Tectonic setting of mineralization in the southern Kootenay Arc and Purcell Anticlinorium, southeastern British Columbia

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Introduction

The geoglogically complex region of southeast British Columbia between Nelson, Salmo and Creston is situated at the interface between three tectonic domains: The Purcell Anticlinorium, Kootenay Arc and the Priest River Complex (Figure 1). This tectonic juxtaposition and contemporaneous magmatism, metamorphism, and deformation occurred during Cordilleran orogenesis in a time interval spanning the Jurassic to Eocene. This study aims to elucidate on the complex tectonothermal history of the area during orogenesis as a means of putting the areas mineral deposits in context

The structure of the rocks in the southern Kootenay Arc and western limb of the Purcell Anticlinorium is affected by at least three phases of penetrative deformation, spanning the time interval from the Middle Jurassic to Eocene (Fyles, 1964, 1967; Leclair, 1988; Glover, 1987; Brown, 1995). In general there is an increase in structural complexity and intensity of deformation going from the west of the area to the east and north, corresponding to progressively deeper structural levels. An exception to this overall pattern are the Purcell Trench fault (PTF) and Midge Creek fault (MCF), across which there are marked differences in structural style and metamorphic grade (Figure 2,3 & 5).

The regional metamorphic grade in the study area is dominantly greenschist facies with two discrete, elongate domains of amphibolite facies metamorphic rocks (Figure 5). In the northern part of the field area the amphibolite facies metamorphism forms a southward facing forked isograd pattern. The western fork is parallel to strike and is truncated by the Midge Creek fault. This fork is a continuation of the metamorphic high mapped north of the west arm of Kootenay Lake by Moynihan and Pattison (2008). The eastern fork is approximately parallel to the Purcell Trench fault and transects the strike of lithological units. The eastern fork continues south into the U.S.A and merges with amphibolite facies metamorphism in the Priest River Complex.

The MCF juxtaposes greenschist-facies phyllite of the Milford Group against sillimanite-zone schist in the footwall. There is also a large contrast in metamorphic grade across the PTF (Figure 5): pelite in the footwall has the mineral assemblage sillimanite±kyanite+garnet+muscovite+biotite+plagioclase+quartz+rutile, whereas pelite in the hangingwall has the assemblage biotite+muscovite+chlorite+albite+quartz (Figure 6). Based on these mineral assemblages, the contrast in peak metamorphic conditions across the fault is >2 kbar and >150°C.

The study area has been intruded by numerous Jurassic (I-type) and Cretaceous (S-Type) plutons that have imparted contact aureoles to the surrounding country rock. Based on mapped mineral assemblages and isochemical phase diagram modeling the Jurassic intrusions were emplaced at deeper levels in the crust than the Cretaceous intrusions (Figure 7). The historic Salmo mining camp is well known for its extensive deformed MVT Pb-Zn deposits and Cretaceous W-Mo-Au skarns. Recent work has delineated a large, previously unidentified contact aureole extending around the Summit stock and Lost Creek pluton. Several skarn deposits on the western margin of the Lost Creek pluton (Jumbo, Molly, MUT) suggest a potential for further Mo-W mineralization in the thermally metamorphosed area extending east to the Summit stock (Figure 5).

