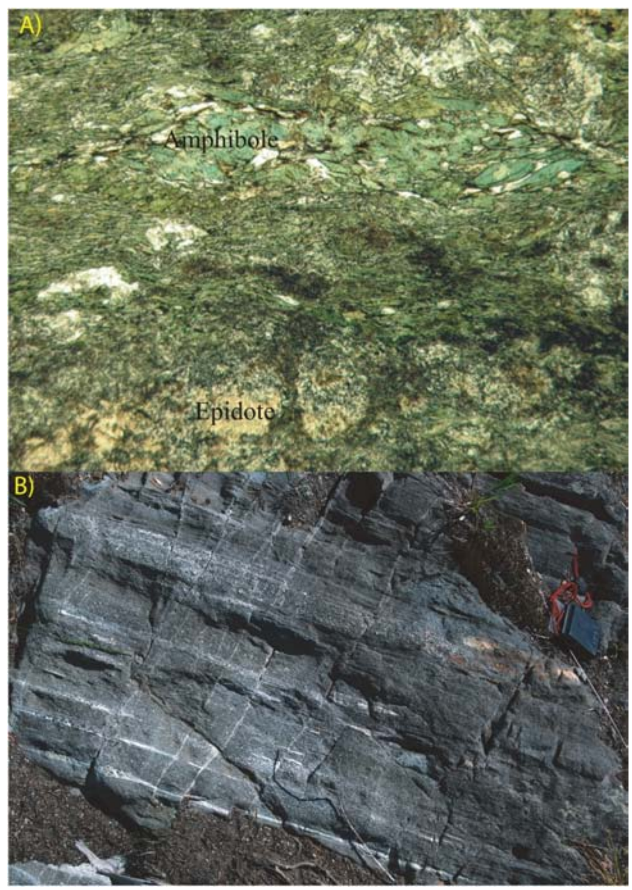

Figure 6. A) Photomicrograph of metamorphosed mafic volcaniclastic rocks containing amphibole, epidote and plagioclase; the amphibole needles define a mineral lineation (3 mm field of view). **B)** This rock forms part of a distinctive, banded volcaniclastic unit in the Green Volcaniclastic succession of the Nicola Group. Outcrop located 7.5 km southwest of Nyland Lake.

the northward-flowing Quesnel River. Interlayered with the massive to thickly bedded conglomerate and forming approximately 40% of the sequence are finer grained silicic and calcareous sedimentary rocks. Early workers included these sedimentary rocks in the upper part of the Quesnel River Group and, from fossil collections identified by H. Frebold, ascribed them an Early Jurassic (Pliensbachian) age (Tipper, 1978). The British Columbia digital geology map (Massey et al. 2005) correlates the Dragon Mountain sedimentary succession with the Ashcroft Formation of southern BC. In the type area, the Ashcroft Formation is mainly dark carbonaceous shale with minor lenses of fine sandstone and thin siltstone, and contains fossils that range in age from Early to Middle Jurassic (Frebold and Tipper, 1969; Travers, 1978). A basal conglomerate, several metres thick and containing granitic rocks in a calcareous sandy matrix, marks the base of the unit that nonconformably overlies the Guichon Creek batholith.

The Dragon Mountain succession within the Quesnel River map area consists of a two-fold subdivision: a lower package of interlayered black and dark grey phyllite and light grey siltstone; and an upper package of interbedded polylithic cobble conglomerate, sandstone, quartz grit, siltstone and limestone. The lower unit is characterized by alternating dark and light, mainly 0.2–1 cm thick layers of phyllite and siltstone that give it a dark banded appearance in outcrop and the field name of 'Dark banded phyllite'. Siliceous, pyritic and carbonaceous, and calcareous varieties of siltstone and phyllite layers are 0.5–2.0 cm thick and make up 30% of the outcrop. phyllite often shows good crenulations, whereas the siltstone does not.

The upper unit consists of massive conglomerate, rich in green and grey polylithic volcanic and plutonic clasts, interbedded with a diverse package of finer grained sedimentary rocks that include pale grey-cream, parallel-bedded siltstone and shale; pale green, fine-grained sandstone and siltstone-shale; white to grey quartz grit; and grey, green and white limestone to limy granule conglomerate. The unit also contains rare pyroxene-phyric basalt flows. The conglomerate is massive to thickly bedded with mainly boulder- to cobble-size clasts of Nicola Group volcanic and sedimentary rocks and associated intrusions. Clast types include coarse pyroxene-phyric basalt; plagioclase-phyric and aphyric, epidote-altered intermediate volcanic rocks; limestone; hornblende±biotite granite; quartz-phyric intrusive rocks; and rare conglomerate (Figure 7).

The contact relationship between the upper and lower packages is believed to be depositional because similar stratigraphic relationships occur in exploration diamond-drilling north of the Gibraltar mine (Bysouth et al., 1995). There, a flat-lying, pyritic black argillite and greywacke sequence, at least 130 m thick, forms the basal member of Jurassic sedimentary and volcanic rocks that unconformably (?) overlie penetratively deformed chert and metavolcanic rocks of the Cache Creek Group and Late Triassic tonalite-trondhjemite of the Granite Mountain pluton (Bysouth, 1987). This same relationship is postulated for the Quesnel

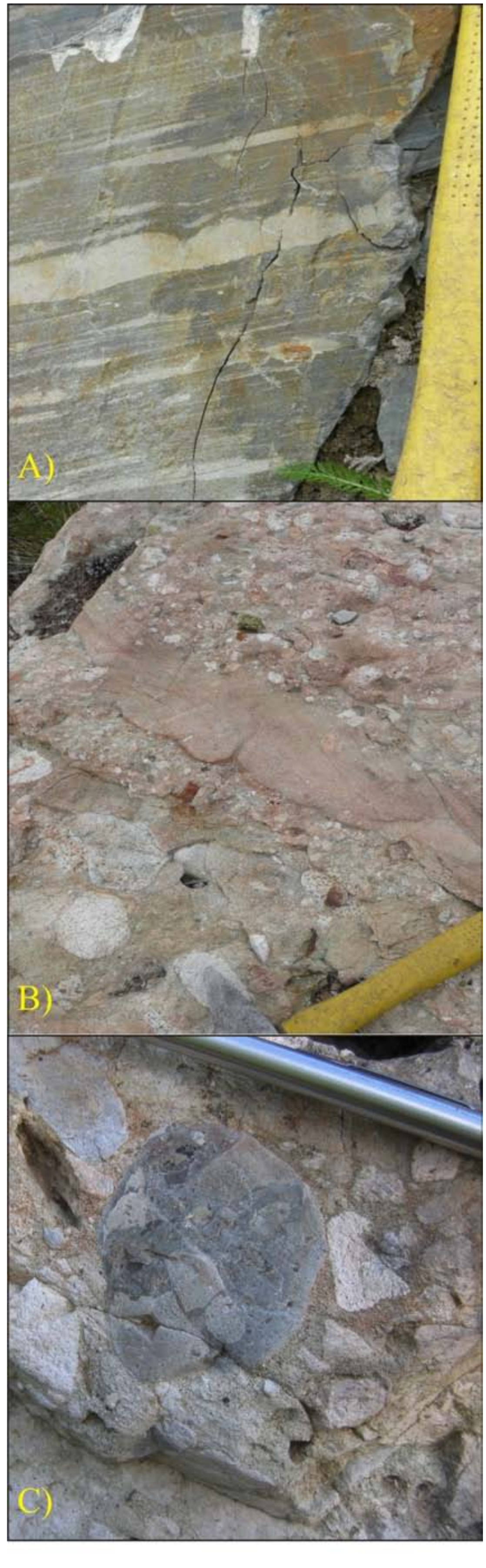

Figure 7. Rocks of the upper Dragon Mountain succession include **A)** parallel-layered and flaser-bedded, grey siltstone and buff sandstone; **B)** normal-graded, matrix-supported polymictic conglomerate with granite, epidote alteration, limestone and volcanic clasts in a coarse granule to sand matrix; **C)** detail of recycled volcanic conglomerate clast.

River map area, but here the lower contact is depositional with Nicola Group volcaniclastic and sedimentary rocks.

Dark banded phyllite (DBP) of the Dragon Mountain succession is faulted against the Middle Jurassic Quesnel River pluton and metavolcaniclastic rocks of the Nicola Group around Gravelle Ferry. The western contact with the Oligocene to Miocene sedimentary rocks is assumed to be faulted along a north-trending structure (Rouse and Mathews, 1979) that parallels the Fraser River.

In proximity to the Quesnel River fault, the DBP is cut by pale green to orange, Fe-carbonate–altered, fine- to medium-grained, pyroxene-porphyritic monzodiorite dikes. Dikes vary from centimetres to metres thick. They are altered and deformed together with the banded phyllite. Alteration varies from weak chlorite-biotite to pervasive and texturally destructive Fe-carbonate–sericite–quartz. Mineral assemblages include chlorite, biotite, muscovite, carbonate, Cr-mica, serpentine and pyrite. Pyroxene phenocrysts (5 mm) are variably altered to hornblende-biotite or entirely replaced by muscovite, producing a distinctive coarse, muscovite-rich, Fe-carbonate rock.

Petersen et al. (2004) assigned an upper Pliensbachian (Kunae Zone) age to the dark-banded phyllite unit cropping out along the French Creek Road. Fossils from the top of Dragon Mountain, collected and reported on by Struik (1984), are Late Triassic, and a U-Pb zircon age from a clast of plagioclase-porphyritic dacite, collected from the same location, yielded a Late Triassic (214 ±4 Ma) age (Petersen, 2001; Breitsprecher and Mortensen, 2004). Thin-banded black graphitic and calcareous phyllite and siltstone are exposed in the Quesnel River on the Gillis Ranch, south of Gravelle Ferry. A collection of aulacocerids (belemnites) from an outcrop underlying the dogleg meander in the river have been tentatively identified by T. Poulton (pers comm, 2008) as late Triassic to Early Jurassic in age. Limestone samples collected from this same section have been submitted to the Geological Survey of Canada micropaleontology laboratory in Vancouver. In addition, poorly preserved ammonites collected from the north end of the DBP unit exposed in Schiste Creek have been tentatively identified as Middle Jurassic (T. Poulton, pers comm, 2008). Interbedded with black and grey siltstone, argillite and limestone are white-weathering quartz grit and quartz wacke. A 20 kg sample of the quartz-bearing grit was collected and submitted to the Pacific Centre for Isotopic and Geochemical Research (PCIGR) laboratory at the University of British Columbia (UBC) for detrital zircon analysis to determine a maximum age.

EOCENE ENDAKO GROUP

An Eocene assemblage of pyroclastic rocks, lava flows and limited sedimentary rocks forms the steep bluffs west of the Fraser River at Kersley, in the southwestern corner of the map area. At this spot, 300–400 m of volcanic stratigraphy is incised and well exposed by Narcosli Creek. Most of the Eocene lavas in the map area are andesite with lesser basalt (Rouse and Mathews, 1979) and include autobreccias, monomictic and diamictic debris deposits that predominate over coherent flows, tuffs and sedimentary rocks (Figure 8). The majority of the exposures in the Narcosli Creek area consist of grey-, green- and red-weathering, plagioclase-phyric andesite breccias; cream-coloured coherent dacite flows; and crystal tuffs interbedded with decimetre-thick coarse block to lapilli breccias of black and grey scoriaceous andesitic basalt. The units trend northwesterly or southerly with moderate east dips. Polygonal and closely spaced (millimetre-scale) orthogonal cooling fractures characterize fine-grained hornblende-biotite dacite units, and hematitic flow breccias are developed at the base of metre-thick coherent grey andesite flows. Pink- to mauve-weathering, grey, plagioclase-phyric andesite consists of plagioclase, hornblende and rare biotite phenocrysts in an aphyric glassy matrix. Phenocrysts locally define a trachytic flow fabric. Phenocrysts include euhedral bimodal plagioclase (2 and 10 mm, 15%) and hornblende (5–7 mm, 10%) in a fine matrix of feldspar and quartz microlites.

