Geological Relationships on the Western Margin of the Naver Pluton, Central British Columbia (NTS 093G/08)

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KEYWORDS: Quesnel, Slide Mountain, Kootenay, Barkerville, Crooked amphibolite, Snowshoe Group, Nicola Group, Naver pluton, deformation, metamorphism, contact aureole

INTRODUCTION

The Naver pluton occupies approximately 700 km^2 southeast of Prince George in east-central British Columbia (Figures 1, 2). It comprises mostly granite and granodiorite. The pluton intrudes rocks of the Nicola Group, the Crooked amphibolite and the Snowshoe Group, and crosscuts tectonically significant boundaries between these units. The pluton was studied by Struik et al. (1992), who obtained U-Pb zircon and monazite crystallization ages of ca. 113 Ma and described the pluton as being nonfoliated except directly adjacent to faults.

Here we report on observations made during preliminary mapping of the southwestern part of NTS map area 093G/08 (1:50 000), incorporating the western part of the Naver pluton and adjacent metasedimentary and metavolcanic rocks. A primary finding is that rather than being a homogeneous post-tectonic intrusion, the Naver pluton is a composite body including a deformed western part. The post-tectonic 113 Ma part of the composite body was intruded at shallow levels into low-grade metamorphic rocks, resulting in a Buchan-type contact aureole. This contrasts with the older part, which was penetratively deformed with midcrustal amphibolite-facies rocks and lacks a contact aureole.

Figure 1. Location of the NTS 093G/08 map sheet, marked with a red box. The Quesnel terrane is shown in green and the Cache Creek terrane in dark grey. The locations of Cu-Au-Ag±PGE alkaline porphyry deposits are also shown.

REGIONAL GEOLOGY

The Naver pluton intrudes across the boundaries separating the Quesnel, Slide Mountain and Kootenay terranes, three major tectonic components of the Canadian Cordillera (Figure 1).

The Quesnel terrane represents an extensive (>2000 km) west-facing calcalkaline-alkaline Late Triassic–Early Jurassic arc that developed outboard or proximal to the western margin of North America. It is characterized by Mesozoic arc volcanic and sedimentary rocks of the Nicola, Takla and Stuhini groups and coeval plutonic rocks. At this latitude, the western part of the Nicola Group is dominated by forearc volcaniclastic-dominated successions that grade eastward across the arc into backarc Middle–Late Triassic fine-grained clastic rocks (the black phyllite unit of Rees, 1987). Rocks of the Nicola Group record an eastward shift in the locus of magmatism through time and a change from early calcalkaline to alkaline magmatism.

The eastern margin of the Quesnel terrane is marked by a discontinuous belt of variably sheared mafic and ultramafic rocks of the Crooked amphibolite. These rocks 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. The Eureka thrust, an east-verging thrust fault, marks the eastern boundary of the Slide Mountain terrane (Struik, 1986). The footwall to the Eureka thrust compromises Proterozoic–Paleozoic Snowshoe Group rocks of the Barkerville subterrane, 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). In this region, a conglomerate close to the base of the Nicola Group contains foliated clasts derived

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from the Snowshoe Group and the Crooked amphibolite (McMullin et al., 1990). This suggests that the western boundary of the Slide Mountain terrane, and where absent, the contact between the Quesnel terrane and the Kootenay terrane, is or was initially an unconformity.

West of the Quesnel terrane is Late Paleozoic–Jurassic oceanic rocks of the Cache Creek terrane, with Late Triassic blueschist-facies rocks (Patterson and Harakal, 1974; Ghent et al., 1996) representing the remnants of a subduction-accretionary complex (Travers, 1977; Mihalynuk et al., 2004) that generated the Quesnel Arc.

Younger rocks in the area include Early–Middle Jurassic and mid-Cretaceous granitic plutons, Eocene sedimentary and volcanic sequences and Miocene flood basalt. The Ste Marie pluton, a hornblende-bearing granite-monzonite exposed north of the Naver pluton, was intruded at 167 Ma (Struik et al., 1992). Further details on the regional setting of the central Quesnel belt can be found in Logan et al. (2007) and Logan and Moynihan (2009).

ROCK UNITS

Snowshoe Group (Proterozoic–Paleozoic)

Rock types contained within the Snowshoe Group on the western margin of the Naver pluton include micaceous quartzite, metapelitic schist, calcsilicate, marble and feldspathic grit. All of these rocks are penetratively deformed. No internal subdivisions within the Snowshoe Group were mapped, but the recognition of outcrop-scale refolded folds suggests its structure is complex.

Crooked Amphibolite (Carboniferous–Permian)

Ultramafic rocks of the Crooked amphibolite occur as discontinuous slivers along the boundary between the Snowshoe and Nicola groups. The rocks form distinctive knobbly dun-coloured outcrops. A tectonic foliation with a moderate dip to the southwest is crosscut by a web-like network of secondary serpentine, talc and tremolite that have replaced olivine. In this area the Crooked amphibolite is, where present, <300 m thick.

Nicola Group (Triassic)

The Nicola Group includes a volcaniclastic-dominated unit (T_{NV}) in the western part of the area and a mostly sedimentary unit (T_{NBP}) close to the Naver pluton.

Rocks in the T_{NBP} have been penetratively deformed, as have rocks of the T_{NV} between the two bands of T_{NBP} in the southwest corner of the area (Figure 2). However, farther west, rocks belonging to this unit are generally massive; locally, a spaced fracture cleavage is developed, and in rare cases, a penetrative fabric.

BLACK PHYLLITE UNIT (T_{NBP})

This unit comprises dark parallel-laminated or homogeneous metapelitic phyllite, banded metasiltstone and dark calcareous phyllite with abundant pyrite porphyroblasts. Metapelite is converted to a spotted hornfels in the contact aureole of the Naver pluton.

These rocks crop out in two belts, separated by an interval of volcaniclastic rocks. Fine-grained sedimentary rocks of the western belt overlie, and are interbedded with, volcaniclastic rocks (T_{NV}); the eastern belt of phyllite is older and underlies volcaniclastic rocks.