Geological Setting

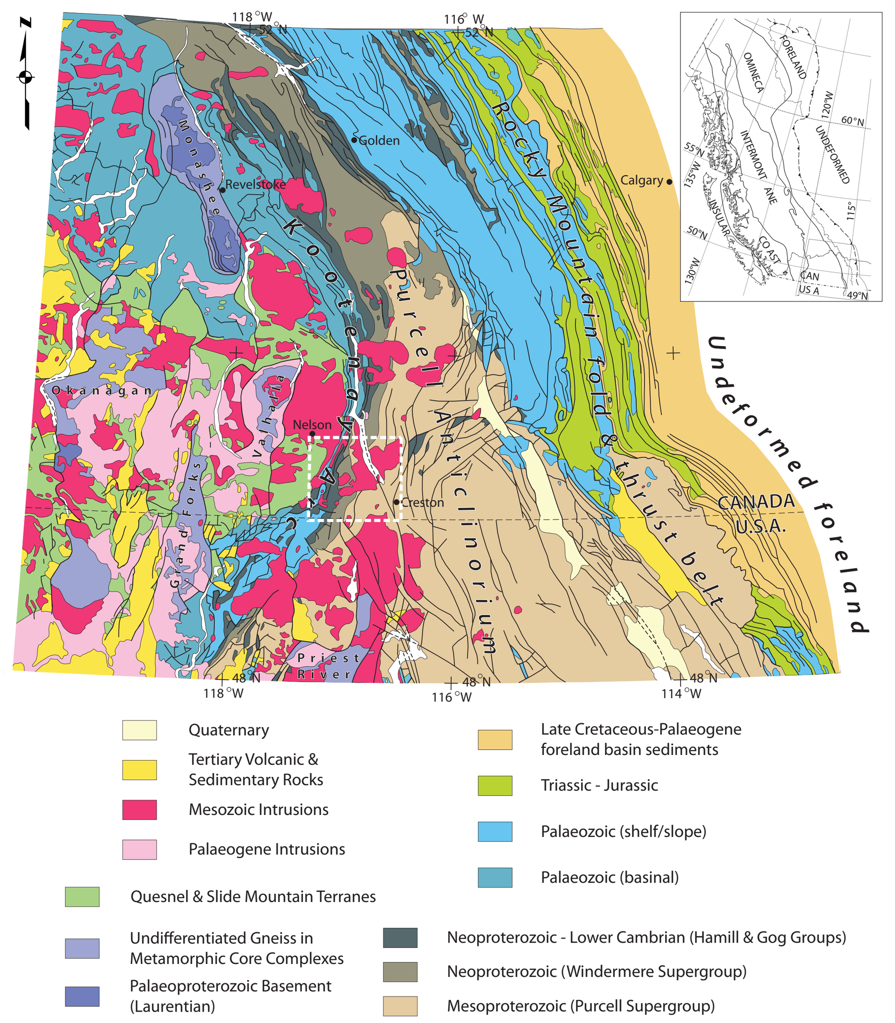

Figure 1. Regional geology map of the southeastern Canadian Cordillera. Study area is highlighted by the white dashed square. Eocene core complexes are labelled on the map as; Okanagan, Priest River, Grand Forks, Monashee and Valhalla. Map modified from Moynihan and Pattison (in press), originally after Wheeler and McFeely, (1991). The Purcell Anticlinorium is a broad northerly plunging fold structure. The Kootenay Arc is a structural arc that is characterised by an increase in metamorphic grade and complexity of deformation, and a decrease in stratigraphic age.