Two exposures of well-bedded, pale-green– to yellow-weathering sandstone, siltstone and conglomerate dominated by felsic volcanic clasts underlie the western side of the map area, 8 km south of Quesnel. The sedimentary rocks are poorly consolidated and include thick-bedded, normal-graded, medium-grained sandstone containing kaolinite-altered feldspar, quartz, plagioclase and biotite crystals; fine siltstone and shale; organic-rich lignite horizons; and channel-cut coarse boulder conglomerate containing shale rip-up clasts and coarse plant material. It is uncertain whether these two exposures represent intraflow Eocene sedimentary rocks or are part of the Oligocene Australian Creek Formation or Miocene Fraser Bend Formation.

East of the Fraser River, scattered outcrops of flat-lying basalt or basaltic-andesite flows cap the highlands east of the 500 Road. The lavas comprise massive grey, brown or black coherent flows interlayered with clastic units of variegated orange, pink-maroon, brown and ochre, block to lapilli breccia. They are locally columnar jointed. The ba-

Figure 8. Coarse, monomictic, hornblende-plagioclase–porphyritic andesite block breccia forms cliffs west of the Fraser River, south of Narcosli Creek. Photo is 1 m across.

salt is aphyric to porphyritic with plagioclase and pyroxene phenocrysts; aligned plagioclase phenocrysts locally define a trachytic texture. The basalt is almost always vesicular and commonly filled with white, grey or chalcedonic silica or calcite.

These volcanic rocks have been dated by K-Ar techniques at 50–44 Ma (49–42 Ma ages of Rouse and Mathews [1979] recalibrated using new decay constants of Dalrymple [1979]). The rocks are age correlative with the Kamloops Group of south-central BC and the Endako Group to the northwest.

TERTIARY SEDIMENTARY ROCKS

Early investigations of the Tertiary rocks in Quesnel include work by Selwyn (1872) and Dawson (1877). Lay (1939, 1940, 1941) described the stratigraphy; Rouse and Mathews (1979) refined its nomenclature and provided palynology and K-Ar age constraints.

In the map area, the Tertiary sedimentary rocks occupy a 15 km wide by 50 km long belt along the Fraser River and tributaries in the area north and south of Quesnel (Figure 2). Here, three mid-Tertiary formations, the Australian Creek, Fraser Bend and Crownite, appear to be confined to a broad valley cut in the pre-Tertiary rocks (Lay, 1940; Rouse and Mathews, 1979), which parallels the present Fraser River. The Early Oligocene Australian Creek Formation includes lignite, clay, silt, sand and gravel. The succession is deformed and separated from the Lower to Middle Miocene Fraser Bend Formation and younger units by an angular unconformity (Figure 3). The Fraser Bend consists of flat-lying, well-sorted gravel and alternating finer and less well sorted gravel and silt, clay and seams of lignite. The overlying Crownite Formation is almost pure diatomite with some clay (Figure 3; Hora, 2008).

CHILCOTIN GROUP

Early Miocene to Pleistocene basalt flows and associated pyroclastic and sedimentary rocks of the Chilcotin Group cover an area of approximately 25 000 km^2, extending from the Okanagan Highland to the Nechako Plateau (Mathews, 1989). In the field area, basalt mapped as Chilcotin occurs as a single, small, isolated, flat-lying exposure capping a hill in the northeastern corner of the map. The lava comprises single or multiple columnar-jointed flow units separated by a thin breccia. Lavas are primarily olivine phyric in a fine-grained grey groundmass.

Diatomite underlies the basalt in a continuous belt west of the Fraser River (Rouse and Mathews, 1979; Hora, 2008).

Quaternary Cover

Unconsolidated Pleistocene and Recent sediments, comprising deglaciation outwash, lake and drift deposits, cover much of the area. These deposits are locally very thick and bedrock is limited to deeply incised creeks and rivers, and hilltops. A major north-trending Pleistocene valley, now infilled with younger sediments, has been documented to the east of the present Fraser River (Figure 2; Rouse and Mathews, 1979).

Gravel and sand eskers and/or drumlins trend northwesterly, and the direction of glacial-ice movement is generally interpreted to have been from southeast to northwest. Overburden thickness varies from 20 to 75 m in the centre of the map to substantially thicker accumulations of glacial lacustrine deposits. West of the Fraser River, the plateau is covered by a basal till with irregular patches of gravel. Drumlins, eskers and striae indicate glacial ice movement was from south to north.

Intrusive Rocks

Intrusive rocks within the Quesnel River map area include a Late Triassic suite (R. Friedman, pers comm, 2006) of alkalic quartz-undersaturated rocks; an Early Jurassic suite of calcalkalic quartz-saturated rocks that forms the constructive period of Quesnel arc magmatism; a Middle Jurassic synkinematic suite of calcalkalic magmatism (T. Ullrich, pers comm, 2006; Logan et al., 2007) that coincides with amalgamation of Quesnellia to North America; and an Eocene suite of alkalic magmatic rocks represented by mafic dikes. A postaccretion suite of Cretaceous plutons intrudes the Quesnel arc north of the current study area (Struik et al., 1992; T. Ullrich, pers comm, 2006; Logan et al., 2007a) but has not been recognized in the Quesnel River area.

LATE TRIASSIC TO EARLY JURASSIC

The Late Triassic to Early Jurassic intrusions are predominantly small, complex plutonic bodies distributed in linear trends that closely follow the regional structural grain and gross lithological packages. Bailey (1989, 1990) subdivided the Late Triassic and Early Jurassic suites on the basis of composition and texture into two groups (7A and B). Our work and studies in the Cottonwood River map area has recognized a third suite, described below (Logan, 2008).

Subunit 7A consists of pyroxene diorite, monzonite and syenite with lesser clinopyroxenite, peridotite and gabbro, and corresponds to Alaskan-type mafic to ultramafic plutonic complexes. Throughout BC, these are spatially and genetically associated with Late Triassic to Early Jurassic volcanic arc rocks of the Nicola-Takla-Stuhini groups in the Quesnel and Stikine terranes (Irvine, 1974, Mortimer, 1987; Nixon et al., 1997). Locally, these plutonic complexes intrude the Western Volcaniclastic succession of the Nicola Group, have elevated concentrations of magnetite and correspond to magnetic highs on residual total magnetic field plots. Similar mafic complexes are present in the Cottonwood River map area to the north (Logan, 2008) and farther south in the Canim Lake area (Schiarizza and Macauley, 2007). These mafic-ultramafic complexes have radiometric crystallization and cooling ages that span the Early Jurassic (Sinemurian to Pliensbachian) from 192 to 183 Ma (Schiarizza and Macauley, 2007; T. Ullrich, pers comm, 2008).

Cantin Creek Mafic-Ultramafic Complex

The Cantin Creek mafic intrusive complex is a northwest-trending composite body that straddles the upper reaches of Cantin Creek, northeast of the centre of the map. It does not crop out but is defined by exploration percussion- and diamond-drilling (Fox, 1985, 1990; MacDonald, 1991). The complex is concentrically zoned, with a melanocratic margin of commingling pyroxenite, gabbro and diorite, and a more felsic interior of monzonite to syenite. Whether faulting has dismembered a single pluton or been localized along the margins of two separate bodies is uncertain, but sheared gabbro/pyroxenite and wide fault zones intersected in drilling indicate that the complex has undergone substantial deformation. The following lithological descriptions are summarized from diamond-drill logs summarized in assessment reports (Fox, 1985, 1990; MacDonald, 1991).

Pyroxene gabbro is a medium- to coarse-grained, equigranular, melanocratic rock consisting of 80% chloritic mafic minerals dominated by either clinopyroxene or hornblende, with biotite, 20% stubby grey plagioclase and 2–3% magnetite. The pyroxene-biotite diorite is a medium-grained, equigranular rock consisting of 50% blocky to lath-shaped white plagioclase, 30% greenish pyroxene and 10% books and irregular flakes of biotite and magnetite. Leucocratic, felsic intrusive rocks spatially associated with the mafic phases include white, stubby, plagioclase±biotite porphyry and K-feldspar±hornblende porphyry syenite.

Potassium-Feldspar Megacrystic Intrusions

Subunit 7B of Bailey (1989, 1990) is primarily syenite in composition and is characterized by megacrysts of orthoclase. In the Cottonwood (NTS 093G/01) and Quesnel River map areas, megacrystic orthoclase syenite intrudes the sedimentary Cottonwood River succession of the Nicola Group, has low concentrations of magnetite and is indistinct on residual total magnetic field plots. A close spatial and temporal association between orthoclase-megacrystic syenite and Cu-Au mineralization has been suggested for the Northeast zone at Mount Polley (Logan et al., 2007a), but there the syenite dikes are intruding the main magmatic axis of the arc, which is composed primarily of volcanic and volcaniclastic rocks.

In this map area, brilliant white-weathering, orange, pink and grey syenite intrudes and alters fine clastic sedimentary rocks of the Cottonwood River succession east of the 500 Road. The intrusions consist of northwest-elongated bodies, ranging from <1 km to 3.2 km in size, of distinctive, crowded, megacrystic, orthoclase porphyritic syenite that crop out in an area extending for approximately 5 km southeast of the 500 Road. The intrusions are complex, comprising equigranular, hornblende quartz syenite containing sparse (2–3%) megacrysts of orthoclase; crowded, coarse-grained, orthoclase-megacrystic syenite containing aligned orthoclase crystals up to 5 cm in length that form 80% of the rock; and fine-grained pink syenite. Apophyses and margins to the plugs have chilled textures characterized by fine-grained green syenite containing rare broken orthoclase megacrysts and partially digested xenoliths of argillite. Cutting all phases of the syenite and the hornfelsed country rock are sheeted and stockwork quartz veins (Figure 9). The syenite has low magnetic susceptibility and therefore no distinctive geophysical signature to distinguish it from the sedimentary rocks on the regional aeromagnetic maps.

The syenite comprises euhedral, lath-shaped orthoclase megacrysts (1.5–3 cm, 50–80%) in a fine to medium equigranular groundmass of orthoclase (0.1–1 mm, 10–25%), plagioclase (1–7 mm, 10%), hornblende (0.2–1 mm, 1–10%), and trace amounts of biotite, sphene, apatite and pyrite.

Early exploration drilling of the Northeast zone at Mount Polley revealed a close association between ore-grade mineralization and the appearance of K-feldspar–megacrystic syenite clasts in the breccias (P. McAndless, pers comm, 2005). Isotopic dating has substantiated a close temporal relationship between the crystallization age of the K-feldspar porphyritic syenite dikes (U-Pb zircon, 205.1 ±0.3 Ma) and the mineralization and alteration system (Ar/Ar biotite, 205.2 ±1.2 Ma) at Mount Polley. Samples of the crowded orthoclase-megacrystic porphyritic syenite have been collected and submitted to the PCIGR-UBC laboratory for crushing and heavy mineral separation to establish if there are sufficient zircon or titanite grains to proceed with U-Pb dating.

Figure 9. Crowded, orthoclase-megacrystic hornblende syenite cut by sheeted quartz vein sets; locally contains sparse galena and potassium-alteration envelopes.

Subvolcanic Plagioclase Porphyry

Grey to white, biotite-hornblende-plagioclase porphyritic andesite (?) or subvolcanic quartz monzodiorite porphyry crop out in the area east of Dragon Lake (Figure 2). The rocks are coarsely porphyritic with tabular, white plagioclase phenocrysts <1 cm in diameter and noticeably finer, acicular hornblende and biotite crystals in a green aphanitic matrix. Quartz commonly forms phenocrysts 1–4 mm in size that constitute up to 5% of the rock.

Brecciated lithic fragments, crystal shards and eutaxitic textures in correlative rocks of the Cottonwood map area (Jonnes and Logan, 2007) indicate extrusive as well as intrusive characteristics for this unit. Hornblende from the plagioclase crystal tuff at Mouse Mountain returned an Early Jurassic cooling age of 192 ±1.3 Ma (Logan, 2008).