The fine-grained clastic rocks of the eastern belt are correlated with the black phyllite unit of Rees (1987), which has been dated as Middle and Late Triassic from conodont-bearing calcareous horizons at Quesnel Lake (Struik and Orchard, 1985). Middle Triassic conodonts have also been identified by M. Orchard (pers comm, 2007) from limestone interbedded with fine-grained siltstone and volcaniclastic rocks exposed along the Swift River, in NTS map area 093B/16.

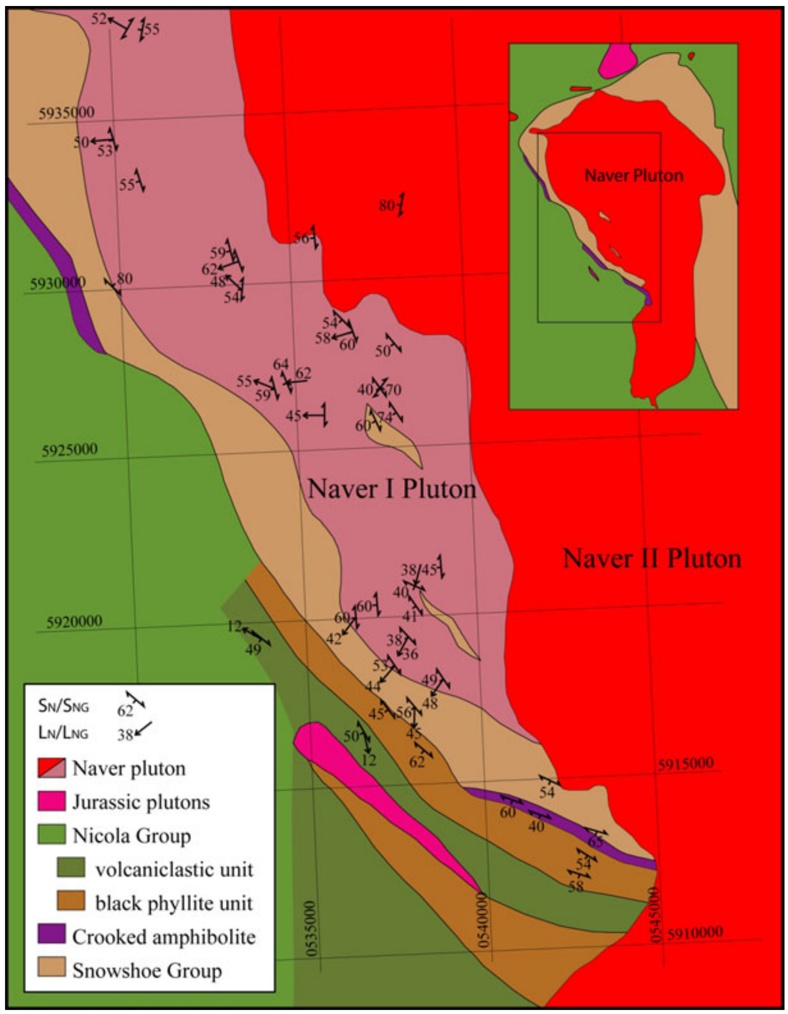

Figure 2. Map of the western margin of the Naver pluton, *modified after* Massey et al. (2005) and based on 2008 fieldwork. The inset shows the full extent of the Naver pluton and its relationship to the boundaries separating the Nicola Group, the Crooked amphibolite and the Snowshoe Group.

VOLCANICLASTIC UNIT (T_{NV})

The volcaniclastic unit is dominated by green- or orange-weathering conglomerate with boulder- to granule-size volcanic and subvolcanic clasts. Conglomerate is interbedded with finer-grained reworked deposits of lithic and crystal sandstone and siltstone, and lesser fine cherty sedimentary rocks. The sandstone and siltstone are well sorted and commonly display normal grading. These epiclastic units are interlayered with coarse pyroxene-phyric±pyroxene-plagioclase–phyric basaltic breccia flows and hyaloclastite deposits.

This unit is correlative with similar rocks to the southeast that have yielded Middle–Late Triassic conodonts (M. Orchard, pers comm, 2007). The magnetic susceptibility values in this area are low, while correlative pyroxene-phyric volcaniclastic rocks located southeast of the study area (NTS 093G/01 and 093B/16) have moderate–high magnetic susceptibility and a distinctive geophysical signature on regional aeromagnetic maps.

Jurassic Mafic Intrusion

An elongate, northwest-trending mafic-ultramafic composite intrusion crops out within the Nicola Group in the southwest corner of the study area (Figure 2). The intrusion consists mainly of commingling melanocratic and leucocratic phases of gabbro, pyroxenite and hornblendite; with lesser porphyritic biotite quartz diorite and felsic segregations. The intrusion is sheared, cut by numerous brittle northwest-trending faults and has been extensively altered to chlorite, epidote and serpentine. Metasomatic alteration has produced decimetre-wide sections of rock containing 75–85% coarse biotite and chlorite. The base- and precious-metal content of the intrusion is low (Kowalchuck, 1988).

Similar mafic complexes are present in the Cottonwood map area (Logan, 2008) and farther south in the Canim Lake area (Schiarizza and Macauley, 2007). Radiometric crystallization and cooling ages from these complexes span the Early Jurassic (Sinemurian–Pliensbachian) from 192 to 183 Ma (Schiarizza and Macauley, 2007; T. Ullrich, pers comm, 2008).

Naver Pluton

The Naver pluton is a composite body including an undeformed eastern and southern part and a deformed western part. Radiometric dating of the undeformed parts of the pluton has yielded U-Pb crystallization ages of 113 Ma and K-Ar biotite cooling ages of 107–98 Ma (Struik et al., 1992). A sample of the deformed western margin was collected and submitted to the Pacific Centre for Isotopic and Geochemical Research at The University of British Columbia for U-Pb and $^{40}Ar/^{39}Ar$ dating. Results are pending.

NAVER II PLUTON

Most of the Naver pluton is, as described by Struik et al. (1992), undeformed orthoclase-megacrystic biotite granite–granodiorite with a variable texture from equigranular to megacrystic. Biotite is contained throughout, locally accompanied by muscovite or hornblende adjacent to contacts, with local alteration of hornblende, biotite and plagioclase. This part of the body includes the eastern two-thirds of the main subspherical northern part, and the elongate tail that cuts across terrane boundaries (Figure 2). We refer to this as the Naver II pluton.