Geology of the Southern Kootenay Arc and Purcell Anticlinorium

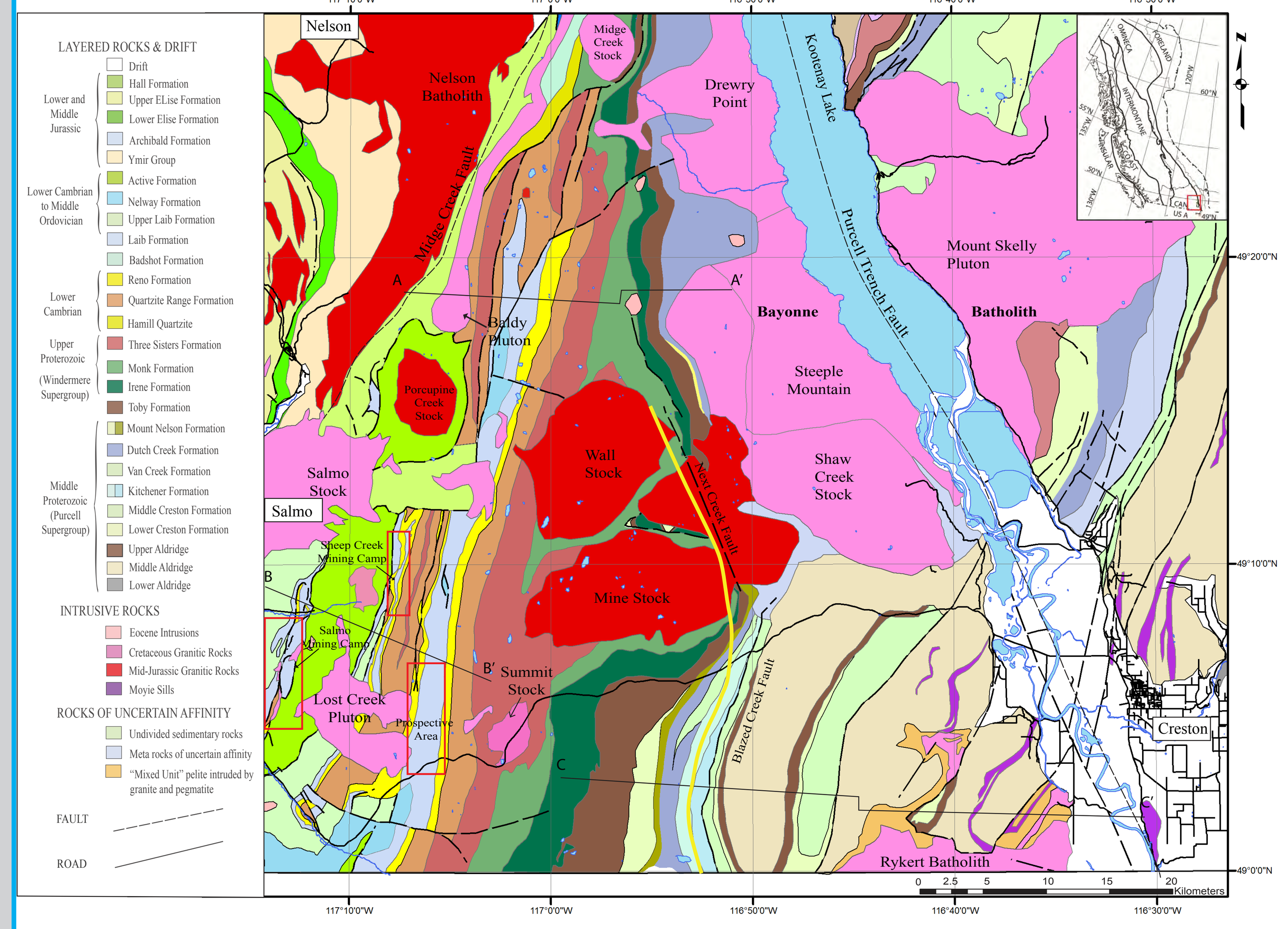

Figure 2: Regional geology map of the study area, compiled from Reesor (1996), Hoy and Dunne (1998), Glombick et al. (2010) and Paradis et al. (2010). The lines of cross sections shown in Figure 3 are displayed. Inset modified after Wheeler and McFeely, (1991). The eastern and western domains are separated by the thick yellow line. The rocks north of the Wall stock are within the northern domain. Inset modified after Wheeler and McFeely (1991).

LITHOLOGY

The study area is situated mainly within deformed and metamorphosed sedimentary rocks of the: Purcell Supergroup, Windermere Supergroup and Paleozoic clastics and carbonates.

GRANITOIDS

The metasediments described above are host to numerous granitoid intrusions that range in age from Middle Jurassic to Eocene and are part of larger intrusive suites extending across southeastern BC.

FAULTING

Two large Eocene normal faults crosscut the study area: the Purcell Trench fault and the Midge Creek fault, across which there are marked differences in structural style and metamorphic grade.

STRUCTURE

As a result of different episodes of deformation that are confined to specific regions of the study area, the structural features are divided into a western, northern and eastern domain.