MIDDLE JURASSIC

Quesnel River Pluton

The Quesnel River pluton is exposed on the northeast side of the Quesnel River and dominates the central and southwestern parts of the map area. It is a 23 km long by 7 km wide, northwest-trending complex granitoid. The northern margin of the pluton is not exposed; the northwestern contact, which follows the Quesnel River, is faulted against Late Triassic to Early Jurassic DBP; and its southern contact intrudes metavolcaniclastic rocks of the GVS.

The pluton consists dominantly of medium- to coarse-grained, equigranular or K-feldspar–megacrystic hornblende-biotite monzogranite. This monzogranite forms the main core of the pluton. It has generally low magnetic susceptibility and is manifested as a large magnetic low on regional airborne magnetic maps. Marginal phases to the main monzogranite body are exposed around the southern margin of the pluton and include gabbro, pyroxenite, biotite diorite, quartz-eye porphyritic granite and late-stage pegmatite and aplite dikes. These units are mineralogically and texturally distinctive but not regionally extensive, and are therefore not shown on the map.

The monzogranite is mainly a leucocratic, pink, equigranular or sparsely K-feldspar–megacrystic rock. Grain size ranges from 3 to 7 mm, with 1–5 cm, euhedral, tabular microcline phenocrysts present locally. Thin sections show 30–40% plagioclase, 30–35% microcline (<10% perthitic microcline megacrysts), 25–30% rounded quartz, 5–7% biotite and 3–5% hornblende. Accessory minerals include sphene, zircon and magnetite.

A 15 kg sample of pink hornblende-biotite granite was collected from the southern end of the Quesnel River pluton and dated using thermal ionization mass spectrometry (TIMS) and inductively coupled plasma–mass spectrometry (ICP-MS) U-Pb techniques at the PCIGR-UBC laboratory. Zircons extracted from the sample yielded a Middle Jurassic crystallization age of 165.6 ±0.3 Ma for the orthoclase megacrystic phase of the granite. A second sample was collected from close to the centre of the pluton, where a southeast-trending mylonite zone cuts the monzogranite. Zircons from this location yielded an age of 158.2 ±0.3 Ma (R. Friedman, pers comm., 2007), thus providing a maximum age for deformation of the pluton.

To further constrain the cooling history of the unit, hornblende and biotite were separated from the granite and analyzed using Ar/Ar incremental-step heating techniques at the PCIGR-UBC laboratory. The hornblende data are complex and inconclusive. The hornblende spectrum indicated excess argon and did not yield an interpretable plateau age. An inverse isochron analysis on five points gave an isochron age of 118.6 ±8.8 Ma, with an initial $^{40}Ar/^{36}Ar$ intercept of 802 ±17 Ma. Reanalyses of the hornblende sample produced a different isochron age (77.62 ±0.5 Ma) and an initial $^{40}Ar/^{36}Ar$ intercept (1599 ±430 Ma) that was much higher than the first run (T. Ullrich, pers comm, 2007). However, the second age does match the biotite isochron age (below). Biotite separated from this same sample gave a well-defined Ar/Ar plateau age of 77.62 ±0.5 Ma, utilizing 74.5% of the ^{39}Ar, and an inverse isochron age of 77.4 ±0.79 Ma with an initial Ar intercept of 299 ±10 Ma (T. Ullrich, pers comm, 2007).

The marginal phases of the pluton are typically more mafic; they also have higher magnetite contents than the monzogranite and, as a result, contribute to the annular magnetic anomaly that surrounds the pluton. In addition, banded magnetite-rich rocks form parts of the metavolcaniclastic sequence adjacent to the southern margin of the Quesnel River pluton. These likely represent metamorphosed, thinly bedded, fine-grained calcareous volcaniclastic horizons and must also contribute to the magnetic anomaly surrounding the main body of the pluton. Rounded mafic inclusions of foliated pyroxenite, amphibolite, hornblende-biotite diorite and partially digested metavolcanic rocks are also concentrated in marginal zones of the pluton. In these rocks, clinopyroxene is typically partially or fully replaced by hornblende.

The biotite quartz monzodiorite is a medium- to coarse-grained mesocratic rock that, in places, contains coarse (up to 20 mm) tabular phenocrysts of biotite. Some of the large phenocrysts consist of aggregates of biotite, suggesting late-stage replacement of hornblende. The coarse phenocrysts of biotite are randomly oriented but portray a graphic textural intergrowth with feldspars and quartz. Minor amounts of 1–2 mm, tabular pyroxene crystals occur interstitial to the biotite phenocrysts (Figure 10).

One of the youngest phases of the Middle Jurassic magmatic suite is a fine-grained, leucocratic, quartz-eye

Figure 10. Contact zone between coarse, platy biotite quartz monzodiorite (marginal phase) and medium-grained, equigranular biotite monzogranite (main phase) of the Quesnel River pluton.

porphyritic granite. It occurs as metre- to decimetre-wide dikes and stocks cutting the Quesnel River pluton and pyroxene volcaniclastic and sedimentary rocks exposed along the Quesnel River at the Kate showing. The granite is characteristically rusty weathering due to finely disseminated pyrite and variable quartz–Fe-carbonate alteration; as a result, it has low magnetic susceptibility. A diagnostic feature is the presence of up to 10%, 1–3 mm euhedral quartz phenocrysts scattered individually or as crystal aggregates throughout a fine-grained feldspar-plagioclase-quartz matrix. Mafic minerals, including biotite (up to several percent) and rare hornblende, are commonly replaced by sericite, carbonate and pyrite.

A 15 kg sample of quartz-porphyritic granite was collected from an outcrop exposed in the Quesnel River at the Kate showing, located approximately 9 km east of Quesnel. Zircons were extracted and four single zircon grains analyzed using thermal ionization mass spectrometry (TIMS) U-Pb geochronological techniques. The resulting $^{206}Pb/^{238}U$ ages were Late Triassic (233.0 and 201.4 Ma), Early Jurassic (182.1 Ma) and Middle Jurassic (162.4 Ma). The zircon with the Middle Jurassic age (162 Ma) was interpreted to be xenocryst free and reflect the crystallization age of the granite (R. Friedman, pers comm, 2007). Xenocryst-rich zircons with 162 Ma rims and primarily Late Triassic cores have been extracted from Middle Jurassic quartz-eye porphyry at Gavin Lake (Logan et al., 2007a).

Fine- to medium-grained leucocratic biotite granite apophyses emanate from the southern margin of the Quesnel River pluton and crosscut the epidote-amphibolite–facies metavolcanic country rocks at a high angle to schistosity. A sample of one of these dikes was collected for U-Pb zircon dating to constrain the age of penetrative foliation. Results are pending.

EOCENE

East-trending biotite lamprophyre dikes crosscut the metavolcaniclastic rocks and quartz-feldspar-biotite porphyry intrusions in the canyon section of the Quesnel River, 9.5 km east of Quesnel. They are also found in the dark banded phyllite of the Dragon Mountain succession. The mafic dikes consist of two varieties, distinguished on the basis of biotite phenocryst size: a fine-grained variety with biotite crystals ranging from <1 to 1 mm and a variety with coarse euhedral biotite books up to 6 mm in length in an aphanitic dark groundmass. The dikes are moderately to strongly magnetic and display fine-grained chilled margins.

Argon/argon step-heating of biotite separates from one of these dikes returned a good plateau age of 51.89 ±0.32 Ma, utilizing 83.3% of the ^{39}Ar released in steps 7 through 11. The inverse isochron solution gave an age of 51.82 ±0.38 Ma, with an initial Ar intercept of 309 ±48 Ma (T. Ullrich, pers comm, 2007).

STRUCTURE

Most rocks in the area are penetratively deformed. Fine-grained clastic rocks have a slaty or phyllitic cleavage defined by aligned phyllosilicate minerals and elongated quartz grains. Volcaniclastic rocks are also penetratively deformed, but a coarser grained matrix leads to a more spaced, scaly cleavage resulting from pressure solution and alignment of metamorphic minerals. Fabrics in the volcaniclastic rocks are also defined by stretched clasts, lapilli and mineral aggregates. However, ductile deformation fabrics are not evident in part of the northeastern half of the map area. For descriptive purposes, the area has been divided into five southeast-trending structural domains (Figure 11).

Domain I

This domain includes the polylithic conglomerate, fine-grained volcaniclastic rocks, banded limestone and grit beds of the Dragon Mountain succession. The foliation (S1) dips quite uniformly to the northeast, with a mean orientation of 281 /66 . Measured bedding (S0) orientations have mostly shallow dips and are spread along a girdle whose axis trends almost horizontally southeast, approximately parallel to the long axes of stretched clasts. The main cleavage (S1) is locally overprinted by spaced cleavages with widely varying orientations.

Domain II

This domain consists exclusively of the dark banded phyllite and siltstone belonging to the lower part of the Dragon Mountain succession. The main cleavage (S1) is parallel to bedding except in the hinge zones of tight to isoclinal F1 folds, which are rarely exposed (Figure 12). The parallel S0/S1 fabric is folded around gently plunging strike-parallel axes. This is manifested in crenulations of micaceous layers, centimetre-scale buckles of quartz veins/layers and larger scale folds between outcrops. These folds are gentle-close and typically have a spaced S2 fabric parallel to their axial planes. Axial planes are variable and dip from northeast to southwest. Fault discontinuities are common in the dark banded phyllite unit at a variety of scales (Figure 13).

Domain III

The Quesnel River pluton and the surrounding mafic volcaniclastic rocks are included in domain III. A penetrative fabric is developed in volcaniclastic conglomerate and associated finer grained sedimentary rocks. A fabric is also well developed in mafic phases around the margins of the Quesnel River pluton. Large parts of the central, felsic part of the Quesnel Lake pluton are unfoliated to weakly foliated. However, this area also includes numerous discrete mylonitic shear zones (Figure 14). These shear zones dip approximately 60º to the southwest, with stretching lineations typically plunging around 40º to the southeast. Curvature of the foliation into these zones and asymmetric delta porphyroclasts suggest oblique-dextral movement. A second, spaced tectonic fabric is evident in some of the volcaniclastic units of domain III. These spaced cleavages have highly variable orientations. Bedding features are scarce in much of this area, but most recorded values dip southwest.

Domain IV

Rocks of the Maroon Volcaniclastic succession and the Cottonwood River succession are not penetratively deformed. They are affected by brittle deformation and locally spaced fabrics are developed; however, unlike other Mesozoic rocks in the area, they do not record any significant ductile strain.

Domain V

This domain approximately coincides with the Black pelite succession. There is generally a cleavage parallel to compositional layering in phyllite that is locally folded around shallow-plunging axes. There is no penetrative fabric in coarse volcaniclastic rocks. Measured cleavage and bedding dip mostly to the northeast in this domain but, as elsewhere, data are limited.

Major Faults

The dominant map-scale structural features of the area are northwest-trending faults. The Quesnel River fault is a steep, northwest-trending structure that follows the Quesnel River. It has been interpreted to represent one of the strands of the Pinchi fault zone that separates Cache Creek from Quesnel (Bailey, 1990). It juxtaposes foliated Middle Jurassic granite and Late Triassic metavolcanic rocks with Late Triassic (?) to Early Jurassic black banded phyllite along most of its length.

Bailey (1990) showed the map area to be regularly dissected by northeasterly-trending, high-angle extensional faults. Although they are rarely observed in outcrop, he interpreted them from aeromagnetic patterns. No substantive evidence for significant faults with this orientation was found during the current study.