NAVER I PLUTON

The Naver I pluton is an elongate, foliated body occupying the northwest part of the composite Naver pluton. It trends parallel to strike and is truncated by the Naver II pluton at its southern end. Its western margin is a gradational zone tens of metres wide comprising country rock mixed with sheets of granite and pegmatite, which are commonly approximately parallel to foliation (Figure 3a). The percentage of country rock decreases eastward across the transition zone, but elongate strike-parallel inclusions are common at a variety of scales throughout the body. The foliation in screens of country rock is consistently oriented parallel to that outside the pluton. These features suggest the Naver I pluton grew by the progressive intrusion of dikes whose orientation was influenced by foliation planes.

Rocks of the Naver I pluton are deformed biotite granodiorite that have undergone recrystallization and grain-size reduction. Large K-feldspar crystals up to 1.5 cm are locally preserved, but porphyroclasts of K-feldspar and plagioclase are typically <5 mm in length. These porphyroclasts sit in a fine-grained, strained matrix of quartz, plagioclase, myrmekite, biotite and accessory phases, with secondary chlorite and muscovite. Locally, where the pluton is well foliated and highly porphyroclastic, the rock takes on the appearance of augen gneiss. Biotite is the only mafic silicate phase present, and primary muscovite is restricted to rocks adjacent to inclusions of the Snowshoe Group. Here it is often concentrated in thin granitic veins, which sometimes also contain garnet. Muscovite and garnet are common in pegmatite on the gradational western margin of the pluton, where granitic sheets are intermixed with country rock.

The boundary between the Naver I and Naver II plutons is constrained by field observations, but the precise location shown in Figure 2 is inferred from aeromagnetic data. The extent to which aeromagnetic patterns accurately define the boundary will be tested during the 2009 field season. The two-fold subdivision adopted here is preliminary; future work may show that it is an oversimplification.

STRUCTURAL GEOLOGY

Deformation of the Naver I Pluton

Granitic rocks belonging to the Naver I phase are foliated and lineated (Figure 3b, c). The S-L fabric is defined by aligned biotite crystals, flattened and elongated quartz-feldspar aggregates and quartz lenses. In most places the foliation (S_{NG}) has a moderate dip to the southwest and the stretching lineation (L_{NG}) pitches steeply, approximately down the dip of the foliation (Figure 4a). In a few locations around the margins, steep foliations with anomalous strikes were measured. Due to the lack of exposure, the relationship between these fabrics and the dominant southeast-trending fabric is unknown, but in some of these locations there are superimposed localized foliated zones oriented close to average S_{NG}.

There is a general westward increase in the intensity of deformation within the Naver I body—deformed granite on the western margin forms slabby outcrops parallel to the topographic slope (Figure 3b), whereas outcrops farther