Metamorphic Geology and Mineral Zones

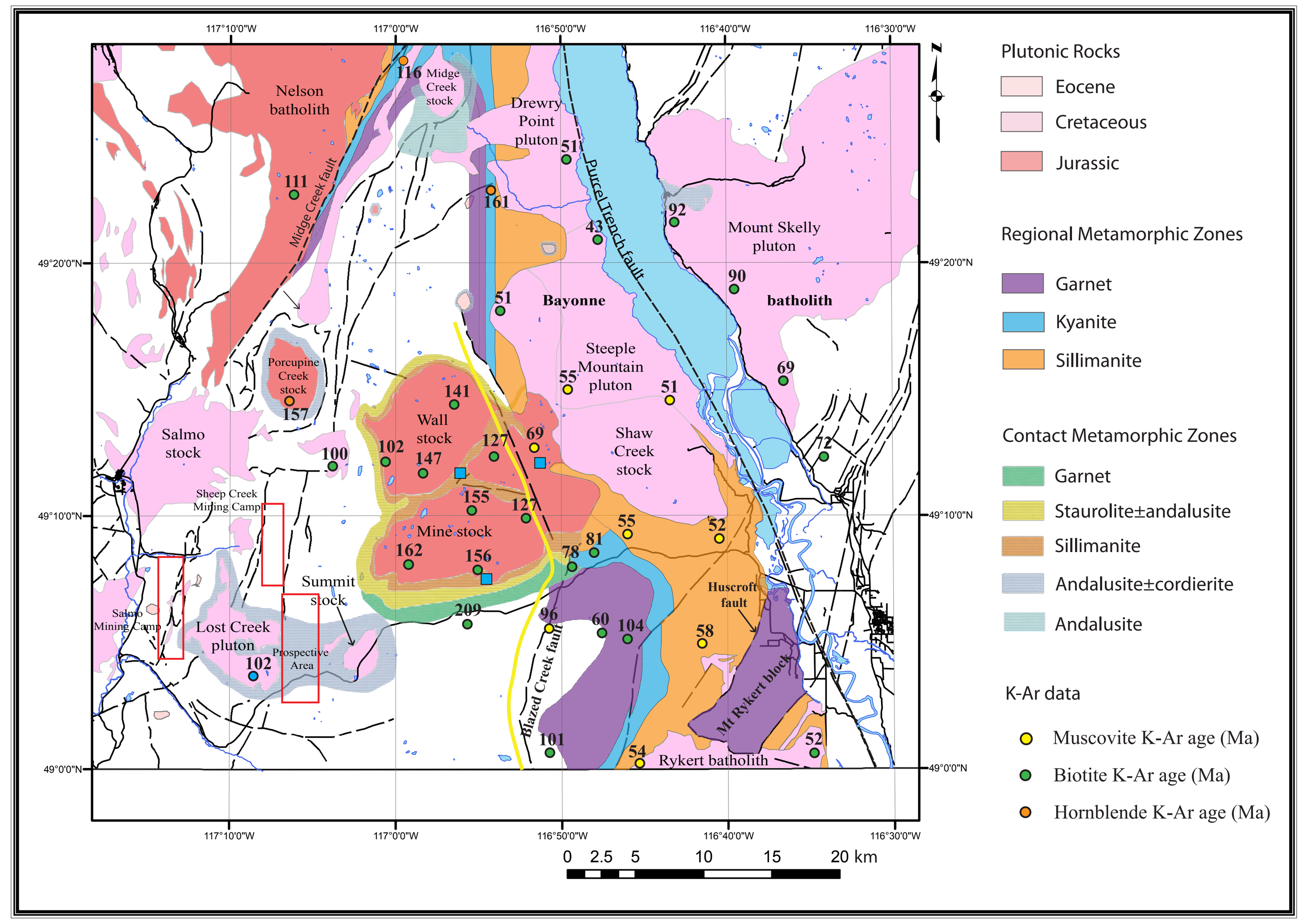

Figure 5. Metamorphic and plutonic map of the study area, compiled from Glover (1978), Archibald et al. (1983), Doughty et al. (1997), Leclair (1988) and new data. Areas with no shading are of low metamorphic grade. Blue squares are occurences of kyanite away from the regional kyanite zone. K-Ar data compiled from Archibald et al. (1983), Leclair et al. (1993) and Brown et al. (1999).

ISOGRAD PATTERN

Two elongate domains of regional middle amphibolite facies rocks merge in the northern part of the study area, forming a southward facing forked isograd pattern that is separated by a large area of greenshcist facies metamorphism.