The Chiaz fault (Bailey, 1988) is a north-trending arcuate fault that follows the eastern boundary of the map area for approximately 40 km northwards from the Quesnel River fault. The fault has a well-defined aeromagnetic signature that crosscuts the northwest-trending regional aeromagnetic grain. Bailey (1990) estimated a minimum of 4 km of dextral displacement along this structure and at least 5 km of vertical displacement (west side up) from offset of granite exposed at its southern end in the Quesnel River and the distribution of basalt across the fault. Additional evidence to support right lateral displacement along this structure is the northwest-trending contact of the Cottonwood River succession of sedimentary rocks and the Western Volcaniclastic succession (located 5 km southeast of Robertson Lake), which displays at least 10 km of

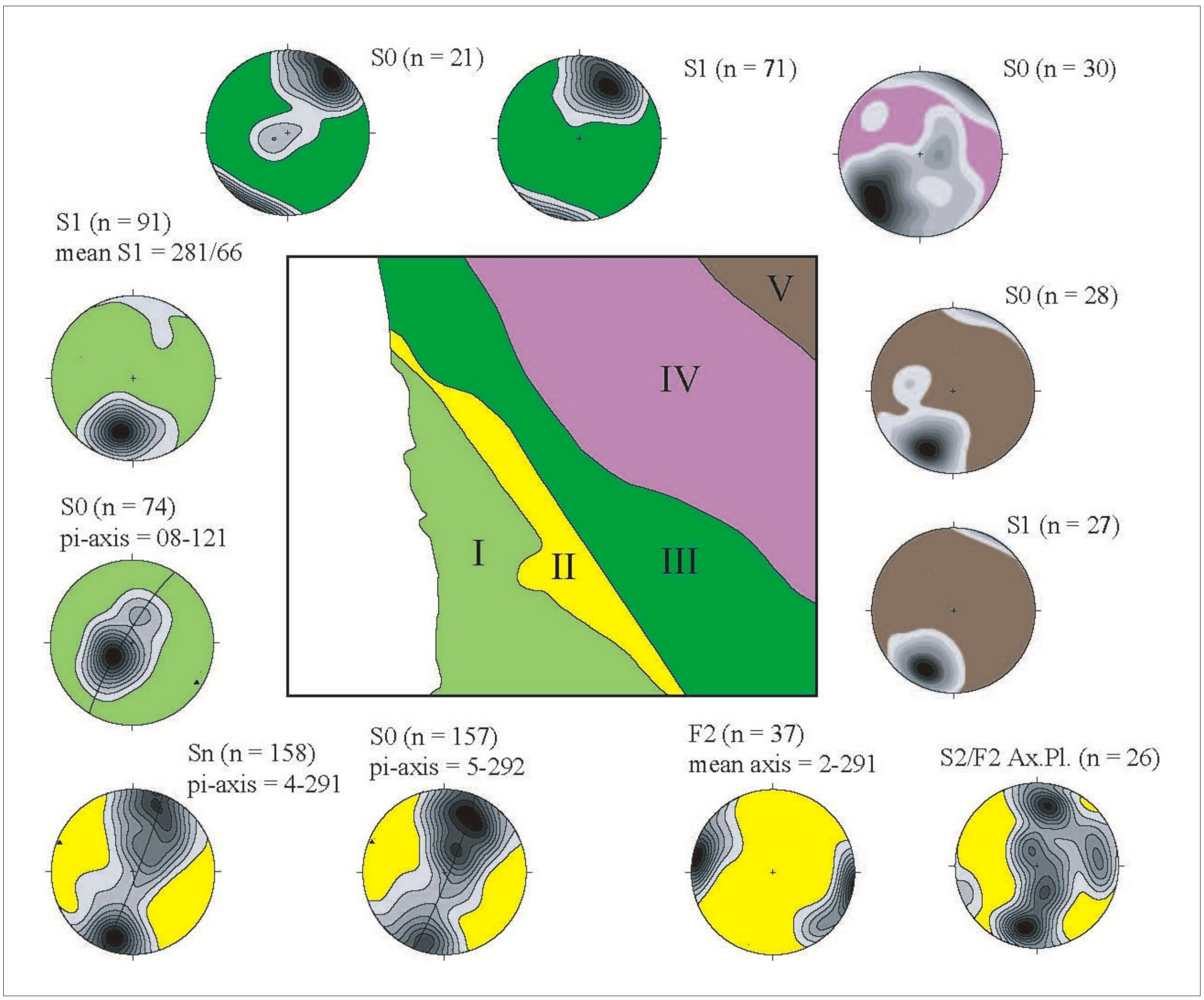

Figure 11. Equal-area lower-hemisphere stereonet projections of structural data from the Quesnel River map area. The map area has been divided into five structural domains (I to V) east of the Fraser River, and the data are colour coded to these areas.

dextral displacement before it reappears east of Nyland Lake.

The Oligocene rocks of the Australian Creek Formation trend northerly and dip generally shallowly, with the exception of a well-developed anticline exposed along the east bank of the Fraser River, 6 km south of Quesnel (Figure 15; Rouse and Mathews, 1979).

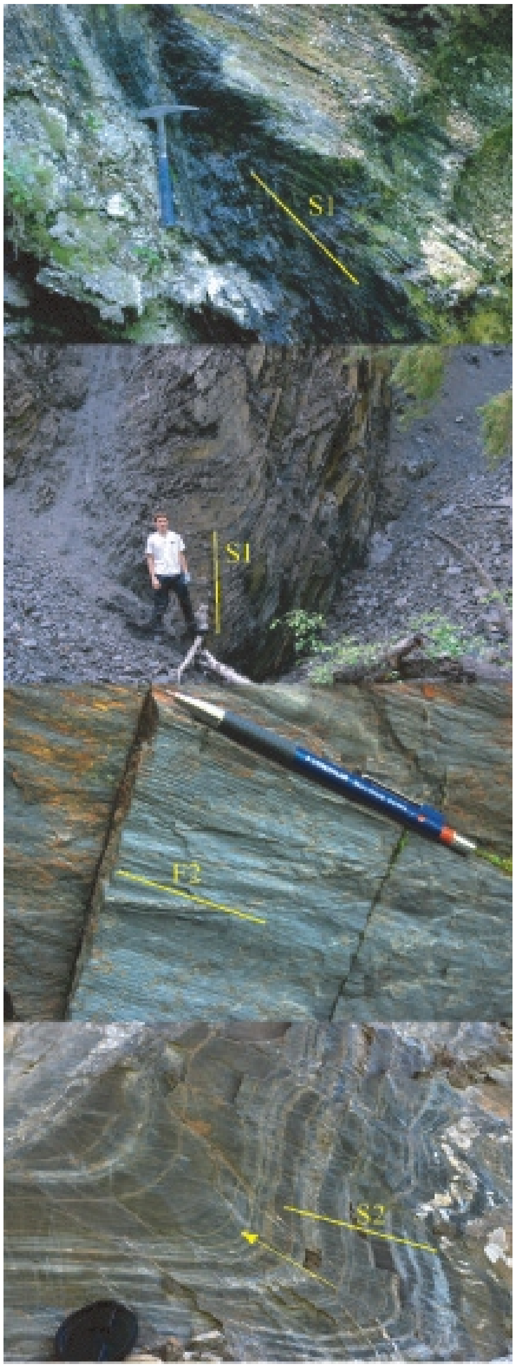

Figure 12. Folds in the dark banded phyllite (structural domain II): **A)** tight F1 fold with gently plunging axis; S1 is axial planar; **B)** larger scale F1 fold exposed in stream canyon; the left limb of the fold has been faulted off; **C)** F2 crenulations of S0/S1 surface in dark phyllite; **D)** F2 fold of banded phyllite with spaced S2; the fold facing direction is given by graded bedding.

Figure 13. Small-scale faults in the dark banded phyllite (Dragon Mountain succession). Note the truncation of the layers on which the hammer rests.

METAMORPHISM

Phyllite in the northeastern part of the area (Black pelite succession) and close to the Quesnel River (dark banded phyllite) has chlorite+muscovite+quartz+plagioclase assemblages, with biotite locally present. Mafic volcanic and volcaniclastic rocks in the northern part of the Green Volcaniclastic succession (GVS) and the Dragon Mountain succession contain amphibole, plagioclase, epidote, carbonate and chlorite. Pyroxene crystals are fully or partly converted to amphibole or chlorite, quartz-epidote veins and replacement pods are widespread, and the rocks have an overall green appearance. In the southern part of the Green Volcaniclastic succession, chlorite is absent and mafic metavolcanic rocks have the assemblage amphibole+epidote+plagioclase. Metamorphic amphibole is aligned parallel to foliation and locally displays a lineation. Although transformed mineralogically, many rocks retain their volcaniclastic or volcanic texture—phenocrysts and detrital crystals are discernible in almost all rocks that are sufficiently coarse grained. Metamorphic mineral assemblages in the area indicate greenschist-facies metamorphism, possibly reaching epidote-amphibolite facies in the southern GVS.

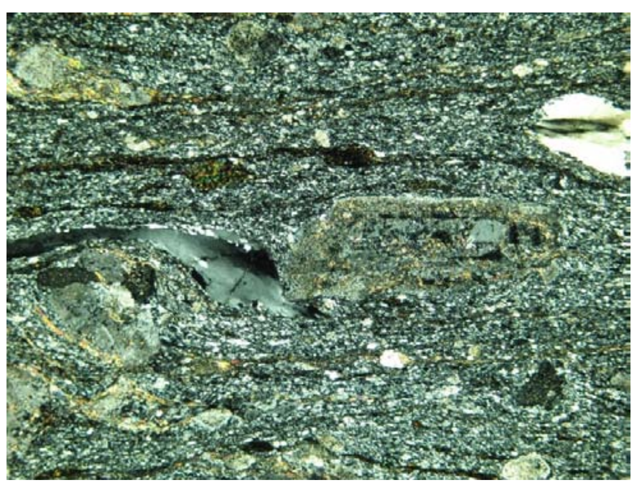

Figure 14. Photomicrograph of mylonite zone in Middle Jurassic K-feldspar–megacrystic monzogranite of the Quesnel River pluton (3 mm field of view; crossed polars).

In contrast, mafic volcaniclastic rocks belonging to structural domain IV have not been substantially affected by metamorphic recrystallization. Many volcaniclastic and volcanic rocks in the Maroon Volcaniclastic succession retain their maroon-coloured matrix and clasts rather than being green. They lack epidote veins and pods and, although plagioclase crystals are altered, detrital pyroxene crystals are commonly fresh. Rocks in this domain therefore differ from those elsewhere in two respects: they were not ductilely deformed and they are much less extensively hydrated and recrystallized.

Volcanic rocks of the Endako and Ootsa Lake groups experienced zeolite facies metamorphism, and the Tertiary sedimentary rocks are unmetamorphosed.

Alteration zones have developed in the volcaniclastic and sedimentary country rocks peripheral to igneous bodies in the map area. With the exception of the Quesnel River pluton, the alteration zones are generally limited to narrow zones of less than 100 m. At the southern end of the Quesnel River pluton, garnet+actinolite+epidote±biotite overprint the metavolcanic rocks immediately adjacent to the contact with the granite. Assuming a vertical contact, the alteration extends 2–400 m outwards from the granite.

Fine-grained black sedimentary units of the Cottonwood River succession are intruded by a cluster of small, north-trending, crowded megacrystic, orthoclase syenite porphyry stocks. Adjacent to the syenite, the sedimentary rocks are variably altered to a fine-grained, brown to dark purple biotite-chlorite-pyrite±pyrrhotite hornfels. Overprinting the hornfels are fracture-controlled, pale, anastomosing bleached zones of Na- and/or K-enriched hydrothermal alteration. Late-stage (?) sheeted quartz veins and stockworks extend beyond the pluton margins into the hornfelsed country rocks. Minor sulphides of Fe, Cu and Pb occur locally. Small, composite, mafic to ultramafic stocks and plugs of hornblendite, diorite, monzonite and syenite intrude green volcaniclastic rocks of the Western Volcaniclastic succession along a medial northwest-trending axis. Dark hornfels and potassic alteration overprints green volcanic rock, with skarn and calcsilicate alteration occurring in calcareous volcaniclastic horizons (MINFILE 093B 027; MINFILE, 2008). No sulphide introduction was recognized.

Figure 15. Upright anticlinal fold in Oligocene Australian Creek Formation conglomerate, sandstone and siltstone units, exposed between the railroad line and the Fraser River, 6 km south of Quesnel.

MINERALIZATION

With the exception of Tertiary and younger placer, coal and diatomite occurrences, mineralization in the Quesnel River area is related to Mesozoic subduction-generated arc magmatism and high-level emplacement of stocks and plutons that occupy the northeastern half of the map area (Figure 16, Table 1).

Two past-producing surficial placer Au deposits are located along the Quesnel River, and sub-bituminous coal and lignite beds are known to occur within sections of the late Early Oligocene Australian Creek Formation exposed in the Fraser River valley. East of the study area, diatomite overlies the coal-bearing stratigraphy (Rouse and Mathews, 1979; Hora, 2008).