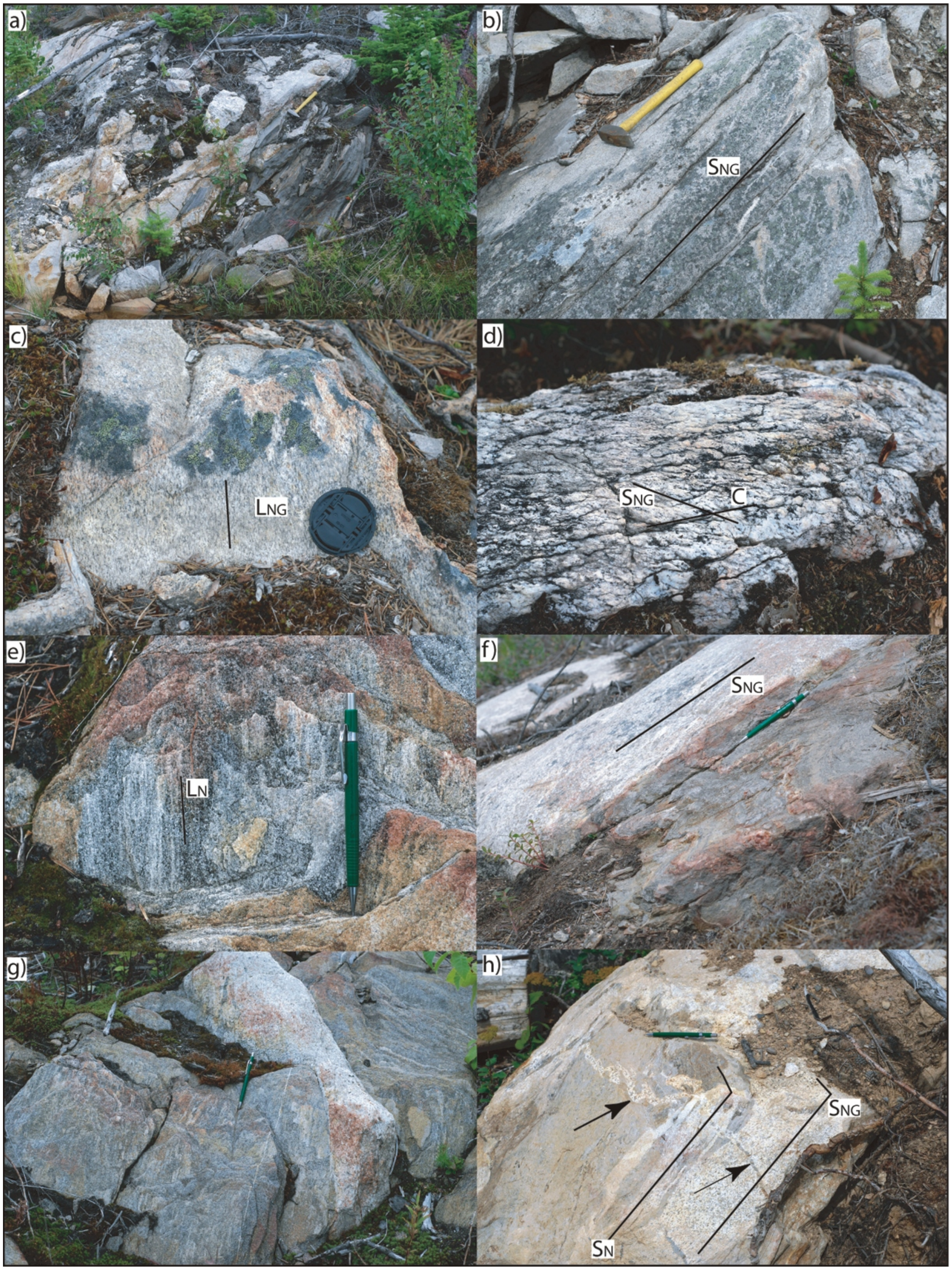

Figure 3. a) Outcrop on the western margin of the Naver I pluton showing rocks of the Snowshoe Group intruded by a granitic sheet, rock hammer for scale. **b)** Foliated granite of the Naver I pluton forms slabby outcrops, rock hammer for scale. **c)** Mineral lineation (L_{NG}) defined by aligned biotite and elongate quartz-feldspar aggregates, viewed on the S_{NG} surface, lens cap for scale. **d)** Two foliations displaying S-C relationship on the western margin of the Naver I pluton. The shape fabric (S_N) is cut by discrete shear bands (SB); width of field of view is 20 cm **e)** Downdip mineral and intersection lineations in the Snowshoe Group on the margin of the Naver I pluton, pencil for scale. **f)** Fold of the dominant fabric (S_N) in the Snowshoe Group on the margin of the Naver I pluton; its axial plane is parallel to average S_N. The granitic sheet cuts S_N, but is foliated parallel to average S_N, pencil for scale. **g)** Granitic dike intruded into the Snowshoe Group on the margin of the Naver I pluton. The dike cuts S_N, but is itself foliated parallel to S_N, pencil for scale. **h)** Granitic dike foliated parallel to S_N in the Snowshoe Group host. This is cut by a thin granitic vein, which is folded. The axial planes of these folds are parallel to S_N in the Snowshoe Group schist, pencil for scale.

east are more massive and the fabric is less well developed. On the western margin of the Naver I intrusion, two fabrics are locally developed (Figure 3d). The S-L fabric is cut by discrete shear bands, forming S-C or S-C' geometry. These fabrics indicate west-side-down (normal-sense) shearing, approximately parallel to L_{NG}. Normal-sense shearing is also indicated by sigmoidal recrystallized tails on K-feldspar porphyroclasts. These features suggest the Naver I body was deformed by a west-side-down (normal-sense) simple or general shear, which was concentrated on its western margin.

Deformation of the Snowshoe and Nicola Groups

D_N

The dominant planar tectonic fabric (S_N) in the Snowshoe and Nicola groups on the western margin of the Naver I pluton dips moderately to steeply to the southwest (Figure 4b). It is variably expressed as a continuous, disjunctive or crenulation cleavage and is typically parallel to compositional layering. A planar fabric with the same orientation is developed in the Slide Mountain rocks. A mineral lineation (L_N) is visible in rocks that are sufficiently coarse-grained, namely schist of the Snowshoe Group and some parts of the volcanic Nicola Group. Wherever observed together, mineral lineations (L_N) and intersection lineations (L_{NI}, intersection of S_N with S_0) are parallel. These lineations pitch at highly variable (shallow–very steep) angles on S_N from the south-southeast (Figure 3e).

Shear band cleavage (S-C' fabric), indicating west-side-down shearing and extension along S_N, is developed in the Snowshoe Group close to its contact with the Nicola Group (around UTM Zone 10, 5917368N, 0537392E, NAD 83). This is the only well-exposed section across the contact that was mapped and metamorphic contrasts suggest the two units are in normal fault contact (*see* below). It is not known whether this postulated fault passes northeast or southwest of ultramafic rocks where they are present along this boundary.

D_{N+1}

Around the western margin of the Naver I pluton, close folds of S_N, whose axial planes are approximately parallel to average S_N, are developed. Axes of these folds pitch gently to steeply on S_N from the south-southeast. Some of these folds are truncated by granitic dikes of the Naver I pluton (Figure 3f). Folds of S_N are also locally developed in enclaves of the Snowshoe Group within the Naver I pluton where S_N lies at a high angle to S_{NG}. Although these folds are classified as F_{N+1} (Figure 4), they can plausibly be interpreted as resulting from progressive D_N rather than a distinct episode of deformation.

D_{N+2}

The youngest ductile structures recognized are crenulations (F_{N+2}), which plunge approximately downdip. These crenulations are gentle–open, with axial planes at a high angle to strike. Crenulations with these orientations and characteristics postdate the formation of porphyroblasts of andalusite and cordierite in the contact aureole; this folding therefore postdates the intrusion of the Naver II pluton at 113 Ma. Larger-scale F_{N+2} folding is interpreted to be responsible for the significant variation in the orientation of S_N across the area, as measured values of S_N are

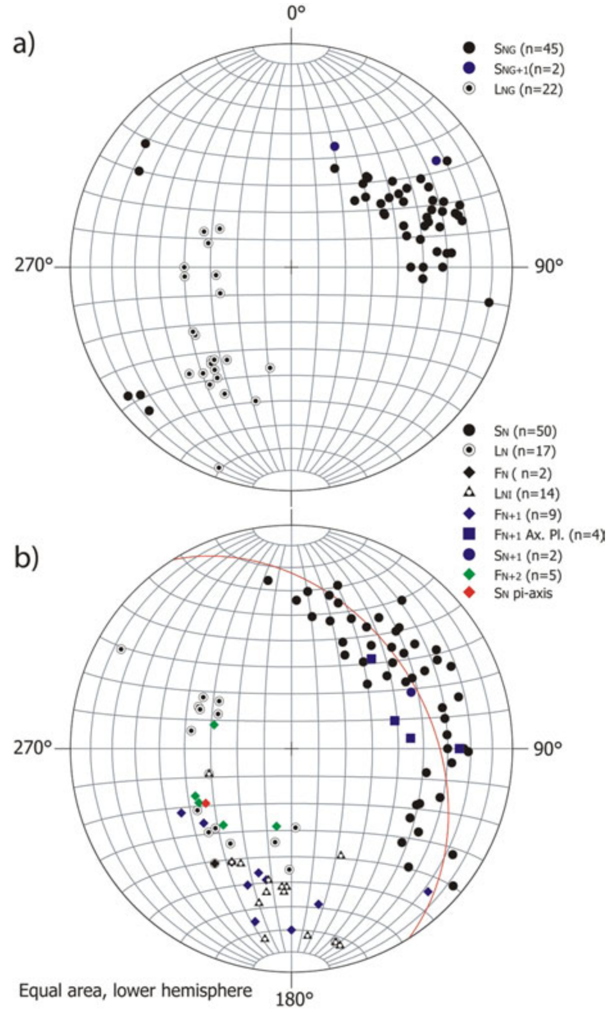

Figure 4. Equal-area lower-hemisphere stereonet projections of structural data from the western margin of the Naver I pluton and adjacent rocks: **a)** data from the Naver I pluton; **b)** data from rocks of the Snowshoe Group, Crooked amphibolite and Nicola Group (black phyllite unit) adjacent to the western margin of the intrusion.

spread along a girdle whose -axis approximately coincides with the orientation of F_{N+2} crenulation axes.