REGIONAL METAMORPHIC ZONES

Three regional amphibolite-facies metamorphic zones have been identified within the map area: garnet, kyanite and sillimanite. These metamorphic zones are typical of Barrovian metamorphism, with the highest metamorphic grade in the footwall of the PTF and MCF, and progressively lower grades with increasing distance from the fault zone.

CONTACT METAMORPHISM

The study area has been intruded by numerous Jurassic and Cretaceous plutons (Figures 2, 5) that have imparted contact aureoles to the surrounding country rock. The contact aureoles typically have a granoblastic texture, unique mineralogy and a coarser grain size that make them distinguishable from the regional metamorphism.

METAMORPHIC CONTRASTS

Across the PTF and MCF there are marked differences in structural style and metamorphic grade. One exception to the large temperature and pressure contrast across the PTF is an area of garnet-zone rocks in the hangingwall of the Huscroft fault itself in the footwall of the PTF. The upper-greenschist-facies rocks in the hangingwall of the Huscroft fault contrast with the sillimanite-zone rocks beneath the fault, implying a large amount of displacement on the fault. Because the PTF cuts the Huscroft fault, the throw on the PTF must be less than implied by the contrast in peak metamorphic assemblages across the PTF outside the Huscroft block.

Contact Metamorphic Bathozones and Mineral Subassemblages

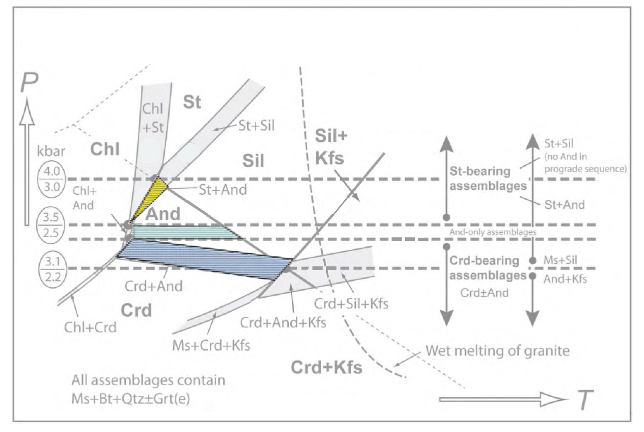

Figure 7. Schematic P-T phase diagram showing the relationship of mineral assemblage domains to key sub-assemblages. Contact aureoles from the field area are highlighted on the diagram with their corresponding colours. As observed on the P-T diagram these mineral assemblages are very sensetive to pressure and help constrain the emplacement depth of the intrusions. The Jurassic intrusions were genrally emplaced at deeper structural levels relative to the Cretaceous intrusions. Diagram modified from Pattison and Vogl (2005). Abbreviations are from Kretz (1983).

JURASSIC METAMORPHISM

Based on the abundant staurolite+andalusite assemblages, contact metamorphism associated with the Mine and Wall stocks occurred at 3.5–4 kbar (Figure 7, yellow domain).

The Porcupine Creek stock is situated 4 km northwest of the Wall stock and has a lower pressure (~3.0–3.5 kbar) contact aureole with cordierite+andalusite (Figures 5, 7).

CRETACEOUS METAMORPHISM

The mid-Cretaceous, post-kinematic Lost Creek pluton (LCP) and Summit stock (SS) have imparted lowest pressure contact aureoles (2.2-3.2 kbar, figure 7 blue domain) on the surrounding country rock.

In summary, the Jurassic intrusions were emplaced at 3.5–4 kbar, which, for a pressure of 2.7 g/cc, corresponds to an 11–13 km emplacement depth, considerably deeper than the Cretaceous intrusions at 7–11 km. This implies approximately 5 km of aggregate exhumation between emplacement of the Jurassic intrusions and the Cretaceous intrusions.