North of the map area, limited production is recorded for the alkalic Cu-Au porphyry mineralization at Mouse Mountain (Sutherland Brown, 1957), and showings of Mo and W mineralization occur near the western margin of the Naver pluton. South of the map area, Cu±Mo porphyry mineralization associated with calcalkaline intrusive complexes at the Gibraltar mine, and Cu±Au porphyry and propylitic Au replacement associated with alkaline intrusive centres at the Mount Polley mine and the QR mine, respectively, represent important exploration models for this part of the Nicola Arc.

Proven and probable reserves at Gibraltar (0.2% Cu cut-off) total 472.4 Mt of 0.315% Cu and 0.008% Mo, with an additional 958 Mt of measured and indicated resources at 0.298% Cu and 0.008% Mo (Taseko Mines Limited, 2008). Proven and probable reserves at Mount Polley incorporate the open pit mining of the Southeast zone, C2 zone and the Springer zone, in addition to the Wight and Bell pits, and total 55.6 Mt at 0.36% Cu, 0.30 g/t Au and 0.66 g/t Ag (Imperial Metals Corporation, 2008), with an additional measured and indicated resource of 104.8 Mt at 0.295% Cu, 0.304 g/t Au and 0.19 g/t Ag. Reserves for the QR mine, estimated by Kinross Gold Corporation on January 1, 1997, were 1.57 Mt grading 3.99 g/t Au, with the main zone hosting an estimated 0.6 Mt at 4.4 g/t Au (MINFILE 093A 121). Development and milling operations at the mine have recommenced, with the first gold pour reported in November 2007 (Cross Lake Minerals Ltd., 2007).

Mineralization in the map area includes

- Au±Cu developed in potassic, skarn and propylitic alteration assemblages in calcareous volcaniclastic rocks adjacent to the Cantin Creek mafic-ultramafic plutonic complex;
- Cu-Au-Mo associated with elevated As-Sb-Bi±Pb-Zn geochemical signatures adjacent to the Middle Jurassic calcalkaline Quesnel River pluton, apophyses and related stocks located northeast of Dragon Lake; and
- weak silicification and pyritic alteration zones with elevated base metals developed peripheral to K-feldspar–megacrystic quartz syenite bodies that intrude the Cottonwood succession (Table 1).

Thirty-two rock geochemical samples were collected from alteration and mineralization over the course of three summers (2006, 2007 and 2008) mapping in the Quesnel River map area (Table 2). The majority of these samples (30) were collected northeast of the Quesnel River fault and attest to the higher mineral potential of the volcanic and plutonic Nicola Group rocks that underlie this area.

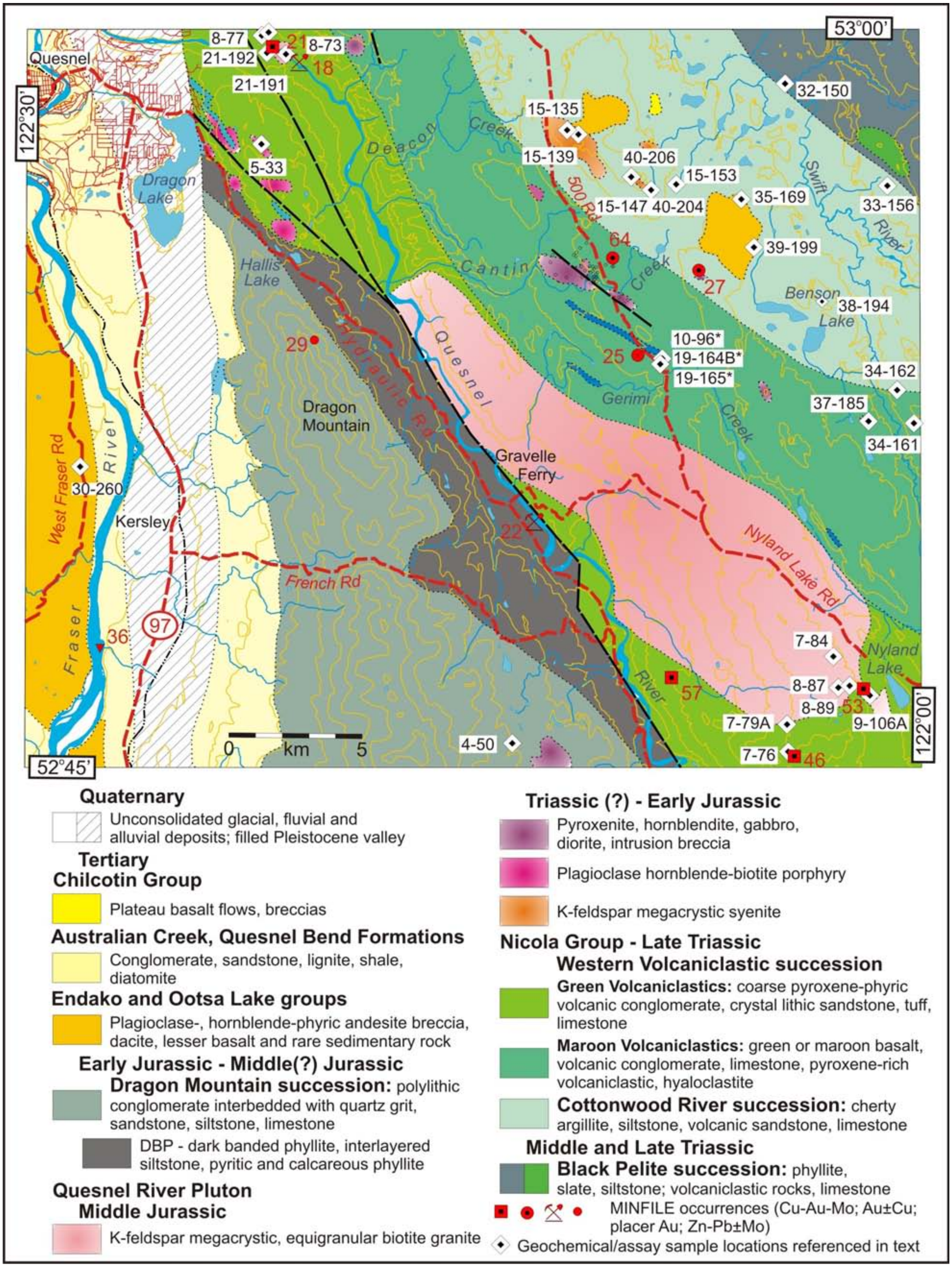

Figure 16. Geology the Quesnel River map area, showing the distribution of MINFILE occurrences described in Table 1 and geochemical/assay sample locations listed in Table 2. The numbers accompanying the MINFILE occurrences and geochemical/assay sample locations correspond to the last part of the 'MINFILE No.' in Table 1 and 'Station No.' in Table 2, respectively.

Table 1. MINFILE occurrences within the Quesnel River map area (NTS 093B/16).

MINFILE No.	Name (Status)	UTM (Zone 10) East	UTM (Zone 10) North	Commodity	Description
Surficial Placers:					
093B 018	**Quesnel Canyon** (developed prospect)	543330	5871755	Au	•Raised bench of Tertiary glacial fluvial deposits consisting of coarse cobble gravels unconformably overlying Nicola Group basement. Test pits and bulk samples have established indicated reserves of 61 785 m^3 grading 0.48 g/m^3 Au (Dolphin, 1988).
093B 022	**Ainsworth, Sardine Flats,** (past producer)	552675	5854326	Au	•Most of the gold production from the Quesnel River has come from dredging operations, but a significant amount of gold has been won from Tertiary benches located adjacent to the present river level.
Sedimentary/Volcanic-Hosted Cu:					
093B 025	**Lynda, Bl, Phantom** (showing)	556604	5860736	Cu, Ag	•Late Triassic Nicola stratigraphic package comprising maroon volcaniclastic rocks and basalt, dolomitic limestone and green polylithic volcaniclastic unit intruded by alkalic trachytic dikes. The limestone is brecciated and mineralized with disseminated pyrite and tetrahedrite; malachite and azurite coat weathered surfaces. Stratigraphically lower maroon basalt and volcaniclastic rocks contain native Cu replacing vesicles and fractures suggestive of red bed Cu–style mineralization.
Au-Quartz Veins:					
093B 064	**Cantin Creek, Deacon** (showing)	555633	5863970	Au	•Propylitic, Fe-carbonate and silica alteration of intermediate to mafic, pyroxene-phyric volcanic flow and clastic volcanic rocks intruded by mafic-ultramafic intrusive complex. Best intersection of 2.64 g/t Au over 1.6 m (Miller-Tait, 2004).
093B 053	**Nyland Lake** (showing)	566632	5847792	Au	•Nicola Group metavolcaniclastic rocks are hornfelsed and skarned adjacent to the contact with granite and diorite of the Quesnel River pluton. Garnet, diopside, epidote, pyrite and biotite alteration assemblages and dike swarms of pegmatite, aplite and quartz characterize the contact zone which contains, anomalous Au values. In addition, anomalous Au values in heavy-mineral pan separates are reported from creeks draining the area (Troup and Freeze, 1985).
Porphyry Cu, Mo, Au:					
093B 021	**Kate** (showing)	542770	5871781	Cu, Mo, Au	•Pyroxene phyric flows, volcaniclastic and tuffaceous argillite-sandstone are intruded by stocks and dikes of Middle Jurassic biotite-feldspar porphyry and quartz porphyry. Pyrite-silica and ankeritic alteration is closely associated with fracture-controlled chalcopyrite mineralization. Best surface assay returned 1.32% Cu over 4 m in quartz porphyry (Fraser, 1974).
093B 057	**TARN, AND, ALSO** (showing)	558007	5848206	Cu, Ag, Au, Mo	•Mineralization consists of Cu, Mo, Ag and Au in silicified, skarned and hornfelsed country rock within the contact aureole of Quesnel River diorite. Pyrite > pyrrhotite with minor chalcopyrite, chalcocite and rosettes of molybdenite are disseminated or occupy fractures in both the country rocks and the dioritic intrusion.
Polymetallic Veins:					
093B 027	**AB, XL, ANO** (showing)	558875	5863537	Pb, Ag	•The showing is underlain by cherty argillite, siltstone and fine-grained tuffaceous rocks of the Cottonwood River succession adjacent to its contact with volcanic and volcaniclastic rocks of the Western Volcaniclastic succession. The area is intruded by a small composite diorite to monzonite intrusive complex. Ubiquitous pyrite and minor galena and tetrahedrite reported (Holland, 1968).
093B 029	**COUSIN JACK** (showing)	544456	5860764	Pb, Ag, Au	•Mineralization consists of galena and pyrite in quartz stringers within an oxidized sheared zone cutting sedimentary and volcanic rocks located on the east side of Dragon mountain. The zone, about 6 m wide and 150 m long, strikes at 068°. A grab sample of vein material assayed 1.24 g/t Au, 130.6 g/t Ag and 9% Pb (Lay, 1935). Actual location uncertain.
093B 046	**MANDY, BLACK BEAR** (showing)	562654	5845297	Ag, Cu, Au, Sb, Zn	• East-trending quartz-ankerite veins up to 1.4 m wide occupy shears cutting Nicola metavolcanic rocks. The main vein, explored by a 6 m decline, follows a 90 cm wide east-trending shear zone and contains 5–10% patchy tetrahedite with chalcopyrite. A 1.5 m chip sample of the quartz-ankerite vein yielded 3.3 % Cu, 0.02 % Pb, 0.45 % Zn, 435 g/t Ag and 0.65 g/t Au (Durfeld, 1986).
Coal:					
093B 036	**Quesnel Coal** (developed prospect)	536527	5849079	Cl	•A number of coal zones containing sub-bituminous "B" and "C" rank coal are present in the lower portion of the Fraser River Member of Lower Oligocene Age.

Table 2. Assays of rock samples collected during 2006, 2007 and 2008 fieldwork, Quesnel River map area (NTS 093B/16); anomalous values are highlighted in yellow.