Relationship of Structures in the Naver I Pluton to those in the Snowshoe and Nicola Groups

The planar fabric (S_N) in the Snowshoe Group and S_{NG} in the Naver I pluton have the same overall orientation. Granitic dikes on the western margin of the Naver I pluton typically cut S_N, but exhibit a foliation (S_{NG}) that is parallel to S_N (Figure 3g). This implies that the strain that produced S/L_{NG} in the Naver I pluton is a subset of the strain that produced S/L_N in the Snowshoe Group. The Naver I and its host were deformed together and display congruent kinematic indicators. The simplest interpretation, adopted here, is that each of these units records the same period of west-side-down simple or general shear. It is possible that this deformation was synchronous with the intrusion of the Naver I pluton; the presence of variably deformed, cross-cutting dikes (Figure 3h) is compatible with, but not diagnostic of, syntectonic intrusion.

The planar fabric (S_N) in the Nicola Group is parallel to that in the Snowshoe Group, and crenulations of S_{N-1} are locally preserved in each. There is evidence in the region for deformation of the Snowshoe Group prior to the deposition of the Nicola Group (McMullin et al., 1990), but earlier structures restricted to the Snowshoe Group were not identified in the course of this study.

METAMORPHIC PETROLOGY

Regional Metamorphism

Rocks of the Nicola Group have undergone regional greenschist-facies metamorphism. This is manifested in chlorite-muscovite-quartz-plagioclase assemblages in phyllitic metapelite of the black phyllite unit, and chlorite-plagioclase (±epidote) assemblages in metabasite of the volcaniclastic unit. Biotite is absent from phyllite but is present, along with amphibole, in calcsilicate belonging to T_{NV}.

In contrast, garnet and biotite are widely distributed in metapelitic schist and micaceous quartzite of the Snowshoe Group (this study; Struik et al., 1992), and the metapelite is coarser-grained than its Triassic equivalents. Amphibolite is also present in the Snowshoe Group. All nonequant metamorphic minerals are aligned in the plane of S_N in both the Snowshoe and the Nicola groups.

The difference in metamorphic grade between the Nicola and Snowshoe groups is exemplified by a series of outcrops west of the Naver I pluton (northeast from UTM Zone 10, 5917157N, 0537203E). Here, there is intermittent exposure in a small stream gully for a cross-strike distance of approximately 260 m. Chlorite-zone phyllite of the Nicola Group is exposed in the southwest, whereas outcrops of Snowshoe Group schist at the northeast end of the section include the assemblage kyanite-staurolite-garnet-biotite-muscovite-chlorite(retrograde)-plagioclase-ilmenite (Figure 5). No direct P-T estimates have been obtained from these rocks, but schist with this assemblage forms under conditions of approximately 650–700ºC and 6.5–8 kb in metapelites of widely varying bulk composition.

The kyanite zone metapelite exhibits shear band cleavage (S-C' fabric) indicating west-side-down (normal-sense) shearing. Overgrowth by kyanite of sigmoidal foliation traces between these shear bands attests to a temporal overlap between normal-sense shearing and peak Barrovian metamorphism.

Given the large difference in metamorphic grade over a cross-strike distance of approximately 260 m, and the evidence for normal-sense shearing in the amphibolite-facies rocks, the Snowshoe Group–Nicola Group contact is interpreted as a normal fault/shear zone.

Contact Metamorphism

A contact metamorphic aureole extends approximately 1 km from the western boundary of the Naver II pluton. Here, the assemblage cordierite-andalusite-biotite-quartz-plagioclase-ilmenite is widely developed in metapelitic rocks of the black phyllite unit of the Nicola Group (Figure 6). Porphyroblasts of cordierite and andalusite overgrow the S_N foliation (locally a crenulation cleavage) with no preferred orientation, giving rise to a hornfelsic texture.