Geological Cross Sections and Structural Domains

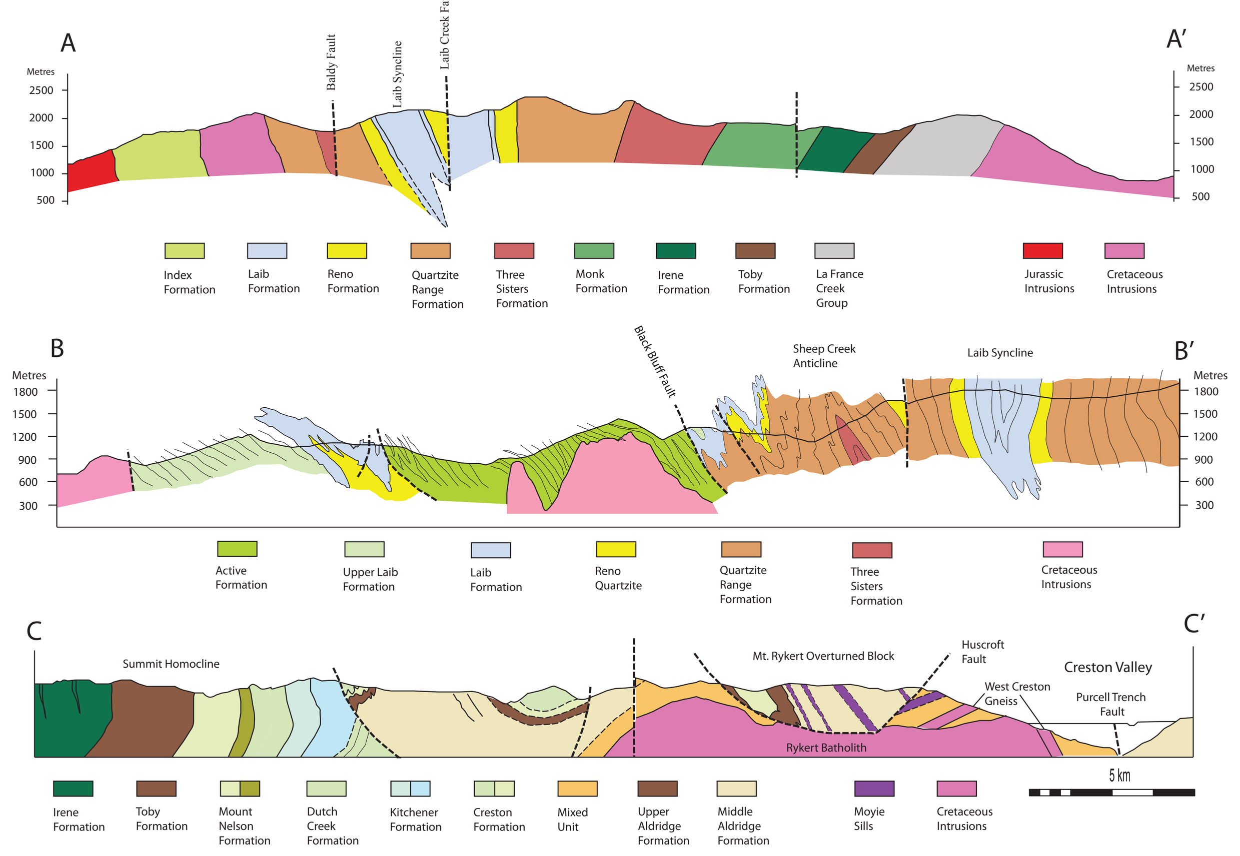

Figure 3. Vertical cross-sections from the study area. The lines of section are shown in Figure 2. Compiled from Leclair (1986; A-A'), Fyles (1959; B-B'), and Brown et al., (1999; C-C').

NORTHERN DOMAIN

The northern domain has a dominant, regional, north-northeast-striking structural trend that is the result of multiple periods of deformation. The deformed, metamorphosed sedimentary rocks in this domain are intruded by plutons of the Bayonne and Nelson suites, which helps separate the timing of the deformation events.

WESTERN DOMAIN

The earliest map scale folds in the western domain are the Laib syncline and Sheep Creek anticline, both of which are isoclines that plunge from north-northeast to south-southwest and are inclined to the west. A well-developed sub-vertical cleavage is axial planar to the folds and is the dominant penetrative foliation in the western domain.