		Element	Ag	As	Au	Ba	Bi	Ca	Cd	Ce	Co	Cr	Cu	Fe	Hf	K	La	Li	Mg	Mn	Mo
		Units	ppm	ppm	ppb	ppm	ppm	%	ppm	ppm	ppm	ppm	ppm	%	ppm	%	ppm	ppm	%	ppm	ppm
		Method	TICP	TICP	FAIC	TICP	TICP	TICP	TICP	TICP	TICP	TICP	TICP	TICP	TICP	TICP	TICP	TICP	TICP	TICP	TICP
		Det'n Limit	2	0.5	2	50	0.02	0.01	0.01	3	0.1	5	0.01	0.01	0.1	0.01	0.5	0.1	0.01	1	0.01
Station Number	**Easting**	**Northing**																			
06JLO5-33	542390	5868110	<.1	1	3	1523	0.1	2.19	0.2	22	6.5	67.1	2.6	2.09	1.2	2.17	9.8	5.7	0.41	432	0.1
06JLO8-73	542745	5871773	6.5	76	610	56	4.8	6.82	0.2	29	12.6	67.5	433	4.53	1.6	2.32	13.9	15.1	3.01	775	160.1
06JLO8-77	541996	5872630	<.1	1	9	1827	<.1	1.74	<.1	28	4.9	73	12.8	1.88	1.1	1.96	14	6.6	0.67	277	0.4
06JLO10-96*	557499	5860024	0.3	11	6	640	<.1	9.16	0.1	32	49.9	138.8	468.6	9.27	1.8	0.9	16.8	28.4	5.00	2013	0.6
06JLO13-123	572109	5843437	<.1	6	16	3232	<.1	4.55	0.2	22	20.8	48.3	32.4	5.54	2	2.94	10	9.2	2.41	1205	0.4
06JLO15-135	554295	5868601	0.4	1	7	634	0.5	2.5	11	21	6.5	181.8	92.1	2.63	2.6	2.21	13	8.3	0.61	288	73.8
Acme Q/C			0.4	<1	2	603	0.6	2.49	10.7	21	6.2	181.3	91.4	2.62	2.7	2.28	13	7.7	0.61	290	73.1
06JLO15-139	553872	5868759	<.1	1	2	1019	0.9	0.65	0.1	8	2.5	122.6	3.2	1.11	1	2.45	4.4	7.1	0.22	326	0.5
06JLO19-164B*	557449	5860053	1.1	16	6	1000	0.1	5.41	0.2	21	20.6	21.1	5504.5	5.66	2.5	3.96	10.1	25.4	2.24	1824	2.6
06JLO19-165*	557554	5860041	0.1	8	<.1	828	0.1	8.66	0.2	38	43.4	220.2	29.2	7.89	1.6	1.45	21.6	24.1	5.38	1329	0.3
07GLE32-152	565793	5868491	<.1	<1	27	1798	<.1	3.95	0.1	30	15.9	75.7	51.8	4.36	2.5	3.55	17.7	15	1.87	1029	0.2
07GLE32-150	562370	5870651	0.1	5	<2	3794	<.1	3.76	0.1	15	21.8	25.5	69.6	6.65	0.8	1.45	6.7	45.1	2.17	1876	0.5
07GLE33-156	565923	5866792	0.3	5	5	945	0.2	1.22	1.9	24	16.4	68.6	120.1	5.05	2.1	2.61	13	25.3	1.97	497	9.2
07GLE34-161	567016	5857871	0.2	5	16	1581	0.1	5.05	0.2	20	21.1	74.5	102.7	5.26	1.6	3.57	10.6	25.9	2.27	1136	1.7
07GLE34-162	566371	5859110	<.1	86	12	172	0.2	0.07	0.1	143	0.9	40.9	14.1	3.64	2.4	8.4	76.6	15.4	0.08	1130	14.3
07GLE35-169	560442	5866226	0.1	2	14	1165	<.1	6.17	0.1	65	43.3	271.7	46.9	7.21	3.8	1.46	33.1	10.8	4.73	1165	0.9
07GLE37-185	565309	5857927	0.1	5	-	1866	<.1	4.11	0.1	19	11.6	30.7	25.7	4.85	1.7	1.78	8.8	4.3	1.48	1165	0.1
07GLE38-194	563515	5862414	0.1	<1	53	42	0.4	2.18	14.6	28	19.1	98.4	140.4	5.04	2.3	3.22	15.3	51.6	1.27	647	140.5
07GLE39-199	560935	5864426	0.1	3	8	1445	<.1	5.9	0.2	90	36	168.4	70.6	7.95	5.2	1.61	45.7	10	2.22	992	1.6
07GLE40-204	557049	5866543	0.2	5	28	1643	0.3	0.46	0.2	14	3.6	55.2	54.3	2.61	1.9	3.7	7.3	15.5	0.22	197	6.5
07GLE40-206	556298	5867023	0.1	6	-	1360	0.1	0.06	<.1	3	<.2	13.3	3.2	0.27	0.5	4.68	2	74.7	0.04	11	1.2
08JLO4-50	552051	5845674	-0.1	-1	-2	25	-0.1	1.47	0.1	-1	1.7	266	4.8	1.38	-0.1	0.04	0.3	2.4	0.12	1756	0.5
08JLO7-76	562473	5845444	-0.1	-1	-2	253	-0.1	0.05	-0.1	10	1.7	128	2.4	0.93	0.2	1.74	5.4	8	0.13	119	0.2
08JLO7-79A	562367	5846491	-0.1	-1	-2	572	-0.1	1.11	-0.1	33	0.6	85	2.1	1.01	0.1	1.46	14.6	4.7	0.23	883	0.2
08JLO7-84	564080	5849065	-0.1	-1	-2	237	-0.1	0.07	-0.1	9	1.6	106	2.1	0.96	0.3	1.71	4.7	7.5	0.13	125	0.2
08JLO7-84rep			-0.1	-1	6	232	0.3	0.08	0.1	9	1.8	112	2.8	0.96	0.3	1.69	4.9	7.2	0.13	129	0.5
08JLO8-87	564279	5847897	-0.1	-1	-2	3361	0.1	3	-0.1	57	19.1	45	31.1	4.76	2.1	2.86	25.3	26.2	1.2	917	0.3
08JLO8-89	564704	5847971	-0.1	-1	-2	47	0.6	15.59	0.3	10	30.9	114	15.9	7.47	1.1	0.03	4.5	1.8	2.67	1985	0.3
08JLO9-106A	565467	5847615	-0.1	4	40	449	-0.1	7.72	0.2	16	23.1	70	31.2	5.43	0.9	0.66	7.2	17	2.48	1193	0.8
08JLO15-147	557050	5866539	0.2	3	11	1756	0.3	0.7	0.4	14	5.3	47	37.5	2.2	2.2	3.73	7.1	13.5	0.19	425	4.2
08JLO15-153	557990	5866763	0.7	1	5	288	0.2	2.29	0.9	16	15	81	73.2	4.01	3	2.17	7.2	16.7	1.64	725	4.8
08JLO21-191	543155	5871686	3.9	165	684	12	91.1	6.9	0.6	7	14.2	113	151.4	15.27	0.2	0.46	3.8	8	2.96	838	130
08JLO21-192	542447	5872422	-0.1	1	13	155	0.9	2.7	0.1	3	8	37	4.4	1.23	0.9	0.36	1	1.3	0.08	311	0.8
08JLO30-260	535708	5855910	0.1	-1	-2	1094	-0.1	3.23	0.2	55	17.4	67	32.3	4.68	5.9	2.58	23.7	6.4	0.98	649	2.1
Std CANMET WPR1			0.6	<1	<.1	19	0.1	1.61	0.2	5	174	2370.6	1692	10.96	0.5	0.09	1.9	4.6	18.57	1352	0.3
Std WPR-1/SY4			0.6	-1	-0.1	19	0.1	1.61	0.2	5	174	2370.6	1692	10.96	0.5	0.09	1.9	4.6	18.57	1352	0.3
Recommended			0.7	1.4	0.042	22	0.19	1.43	0.43	6	180	3300	1640	9.93	0.61	0.165	2.2	4.2	18.69	1549	0.9
% Difference			3.8	300.0	122.4	3.7	15.5	3.0	18.3	4.5	0.8	8.2	0.8	2.5	5.0	14.7	3.7	2.3	0.2	3.4	25.0

Table 2 (continued)