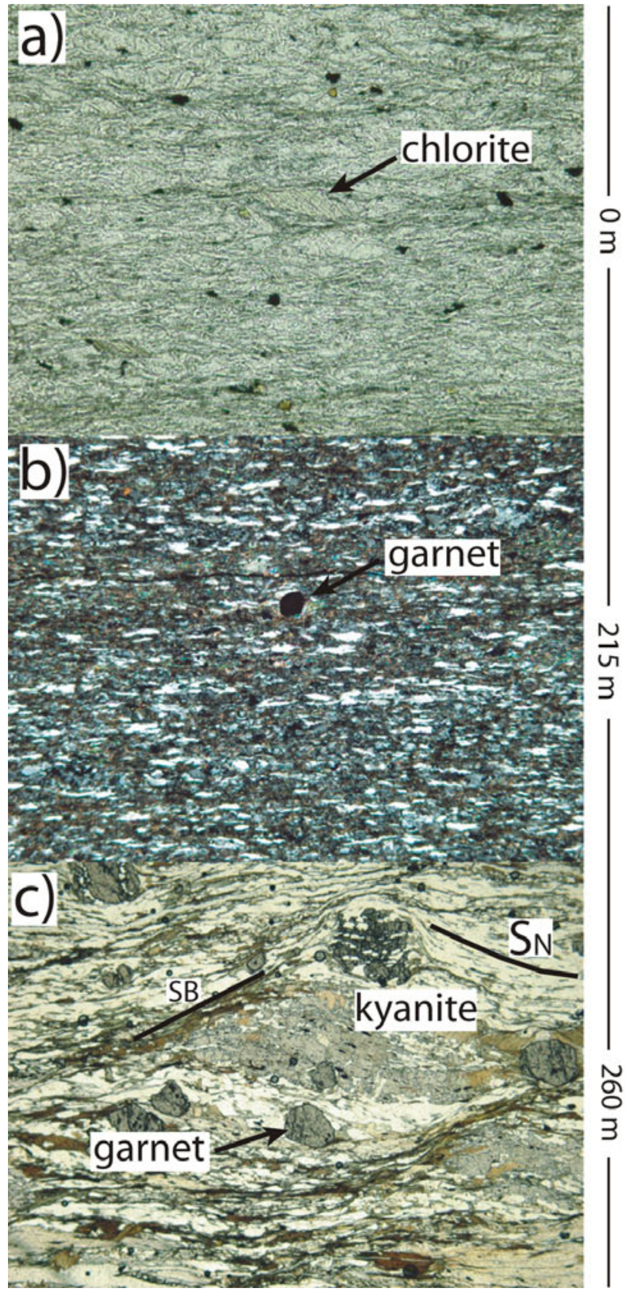

Figure 5. Photomicrographs of three rocks sampled perpendicular to the metamorphic discontinuity at the Nicola Group–Snowshoe Group boundary; the rock shown in a) is separated from the rock shown in c) by a cross-strike distance of 260 m: **a)** greenschist-facies Nicola Group phyllite with chlorite- and muscovite-rich matrix and small chlorite porphyroblasts; field of view = 1.5 mm; **b)** phyllite/fine-grained schist with biotite- and muscovite-rich matrix and small garnet crystals; field of view = 3 mm; **c)** Snowshoe Group kyanite-garnet schist with well-developed shear bands; kyanite crystals overgrow sigmoidal deflections into west-side-down shear bands; field of view = 6 mm; the large change in metamorphic grade across this transect and the evidence for normal-sense shearing in the Snowshoe Group suggests the Nicola Group–Snowshoe Group contact is a fault or shear zone.

Limited exposure hampered identification of mineral zones within the aureole, but the cordierite-andalusite hornfelsic assemblage constrains the pressure at the time of contact metamorphism and consequently the depth of intrusion.

Figure 7 is an equilibrium pressure-temperature mineral assemblage stability diagram for a rock with the measured composition of 08DMO36-393, a representative sample of hornfelsic metapelite (Table 1). This was constructed in the ten-component system MnO-Na_2O-CaO-K_2O-FeO-MgO-Al_2O_3-SiO_2-H_2O-TiO_2 (MnNCKFMASHT) using Theriak-Domino software (de Capitani and Brown, 1987) and the thermodynamic database of Holland and Powell (1990), version 5.5, assuming H_2O saturation. The solution models used are those given in Tinkham and Ghent (2005) with two exceptions: margarite was not considered as a component in white mica, and the ternary feldspar model of Holland and Powell (2003) was used. A melt phase was not considered. The diagram shows that the mineral assemblage cordierite-andalusite-biotite-quartz-plagioclase-ilmenite is stable over a pressure range of approximately 1.5–3 kb. Assuming a typ-

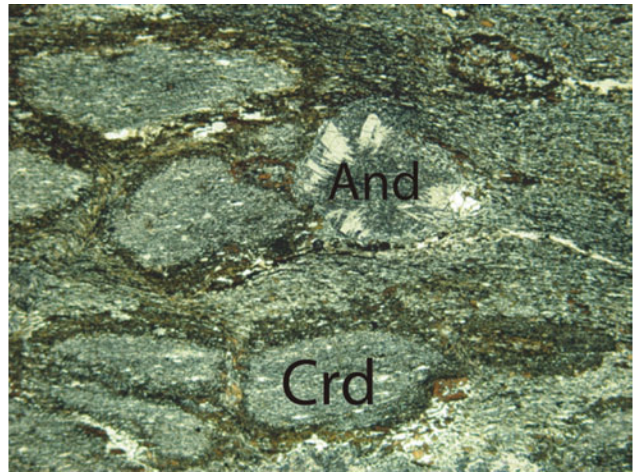

Figure 6. Photomicrograph of cordierite-andalusite hornfels from the contact aureole of the Naver II pluton. Field of view = 6 mm. The predicted stability field for this assemblage in this rock is shown in Figure 7. Abbreviations: And, andalusite; Crd, cordierite.