EASTERN DOMAIN

In the eastern domain there are kilometer-scale, open to tight folds of Belt-Purcell Supergroup. Penetrative structures from multiple phases of deformation all have a similar north-northeast strike and trend of fold axes.

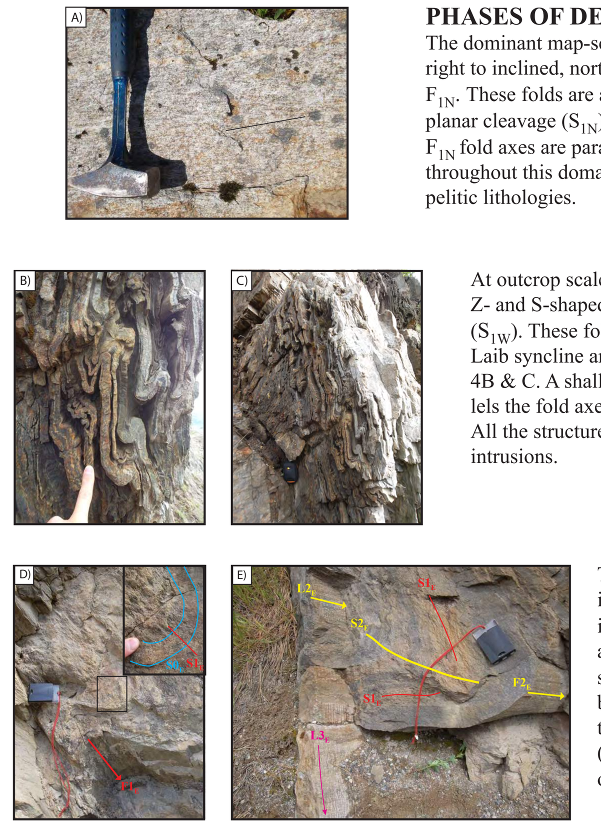

Figure 4A) Corn Creek Gneiss with a shallowly plunging stretching lineation, highlighted by the thin black line. B & C) S shaped F1W folds in carbonates of the Laib syncline. D) F1E folds showing an axial planar foliation. E) Gently plunging, recumbent F2E fold with sub-horizontal axial plane (S2E). Steeply plunging crenulation lineation (L3E).

PHASES OF DEFORMATION

The dominant map-scale structures in the area are tight to isoclinal, upright to inclined, north-northeast trending folds with subhorizontal axes, F_{1N}. These folds are associated with a regionally penetrative, axial-planar cleavage (S_{1N}) that is generally subparallel to bedding (S_{0N}). The F_{1N} fold axes are parallel to a mineral and stretching lineation (L_{1N}) throughout this domain. Two later crenualtions are also observed in pelitic lithologies.

At outcrop scale, F_{1W} folds are typically asymmetrical, upright, Z- and S-shaped isoclinal folds with an axial-planar foliation (S_{1W}). These folds are best observed in carbonate layers of the Laib syncline and Sheep Creek anticline, as illustrated in Figure 4B & C. A shallowly plunging stretching lineation (L_{1W}) parallels the fold axes. A later crenulation is evident in pelitic layers. All the structures in this area are cross cut by the Cretaceous intrusions.

The earliest folds (F_{1E}) are upright to recumbent, isoclinal to open folds with an axial-planar schistosity (S_{1E}; Figure 4D). The fold axes commonly have a gentle plunge to the north-northeast or south-southwest. The F_{1E} folds and S_{1E} schistosity have been refolded by gently plunging, north-northeast trending, upright to recumbant, open to tight folds (Figure 4E). A third period of deformation is locally observed as a centimetre-scale crenulation.