Station Number	Easting	Northing	Na	Nb	Ni	P	Pb	Rb	S	Sb	Sc	Sn	Sr	Th	Ti	U	V	W	Y	Zn	Zr
		Units	%	ppm	ppm	%	ppm	ppm	%	ppm	ppm	ppm	ppm	ppm	%	ppm	ppm	ppm	ppm	ppm	ppm
		Method	TICP	TICP	TICP	TICP	TICP	TICP	TICP	TICP	TICP	TICP	TICP	TICP	TICP	TICP	TICP	TICP	TICP	TICP	TICP
			0.001		0.1	0.001	0.01		0.02	0.02	0.1		0.5	0.2	0.001	0.5	2	1		0.1	
06JLO5-33	542390	5868110	3.11	1.5	12.4	0.07	17.2	49.6	0.4	3	5	0.8	224	2.7	0.11	1.30	50	0.5	4.9	71	20.8
06JLO8-73	542745	5871773	0.04	3.7	25.7	0.08	101.1	58.8	2.7	138.3	5	0.8	214	3.4	0.21	6.20	89	18.4	11.9	90	48.2
06JLO8-77	541996	5872630	3.93	7.5	17.3	0.06	9.8	51.4	<.1	0.4	4	1.3	582	3.8	0.22	1.30	35	1.2	5.8	43	21.6
06JLO10-96*	557499	5860024	3.08	2.7	36.5	0.35	7.6	21.8	-0.1	0.1	46	0.9	1023	2.3	0.54	-	335	0.4	16	116	44.2
06JLO13-123	572109	5843437	2.69	3.2	14.7	0.17	2.4	48.8	0.3	1	17	0.6	841	3.2	0.52	1.40	252	0.6	15.8	57	61.2
06JLO15-135	554295	5868601	2.10	5.6	52.9	0.06	73.8	50.9	1	0.4	13	1.1	368	2.3	0.38	4.80	888	0.9	34.4	543	90.4
Acme Q/C			2.08	5.3	52.6	0.06	72.1	48.3	1	0.4	13	1.1	360	2.3	0.40	4.80	891	0.9	34.6	543	87.9
06JLO15-139	553872	5868759	1.70	5.5	8.3	0.03	31.7	48.9	<.1	0.1	2	2.7	289	1.3	0.10	0.60	110	0.2	4.6	36	28.9
06JLO19-164B*	557449	5860053	2.75	5.4	3.1	0.20	-	41.1	0.1	0.3	8	1	958	2.6	0.39	-	187	1.1	15.3	113	89.6
06JLO19-165*	557554	5860041	2.40	3	52.8	0.28	-	23.7	<.1	0.1	35	1	1053	3.2	0.46	-	275	0.6	13	80	44.5
07GLE32-152	565793	5868491	3.90	6.3	21.2	0.13	5.7	93.2	<.1	0.3	15	0.7	1030	4.90	0.33	2.7	195	0.5	12.3	48	81.3
07GLE32-150	562370	5870651	3.72	2	11.5	0.12	3.6	33.8	0.5	0.5	16	0.8	637	0.60	0.53	0.5	254	0.3	10.2	125	18.1
07GLE33-156	565923	5866792	2.24	4.4	32.1	0.13	10.5	64.4	0.4	1.7	20	1.1	363	3.30	0.47	3.1	407	0.5	16.8	190	65.6
07GLE34-161	567016	5857871	3.73	3.1	30.5	0.16	13.3	66.3	0.5	0.3	15	0.6	1535	1.40	0.34	1	246	0.3	14.5	94	48.6
07GLE34-162	566371	5859110	1.06	68.1	11.4	0.03	8.9	113.1	1.9	6.5	1	6.3	126	5.00	0.06	0.8	20	6.6	11.5	58	83
07GLE35-169	560442	5866226	2.03	8.8	195.3	0.26	7.6	36.9	0.1	0.1	26	1	916	2.30	0.82	0.8	243	0.3	20.1	92	146.2
07GLE37-185	565309	5857927	2.93	1.8	3.3	0.11	3.4	39.1	0.2	0.6	14	0.4	532	2.40	0.36	1	175	1	14.4	58	53.2
07GLE38-194	563515	5862414	4.18	9.9	72.8	0.11	16.6	57	4	0.4	14	1.3	339	3.10	0.34	6.1	666	0.6	22.8	665	73.3
07GLE39-199	560935	5864426	3.53	16.8	115	0.48	8.7	29.9	0.1	0.1	20	1.6	1259	2.80	1.09	1.2	237	0.5	21.4	115	189.2
07GLE40-204	557049	5866543	2.70	7.3	8.5	0.07	28.2	101.6	0.3	0.9	6	0.8	521	2.30	0.23	2.3	87	1	7.9	53	59.9
07GLE40-206	556298	5867023	0.77	9.4	0.4	0.01	17.7	45.1	0.1	0.8	1	1.2	1038	1.20	0.05	0.8	108	0.8	1.1	8	23.4
08JLO4-50	552051	5845674	0.06	-0.1	4.7	0.00	0.8	1.7	-0.1	0.2	1	0.3	48	0.10	0.01	-0.1	2	0.2	0.8	46	1.7
08JLO7-76	562473	5845444	3.94	1.2	9.1	0.02	10.3	56.2	-0.1	0.9	1	0.4	93	2.60	0.03	2.4	24	0.6	0.7	27	4.9
08JLO7-79A	562367	5846491	3.32	5.9	2	0.02	7.7	33.6	-0.1	0.2	1	0.9	237	2.80	0.08	0.8	-1	0.2	7.5	47	3.9
08JLO7-84	564080	5849065	4.22	1.1	8.7	0.03	10.9	52.9	-0.1	1	1	0.4	89	1.90	0.03	1.8	25	0.5	0.8	24	5.9
08JLO7-84rep			4.09	1.2	9.2	0.02	12	52.3	-0.1	1.1	1	0.5	85	2.30	0.04	2.2	25	0.6	0.9	22	4.7
08JLO8-87	564279	5847897	3.45	3.6	8.9	0.25	30.7	70.5	-0.1	0.1	10	1	820	5.60	0.31	1.8	155	0.2	11.5	93	91.1
08JLO8-89	564704	5847971	0.10	0.8	23.6	0.05	9	1.7	-0.1	0.9	38	0.5	560	0.80	0.42	1.5	389	0.9	18.7	98	31.5
08JLO9-106A	565467	5847615	3.18	1	24.7	0.08	4.2	22.3	-0.1	0.3	28	0.3	294	1.60	0.39	1.6	236	0.6	15.2	76	19
08JLO15-147	557050	5866539	2.76	9.7	7.1	0.06	38.6	107.8	0.1	1	4	0.9	714	2.90	0.22	2.7	79	0.7	9.4	64	82.3
08JLO15-153	557990	5866763	3.69	3	18.9	0.11	13.1	39.1	2.4	0.6	23	1.2	294	1.10	0.54	1.3	181	1.6	30.4	127	90.6
08JLO21-191	543155	5871686	0.03	0.3	29.4	0.02	154	15.8	>10.0	66.7	3	0.3	168	0.30	0.05	9.9	62	3.9	6.3	154	5.6
08JLO21-192	542447	5872422	7.14	2.3	1.9	0.03	3.6	10.1	1.2	1.5	2	0.3	209	0.70	0.09	0.6	30	6.8	2.2	9	19
08JLO30-260	535708	5855910	3.13	14.8	31.8	0.23	10.4	73	-0.1	0.1	12	1.3	671	5.70	0.61	2	138	0.6	15.1	88	248.1
Std CANMET WPR1			0.017	1.8	3150.9	0.018	5.7	3.8	0.8	0.7	11	0.7	6	0.3	0.204	0.1	72	0.1	4.3	94	14.2
Std CANMET WPR1			0.017	1.8	3150.9	0.018	5.7	3.8	0.8	0.7	11	0.7	6	0.3	0.204	0.1	72	0.1	4.3	94	14.2
Recommended				2.4	2900	0.013	6	5	0.9	0.9	12	1.1	7	0.4	0.179	0.2	65			95	18
% Difference			50.0	7.1	2.1	8.1	1.3	6.8	2.9	6.3	2.2	11.1	3.8	7.1	3.3	16.7	2.6	50.0	50.0	0.3	5.9

Late Triassic (?) to Jurassic Zn-Pb-±Mo-Au Mineralization

Quartz-sulphide vein mineralization at the AB-XL showing (MINFILE 093B 027; Table 1) is associated with small stocks of orthoclase-megacrystic syenite and a monzonite, which intrude sedimentary rocks of the Cottonwood River succession.

Miarolitic, orthoclase-megacrystic syenite intrusions underlie the 10 km^2 area that extends from the headwaters of Deacon Creek southeast across the 500 Road. They are composite bodies consisting of 1) coarse-grained, equigranular, orthoclase- and hornblende-phenocrystic syenite, intruded by 2) crowded, orthoclase-megacrystic porphyry syenite and 3) fine-grained dikes of orthoclase. Sheeted and stockwork quartz veins crosscut all three phases of the intrusion and the fine-grained black and green argillite and phyllite country rocks. The veins are late-stage, brittle quartz±orthoclase veins that occasionally display orthoclase alteration envelopes. The vein quartz is massive and white, with crystals oriented perpendicular to vein walls or zones of bullish white quartz filling brittle fractures and healing breccia zones. In addition, the quartz occupies miarolitic cavities and comb quartz layers, and rarely is mineralized with pyrite and sparse galena. The mean principal orientation for quartz veins cutting the syenite is 347 /72 , but these sheeted vein sets are commonly cut by a younger orthogonal set of veins trending 250 /80 .

Samples of the orthoclase-megacrystic syenite (07GLE40-204, -206, 08JLO14-140A, 08JLO15-147), the sheeted quartz veins and stockwork that cut the intrusion (06JLO15-139), and hornfelsed, quartz-veined argillaceous country rock (06JLO15-135) that host the intrusions were collected and analyzed to assess the potential of this suite of alkalic intrusions to host Cu-Au mineralization. The results in Table 2 indicate that the highest anomalies occur in the altered and quartz-veined country rocks adjacent to the syenite. Argillite sample 06JLO15-135 is hornfelsed and silicified by discrete vitreous quartz veinlets with wide alteration envelopes, typically 2–3 times the width of the veinlet, and returned elevated Zn, Pb, Cd, ±Cu ±Mo values (Figure 17). The quartz veins sampled that cut the intrusions contained only background values. However, crosscutting vein samples yet to be analyzed contain disseminated galena. Two of the four syenite samples contained slightly elevated Au values but no coincident anomalous values for other elements.

A northwest-trending ridge of rusty-weathering black argillite and lesser green siltstone is located north of Benson and Robertson lakes. The rocks are massive, with faint, cryptic, fine laminations suggestive of bedding. They possess a splintery or conchoidal fracture pattern resulting from silica or hornfels alteration. Bailey (1989) showed an intrusive body of grey porphyritic syenite (his unit 7B) northeast of this location that could account for the observed hornfels alteration. Pale greenish alteration envelops and bleaches the argillite adjacent to centimetre-scale, sulphide-rich quartz veins. Where vein density is high, disseminated pyrite occurs throughout the argillite. Grab samples from this location (07GLE38-194) returned anomalous values for Zn, Cd and Mo, with slightly elevated Cu and Au (Table 2). This element association is similar to that of mineralization associated with sediment-hosted, K-feldspar–megacrystic syenite that intrudes sedimentary rocks of the Cottonwood succession.

Early Jurassic Au±Cu Mineralization

CANTIN CREEK

The Cantin Creek showing (MINFILE 093B 064) is located west and east of the 500 Road, approximately 10 km north of its junction with the Nyland Lake Road in the upper reaches of Cantin Creek. It was explored first in 1964 (Bacon, 1964) and again in the late 1980s and early 1990s, with substantial geophysical, geochemical and diamond-drilling (~4000 m) programs looking for another QR-type deposit (Fox, 1975, 1985, 1990; Goodall and Fox, 1989). Outcrop is scarce and historical drilling intersected between 40 and 90 m of overburden consisting of gravel and water-soaked clay (Fox, 1985). Recent exploration has included additional diamond-drilling designed to test induced-polarization (IP) and geochemical targets peripheral to, and distal from, the Cantin Creek stock (Miller-Tait, 2004). The stock is a mafic-ultramafic complex composed of pyroxenite, diorite and gabbro. Early exploration drilling focused on defining the extent and metal content of this

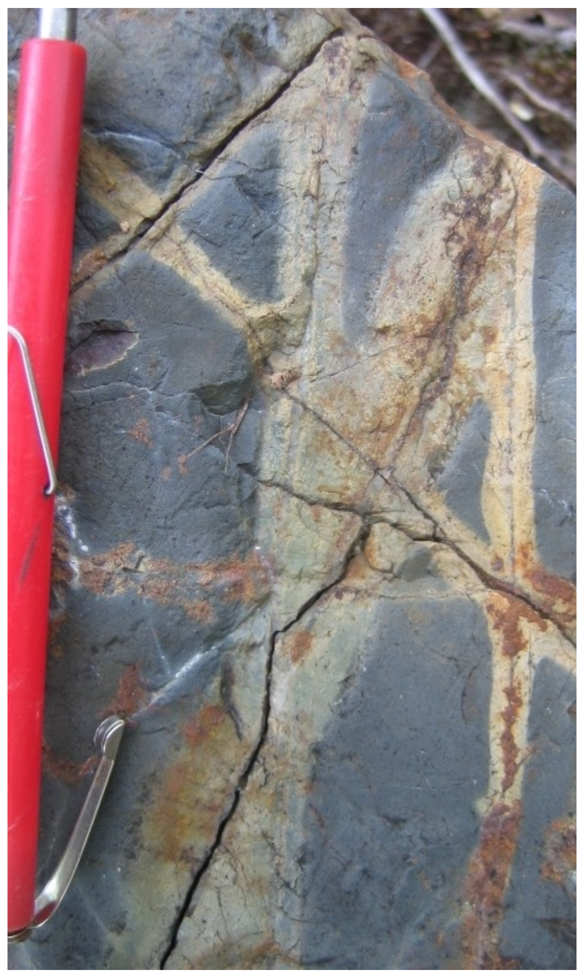

Figure 17. Hornfelsed and veined argillite of the Cottonwood River succession, located peripheral to crowded orthoclase-megacrystic syenite. Pyrite±pyrrhotite vein stockworks are characterized by pale anastomosing bleached alteration envelopes of Na and/or K- alteration.

body. Assay results from more than 150 one-metre sample intervals of the pyroxenite, gabbro and diorite returned low Au values of <50 ppb (Fox, 1985) to 5 ppb (Goodall and Fox, 1989), while felsic intrusions averaged 15 ppb and locally up to 130 ppb (Goodall and Fox, 1989). However, the best assay results were intersected in marble±calcsilicate skarn and propylitic alteration zones peripheral to the main Cantin Creek stock.

Interbedded hornfels, diopside and garnet calcsilicate and marble intruded by narrow felsic dikes in drillhole G-10 returned a high value of 3690 ppb Au and seven one-metre samples with values greater than 1000 ppb Au (Goodall and Fox, 1989). Propylitically altered basalt cut by 2–5 m wide felsic dikes intersected in drillhole 20 returned 16 one-metre samples with greater than 100 ppb Au and one of 1779 ppb Au (Fox, 1990). Auriferous calcite-fluorite veining in pyroxene-plagioclase–phyric breccia, intersected between 131 and 139 m in drillhole 21, returned 1.8 g/t Au over 8 m. Drillhole 25 was drilled to test the IP anomaly located northeast of the stock and returned some of the more continuous mineralization (Fox, 1990). Anomalous Zn and Cu values (1 m samples as high as 1.9% Zn and 0.2% Cu) with low Au values were intersected in pyritic epidote hornfels between 63 and 73 m; propylitized calcareous volcaniclastic rocks between 112 and 120 m returned 212 ppb Au over 8 m; a 6 m interval of propylitic basalt between 136 and 142 m returned 1.7 g/t Au and low Zn and Cu values; and a felsic dike intersected at 151 m returned 391 ppb Au over 3 m. Fox (1990) concluded that the mineralized material and local stratigraphic section at Cantin Creek were typical of the QR Au deposit.