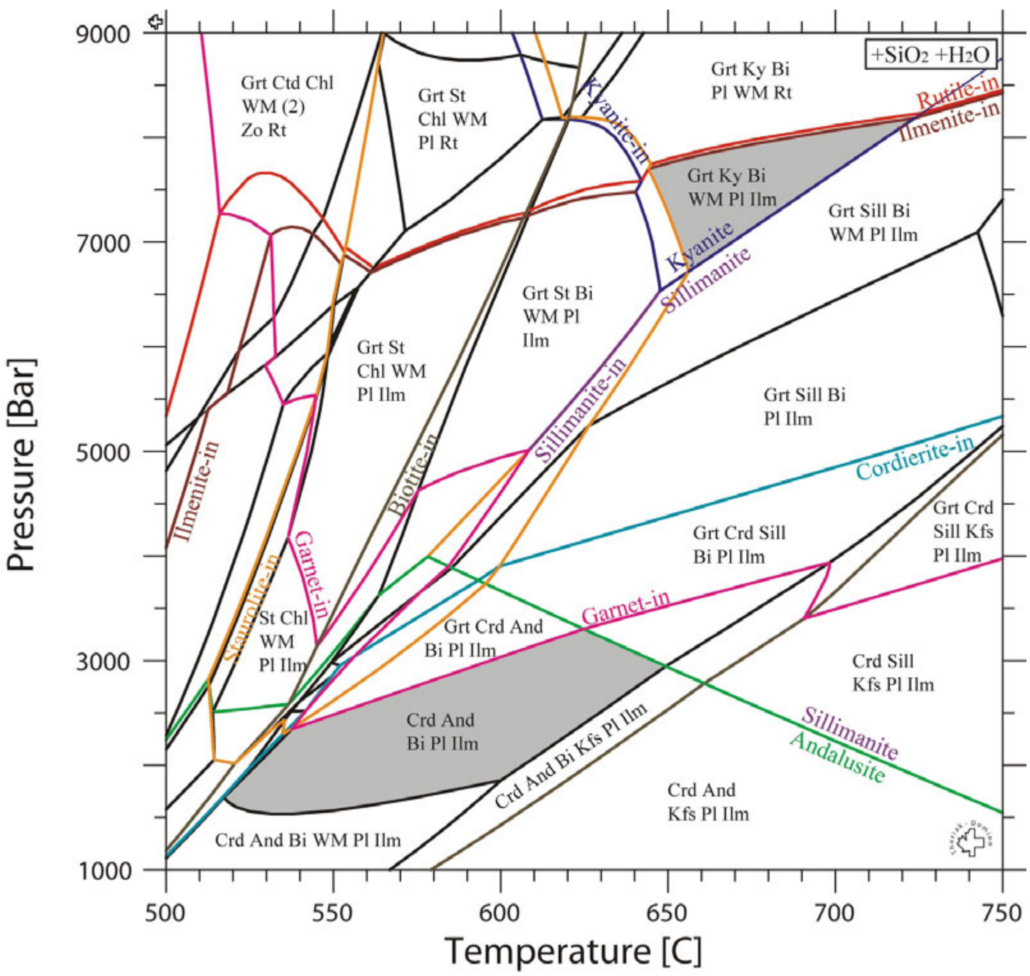

Figure 7. Mineral assemblage stability diagram for a rock with the composition of 08DMO36-393: a hornfelsic sample of Triassic black phyllite. *See* text for details. The assemblage cordierite-andalusite-biotite-quartz-plagioclase-ilmenite, which is widely developed in the contact aureole, is only stable below ~3 kb. The stability field of kyanite-garnet-biotite-muscovite-plagioclase-quartz-ilmenite is also shown. Although the diagram is composition-specific, the stability field of this assemblage varies little in metapelite. Abbreviations: And, andalusite; Bi, biotite; Crd, cordierite; Chl, chlorite; Ctd, chloritoid; Grt, garnet; Ilm, ilmenite; Kfs, K-feldspar; Ky, kyanite; Pl, plagioclase; Rt, rutile; Sill, sillimanite; WM, white mica; Zo, zoisite.

Table 1. Whole-rock x-ray fluorescence (XRF) major-element analysis of 08DMO36-393: a metapelitic hornfels sample from the contact aureole of the Naver pluton.

SiO_2	56.79%
TiO_2	1.10%
Al_2O_3	22.98%
Fe_2O_3	7.06%
MnO	0.07%
MgO	1.80%
CaO	1.01%
Na_2O	1.53%
K_2O	2.04%
P_2O_5	0.16%
Ba	0.08%
LOI	4.66%
Total	99.28%

ical crustal density, this means that the 113 Ma Naver II pluton was intruded at a depth of approximately 10 km or less.

This diagram also places a constraint on the regional metamorphism undergone by Nicola Group phyllite prior to the intrusion of the Naver II pluton. As these rocks did not develop biotite, garnet or staurolite during regional metamorphism, the temperature cannot have exceeded approximately 510–540ºC (depending on pressure).

DISCUSSION

The interpretations presented here are based on a small dataset and are preliminary. Nevertheless, the new observations contradict previous work and require a revised interpretation of the Naver pluton and its contact relations.

The main, younger part of the Naver pluton has a simple history. It was intruded into the upper crust at 113 Ma, after deformation and metamorphism of surrounding rocks, and cooled below approximately 280ºC (the closure temperature of biotite) by 107–98 Ma (Struik et al., 1992). It crosscuts structures and places a minimum age on major boundaries between units.

The older part of the Naver pluton lacks a contact aureole and does not cut across strike. Instead it was deformed with middle-amphibolite–facies rocks that recrystallized in the middle crust. Normal-sense shearing in the Snowshoe Group overlapped with peak metamorphism, and if the same period of normal-sense shearing affected the Naver I pluton, it must also have been deformed and metamorphosed under the same conditions.

All the rocks in the area were exhumed to shallow levels by 113 Ma. The difference in pressure between the Barrovian regional metamorphism in the Snowshoe Group and the Buchan contact metamorphism provides an estimate of net exhumation of the Snowshoe Group between the time of peak deformation and the intrusion of the Naver II body. The difference is approximately 5 kb, implying approximately 18 km of exhumation during this interval.

The Naver II pluton provides a lower age limit to the deformation in all units. It crosscuts the deformation fabrics and the postulated normal fault between the Snowshoe and Nicola groups. Work is underway to ascertain the crystallization age of the Naver I pluton, but at this time the only absolute constraints are provided by the depositional ages of the units themselves. The Ste Marie pluton, which was intruded at 167 Ma, is post-tectonic with respect to the regional foliation in the surrounding Nicola Group. It is therefore likely that deformation and metamorphism in the Nicola Group around the Naver pluton predated the intrusion of the Ste Marie pluton. However, the possibility that, as in the Cariboo Mountains, metamorphism and deformation in the higher-grade rocks are younger than at shallower structural levels (Reid, 2003) cannot be ruled out.

The Snowshoe Group–Nicola Group contact is interpreted as a normal fault or shear zone due to the large, discrete contrast in metamorphic grade and the presence of normal-sense kinematic indicators close to the contact. No evidence for thrust-sense shearing was observed. Snowshoe Group rocks record a higher metamorphic grade than the Nicola Group black phyllite along strike to the southeast (Logan, 2008; Struik, 1988), and the possibility that the contact is a normal fault elsewhere along this boundary is worthy of investigation. This postulated normal fault is much older than similar Tertiary structures in southeast BC (Parrish et al., 1988) as it is truncated by the Naver II pluton. The only ductile structures that are demonstrably younger than 113 Ma are F_{N+2} folds, which postdate the Naver II contact aureole.

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REFERENCES

Colpron, M. and Price, R.A. (1995): Tectonic significance of the Kootenay Terrane, southeastern Canadian Cordillera: an alternative model; *Geology*, Volume 23, pages 25–28.

de Capitani, C. and Brown, T.H. (1987): The computation of chemical equilibrium in complex systems containing non-ideal solutions; *Geochimica et Cosmochimica Acta*, Volume 51, pages 2639–2652.