Metamorphic Contrast across the PTF

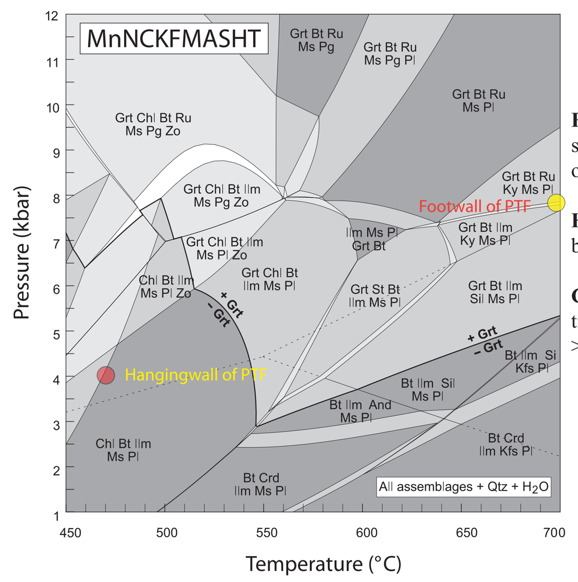

Figure 6. Isochemical phase diagram section for an average pelite composition from the Nelson area. Modified from Pattison and Tinkham, (2009). The chemical system used to model the phase equilibria was MnNCKFMASHT (MnO-Na2OCaO-K2O-FeO-MgO-Al2O3-SiO2-H2O-TiO2, with C and P2O5 omitted from the whole-rock analysis, followed by projection from pyrrhotite). The Yellow circle represents the stable mineral assemblage in the footwall of the PTF. The red circle represents the stable mineral assemblage in the hangingwall. Abbreviations are from Kretz (1983). The apparent offset on the fault is approximately 7-12km.

FOOTWALL mineral assemblage: sillimanite±kyanite+garnet+muscovite+biotite+plagioclase+quartz+rutile

HANGINGWALL mineral assemblage: biotite+muscovite+chlorite+albite+quartz

CONTRAST in peak metamorphic conditions across the fault is >2 kbar and >150°C (Figure 6).

Links to Mineralization

A 50–75 km wide arcuate belt of Cretaceous intrusions, known as the Bayonne magmatic suite, extends from the Canada–United States border to north of Quesnel Lake, crosscutting the study area. The Bayonne magmatic suite is associated with Sn, W, W-Mo, U and Ag-Pb-Zn-Au deposits (Logan, 2002). The commodities of interest varies depending on the emplacement depth of the intrusion (Lang and Baker, 2001). Undeformed mid-Cretaceous intrusions that were emplaced at 7-11 km are found throughout the study area. The Cambrian Laib Formation hosts Mo-W skarns adjacent to the Emerald and Dodger stocks within the historic Salmo mining camp (Figure 2 & 5). These two intrusions imparted cordierite and andalusite contact aureoles to the surrounding country rock in the sparsely distributed pelitic lithologies. On the eastern margin of the Salmo mining camp is the Lost Creek pluton. This intrusion similarly has an extensive cordierite and andalusite contact aureole that extends east to the Summit stock (Figure 2). Therefore, the possibility exists for further Mo-W skarn mineralization in the Laib Formation to the east (Figure 5), in the Lost Creek pluton contact aureole.

Conclusions and Future Work

- Eocene extension and exhumation resulted in deeper structural levels, higher metamorphic grade and younger cooling ages being exposed in the footwall of the Purcell Trench fault and Midge Creek fault.
- There are three domains with different structural styles and ages of penetrative deformation from the Middle Jurassic to Late Cretaceous. Future Ar-Ar work will focus on addressing the type of interface between these domains (e.g. fault, gradational or overprinting).
- The Mt. Rykert block of lower grade metamorphic rocks, situated within the footwall of the Purcell Trench fault is probably an extensional klippe, riding on an original low-angle detachment (Figure 3), that was stranded when the steeper PTF developed. This implies that the inferred displacement on Eocene extensional faults in the area could be much less than previously thought.
- The elongate domains of regional middle amphibolite facies rocks merge in the northern part of the study area forming a southward facing forked shaped isograd pattern. Despite the apparent continuity of the isograd pattern it is actually an interplay of multiple periods of metamorphism from the Middle Jurassic to Late Cretaceous. Future U-Pb monazite dating is planned to better constrain the interface between the different periods of metamorphism.

Acknowledgements

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