LYNDA

The Lynda showing (MINFILE 093B 025) is located 3 km south of the Cantin Creek showings in outcrops exposed along the 500 Road. It is characterized by sedimentary/volcanic-hosted Cu mineralization consisting of finely disseminated tetrahedrite and chalcocite replacements of limestone, and stratabound native Cu replacements of amygdules, vesicles and fractures in basalt flows and volcaniclastic rocks. Malachite and azurite are common on weathered surfaces. A 1 m chip sample of mineralized dolomitic limestone returned 2445 ppm Cu, 69 ppm Pb, 321 ppm Zn, 3600 ppb Hg, 3.4 ppm Ag and 15 ppb Au (Turner, 1983). Geochemical analyses of altered and mineralized maroon volcanic rocks (06JLO10-96 and 19-165) that underlie the limestone and an alkalic dike (JLO19-164b) are listed in Table 2. The volcanic rocks show anomalous Cu values but low Au, Ag and base-metal contents.

Middle Jurassic Cu-Au-Mo Mineralization

KATE

The Kate showing (MINFILE 093B 053) is located in the Quesnel River canyon, approximately 9 km upstream from Quesnel. Pyroxene-phyric flows and volcaniclastic and fine-grained sedimentary rocks of the Late Triassic Nicola Group are intruded by a suite of quartz-saturated Jurassic stocks and Eocene mafic dikes. Contacts are sharp, crosscutting and chilled for subsequent phases. Textures suggest an early fine-grained equigranular monzodiorite, followed by a feldspar-quartz-biotite–porphyritic monzonite, and a late phase of quartz-porphyritic granite. All units except the cemented Tertiary gravel are cut by metre-wide, east-trending, biotite lamprophyre dikes.

Sulphide mineralization comprises pyrite, chalcopyrite and minor tetrahedrite in fractures, and quartz-carbonate veins and disseminations in the metavolcanic country rock peripheral to the quartz porphyry granite. Carbonate and sericite alteration accompanies mineralization. In zones of high-density fracturing, Fe-carbonate replacement is pervasive, texturally destructive and produces pink- to buff-coloured rock. An assemblage of dolomite, pyrite, calcite, quartz and sericite dominates this alteration. Secondary minerals include malachite, azurite and hematite. Two geochemical samples of sulphide mineralization (05JLO8-73 and 08JLO21-191) were collected from the Quesnel River canyon at the Kate showing (Figure 18). Results show a multi-element suite of elevated to anomalous values for Au, Ag, As, Bi, Cu, Mo, Sb, Pb and Zn (Table 2).

At Mouse Mountain, these Middle Jurassic Fe-carbonate alteration zones (trending north and east) overprint the Late Triassic alkalic alteration assemblage and can dilute Cu-Ag grades of the monzonite-related mineralization. Zones of Fe-carbonate alteration are characterized by elevated As, Sb and Mo values (Jonnes and Logan, 2007).

MANDY

The Mandy showing (MINFILE 093B 046) is located 1.3 km south of the southern margin of the Quesnel River pluton in hornfelsed metavolcaniclastic rocks of the Nicola Group. Mineralization is hosted in Fe-carbonate (ankeritic)–quartz veins developed in sheared metavolcanic rocks and includes sporadic Cu, Zn, Ag and Au values

Figure 18. Massive, fine-grained pyrite vein with Fe-carbonate and silica alteration envelope, hosted in metavolcanic rocks adjacent to a quartz porphyry intrusion at the Kate occurrence (MINFILE 093B 053).

over widths of 1.5 m. The veins strike easterly, dip steeply north and occupy an en échelon northeasterly-stepping distribution. They are sheeted, milky white massive quartz banded with discontinuous blebs and layers of sulphides that include pyrite, chalcopyrite and tetrahedrite.

A grab sample of tetrahedrite-mineralized vein material from pit 1, which is explored by a 6 m decline, returned 13.54% Cu, 1530 g/t Ag, 2.36 g/t Au and 7.49% Sb (Larabie, 1985). A random chip sample across 1.5 m of the same quartz-ankerite vein, hosted in sheared metabasalt, yielded 3.3% Cu, 0.02% Pb, 0.45% Zn, 435 g/t Ag, 0.65 g/t Au and 0.29% As (Durfeld, 1986). Elevated As and Sb values suggest the presence of tennantite ($Cu_{12}As_4S_{13}$) in addition to tetrahedrite ($Cu_{12}Sb_4S_{13}$) within the veins. A weakly pyritized north-trending Fe-carbonate alteration zone crosscuts quartz-epidote±pyrite–replaced volcaniclastic rocks in an exploration pit adjacent to the logging road access. A grab sample from this alteration zone is barren (Table 2, station 08JLO7-76,).

TARN

The Tarn showing (MINFILE 093B 057) is located 1.5 km northeast of the Quesnel River in epidote-amphibolite–facies metavolcanic rocks of the Green Volcaniclastic succession. The showing is spatially associated with an aeromagnetic high coincident with the southwestern contact aureole of the Quesnel River pluton. Sparse Cu, Mo, Au and Ag mineralization has developed along fractures and as local disseminations in the metavolcanic rocks adjacent to hornblende-biotite monzogranite, coarse biotite quartz monzodiorite and felsite units that characterize the southern margin of the pluton. Trenching and sampling around the original discovery site returned values that averaged 0.67% Cu, 0.029% Mo, 7.3 g/t Ag and 0.4 g/t Au (Campbell et al., 1981). Follow-up rock sampling of skarn-, chlorite- and silica-altered metavolcanic, felsite, diorite and feldspar porphyry units could duplicate but not expand these anomalies beyond the original showings. Soil geochemistry recognized anomalous Cu, Mo, Ag and Au values, but their erratic distribution led Campbell et al. (1981) to conclude there was not an economic target present on the property.

The mineralized showings were not sampled during the current mapping project.

NYLAND LAKE

The Nyland Lake showing (MINFILE 093B 053) is classified incorrectly as a Mo showing located in the centre of Nyland Lake. Assessment reports covering the area indicate anomalous Au values in heavy-mineral pan concentrates and concluded a lode Au potential for the area (Troup and Freeze, 1985). The area, approximately 1.5 km west of Nyland Lake, contains the east-trending altered contact between Nicola Group metavolcanic rocks and granite of the Quesnel River pluton. Calcsilicate and sulphide assemblages overprint the metavolcanic rocks adjacent to the southern contact zone of the pluton, which is characterized by abundant narrow granite apophyses and aplite and pegmatite dikes. A single grab sample of epidote-garnet-chlorite-quartz–altered metavolcanic rock, taken adjacent to the contact with granite, returned a Au-only anomaly of 40 ppb (Table 2).

MISCELLANEOUS MINERALIZATION

Geochemical grab sample 07GLE34-162 consists of strongly altered (bleached, silicified and pyritized), grey to green, fine-grained volcaniclastic rock cut by sulphide-bearing centimetre-thick quartz veins. Bleaching and surface oxidation have produced an outcrop of brown-, orange- and green-weathered rock that returned anomalous values in As, Nb and W (Table 2). The sample site is located close to the contact between the Cottonwood River succession and the Western Volcaniclastic succession.

Molybdenum mineralization is associated with aplite dikes cutting diorite at the Daphne showing (MINFILE 093A 123), located immediately adjacent to the southeast corner of NTS area 093B/16. Molybdenite occurs with quartz in stringers, as specks in the aplite and as fracture coatings in the diorite (Petersen, 1976).

CONCLUSIONS

The Quesnel River map area includes Middle Triassic to Early Jurassic sedimentary, volcanic and plutonic rocks of the Quesnel terrane and younger units that overlie the Cache Creek terrane in the southwestern part of the map area.

These younger rocks include Jurassic Dragon Mountain sedimentary rocks; Eocene dacite and basalt; Oligocene to Miocene sedimentary rocks; and thick accumulations of unconsolidated Quaternary deposits. The thickest accumulation of Quaternary deposits is preserved in a 4 km wide, north-trending Pleistocene valley that follows the east side of the Fraser River.

The Nicola Group has been divided into two main units in the Quesnel River map area: an Eastern Sedimentary succession (ESS) and Western Volcaniclastic succession (WVS). These can be traced northwestward along strike into correlative Nicola units of the Cottonwood map area (Logan et al., 2008) and southeast into the Mount Polley area (Logan et al., 2007b). The ESS comprises a package of disrupted, green and grey cherty argillite, siltstone, limestone and tuffaceous sandstone that correlates with the Cottonwood River succession (Logan, 2008), and a mixed package of pyroxene volcaniclastic rocks and Middle Triassic dark phyllite, siltite and slate that correlate with the Eastern Volcaniclastic and Black pelite successions to the north in the Cottonwood map area (Logan et al., 2008). The WVS is a pyroxene-rich volcaniclastic succession, characterized by green and maroon, polylithic volcanic conglomerate interbedded with limestone, maroon and/or green pyroxene basalt, and fine-grained, bedded volcaniclastic rocks, that correlates with rocks of the same name in the Cottonwood map area (Logan, et al., 2008). The Cottonwood River succession and conformably overlying Western Volcaniclastic succession are Late Triassic or older because the upper part of the succession is cut by monzonite of the Late Triassic (207 Ma) Mouse Mountain stock.

The isolated limestone located north of Hallis Lake has been reinterpreted as a crinoid ossicle–rich, Late Triassic grainstone rather than a Cambrian archaeocyathid-bearing rock (Tipper, 1978).

The area southeast of the Quesnel River is underlain by a coarsening-upward sequence of sedimentary rocks of Triassic (?)/Early Jurassic to Middle (?) Jurassic age that comprises a lower package of black, thin-banded phyllite and pyritic and calcareous argillite and siltstone, and an upper sequence of thick-bedded or massive, volcanic- and plutonic-clast conglomerate, quartz grit, limestone and greywacke. The Ashcroft Formation of southern BC formed in a fore-arc basin from material shed from the uplifted Nicola volcanic-plutonic arc and Cache Creek accretionary wedge (Travers, 1978). A similar interpretation is postulated for the Dragon Mountain succession in the Quesnel River map area. Cache Creek rocks form the basement to the southwestern part of the map area, where they are overlain mainly by the Dragon Mountain succession. A gradational stratigraphic contact between the Late Triassic Green Volcaniclastic succession (Nicola Group) and Early Jurassic Dragon Mountain succession is apparent east of Dragon Lake, suggesting that deposition was continuous from Late Triassic through early Jurassic. This implies that the Dragon Mountain succession is an overlap assemblage linking the Cache Creek basement rocks in the map area to the Nicola Group fore-arc (Quesnel terrane) prior to the end of the Late Triassic. This interpretation is further supported by relationships at the Gibraltar mine, 30 km to the south. Here 212 Ma subduction-generated arc plutons intrude Cache Creek rocks that probably occupied a fore-arc setting to the nascent Nicola arc prior to the culmination, in the Late Triassic, of Nicola Group arc magmatism.

Intrusive rocks in the map area include the Early Jurassic (ca. 193 Ma) Polaris suite of mafic-ultramafic complexes, synkinematic Middle Jurassic (165, 160, 158 Ma) suite of granite, and Tertiary (ca. 50 Ma) suite of alkalic mafic dikes. Discrete brittle shear zones with oblique-dextral sense of shear cut across the Middle Jurassic Quesnel River pluton.

Mineralization in the Quesnel River map area is associated with emplacement of high-level intrusions and comprises a Late Triassic (?) to Early Jurassic episode characterized by Zn-Pb±Mo-Au, an Early Jurassic episode of Au±Cu and a Middle Jurassic episode of Cu-Au-Mo deposition.

An early Miocene tectonic event produced anticlines in Oligocene sedimentary rocks.

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