Ghent, E.D., Erdmer, P., Archibald, D.A. and Stout, M.Z. (1996): Pressure-temperature and tectonic evolution of Triassic lawsonite-aragonite blueschists from Pinchi Lake, British Columbia; *Canadian Journal of Earth Sciences*, Volume 33, pages 800–810.

Holland, T.J.B. and Powell, R. (1990): An enlarged and updated internally consistent thermodynamic dataset with uncertainties and correlations: the system K_2O-Na_2O-CaO-MnO-MgO-FeO-Fe_2O3-Al_2O_3-TiO_2-SiO_2-C-H_2-O_2; *Journal of Metamorphic Geology*, Volume 8, pages 89–124.

Holland, T.B.J. and Powell, R. (2003): Activity-composition relations for phases in petrological calculations: an asymmetric multicomponent formulation; *Contributions to Mineralogy and Petrology*, Volume 145, pages 492–501.

Kowalchuck, J.M. (1988): Diamond drilling report on the Yardley Lake property, Cariboo Mining Division, BC; submitted by Gabriel Resources, *BC Ministry of Energy, Mines and Petroleum Resources,* Assessment Report 15926, 247 pages.

Logan. J.M. (2008): Geology and mineral occurrences of the Quesnel Terrane, Cottonwood map sheet, central British Columbia (NTS 093G/01); *in* Geological Fieldwork 2007, *BC Ministry of Energy, Mines and Petroleum Resources*, Paper 2008-1, pages 69–85.

Logan, J.M. and Moynihan, D.P. (2009): Geology and mineral occurrences of the Quesnel River map area, central British Columbia (NTS 093B/16); *in* Geological Fieldwork 2008, central British Columbia, *BC Ministry of Energy, Mines and Petroleum Resources*, Paper 2009-1, pages 127–152.

Logan, J.M., Bath, A.B., Mihalynuk, M.G., Ullrich, T.D., Friedman, R. and Rees, C.J. (2007): Regional geology of the Mount Polley area, central British Columbia; *BC Ministry of Energy, Mines and Petroleum Resources*, Geoscience Map 2007-1, scale 1:50 000.

McMullin, D.W.A., Greenwood, H.J. and Ross, J.V. (1990): Pebbles from Barkerville and Slide Mountain terranes in a Quesnel Terrane conglomerate: evidence for pre-Jurassic deformation of the Barkerville and Slide Mountain terranes; *Geology*, Volume 18, pages 962–965.

Massey, N.W.D., MacIntyre, D.G., Desjardins, P.J. and Cooney, R.T. (2005): Digital geology map of British Columbia: whole province; *BC Ministry of Energy, Mines and Petroleum Resources*, Geofile 2005-1.

Mihalynuk, M.G., Erdmer, P., Ghent, E.D., Cordey, F., Archibald, D.A., Friedman, R.M. and Johannson, G.G. (2004): Coherent French Range blueschist: subduction to exhumation in <2.5 m.y.?; *Geological Society of America Bulletin*, Volume 116, Number 7/8, pages 910–922.

Monger, J.W.H. and Berg, H.C. (1984): Lithotectonic terrane map of western Canada and southeastern Alaska: *in* Lithotectonic Terrane Maps of the North American Cordillera, Siberling, N.J. and Jones, D.L., Editors, *United States Geological Survey*, Open File Report 84-523.

Parrish, R., Carr, S. and Parkinson, D. (1988); Eocene extensional tectonic and geochronology of the southern Omineca Belt, British Columbia and Washington; *Tectonics*, Volume 7, pages 181–212.

Patterson, I. and Harakal, J. (1974): Potassium-argon dating of blueschists from Pinchi Lake, central British Columbia; *Canadian Journal of Earth Sciences*, Volume 11, pages 1007–1011.

Rees, C.J. (1987): The Intermontane-Omineca belt boundary in the Quesnel Lake area, east central British Columbia: tectonic implications based on geology, structure and paleomagnetism; Ph.D. thesis, Carleton University, 421 pages.

Reid, L.F. (2003): Stratigraphy, structure, petrology, geochronology and geochemistry of the Hobson Lake area (Cariboo Mountains, British Columbia) in relation to the tectonic evolution of the southern Canadian Cordillera; Ph.D. thesis, University of Calgary, 221 pages.

Roback, R.C., Sevigny, J.H. and Walker, N.W. (1994): Tectonic setting of the Slide Mountain Terrane, southern British Columbia; *Tectonics*, Volume 13, pages 1242–1258.

Schiarizza, P. (1989): Structural and stratigraphic relationships between the Fennell Formation and Eagle Bay assemblage, western Omineca Belt, south-central British Columbia: implications for Paleozoic tectonics along the paleocontinental margin of western North America; M.Sc. thesis, University of Calgary, 343 pages.

Schiarizza, P. and Macauley, J. (2007): Geology and mineral occurrences of the Hendrix Lake area, south-central British Columbia (093A/02); *in* Geological Fieldwork 2006, *BC Ministry of Energy, Mines and Petroleum Resources*, Paper 2007-1 and *Geoscience BC*, Report 2007-1, pages 179–202.

Struik, L.C. (1986): Imbricated terranes of the Cariboo gold belt with correlations and implications for tectonics in southeastern British Columbia; *Canadian Journal of Earth Sciences*, Volume 23, pages 1047–1061.

Struik, L.C. (1988): Structural geology of the Cariboo gold mining district, east-central British Columbia; *Geological Survey of Canada*, Memoir 421, 100 pages.

Struik, L.C., Parrish, R.R. and Gerasimoff, M. D. (1992): Geology and age of the Naver and Ste Marie plutons, central British Columbia; *in* Radiogenic Age and Isotopic Studies: Report 5, *Geological Survey of Canada*, Paper 91-2, pages 155–162.

Tinkham, D.K. and Ghent, E.D. (2005): Estimating P-T conditions of garnet growth with isochemical phase diagram sections and the problem of effective bulk composition; *The Canadian Mineralogist*, Volume 43, pages 35–50.

Travers, W.B. (1977): Overturned Nicola and Ashcroft strata and their relations to the Cache Creek Group, southwestern Intermontane Belt, British Columbia; *Canadian Journal of Earth Sciences*, Volume 15, pages 99–116.