Relationship between Deformation and Metamorphism in the Interface between the Purcell Anticlinorium and the Kootenay Arc, Southeastern British Columbia (NTS 082F, G)

N.A. Rioseco, Department of Geoscience, University of Calgary, Calgary, AB, nicole.rioseco@ucalgary.ca

D.R.M. Pattison, Department of Geoscience, University of Calgary, Calgary, AB

R.E. Ashton, Department of Geoscience, University of Calgary, Calgary, AB

Rioseco, N.A., Pattison, D.R.M. and Ashton, R.E. (2019): Relationship between deformation and metamorphism in the interface between the Purcell Anticlinorium and the Kootenay Arc, southeastern British Columbia (NTS 082F, G); *in* Geoscience BC Summary of Activities 2018: Minerals and Mining, Geoscience BC, Report 2019-1, p. 1–14.

Introduction

The area between the towns of Kimberley, Creston and Crawford Bay in southeastern British Columbia (BC) encompasses the interface between two major Cordilleran tectonic domains, the Purcell Anticlinorium and the Kootenay Arc. These domains comprise part of the mineralogically rich East Kootenay region. The aim of this project is to elucidate changes in structure, metamorphism and exhumation history across the interface to provide further geological context for the different types of mineral deposits that occur within the region.

Regional Geology

The study area (Figure 1) straddles the interface between marginal rocks of North American affinity (Monger et al., 1982) to the east, and pericratonic and accreted island-arc rocks (Monger et al., 1982; Unterschutz et al., 2002) to the west. This region owes its complexity to a history of geological evolution that spanned roughly 1.4 billion years, from the Mesoproterozoic to the Eocene. The eastern portion of the field area is dominated by the Purcell Anticlinorium, a regional-scale, northwest-plunging anticlinal structure that is cored by rocks of the Belt-Purcell Supergroup (BPSG). This regional structure transitions westward into the Kootenay Arc, an arcuate salient composed of Neoproterozoic through Paleozoic pericratonic and accreted island-arc rocks.

The study area is primarily situated within rocks of the BPSG that occupy the core of the Purcell Anticlinorium (Figure 2). The BPSG comprises rift-related clastic rocks and synsedimentary mafic sills interpreted to have been deposited in an intracratonic rift basin (Price, 1964; Harrison, 1972). The lowermost unit of the BPSG, the Aldridge Formation, comprises predominantly turbiditic deposits. The age of clastic rocks of the BPSG is constrained by the age of the Moyie Sills that are hosted in rocks of the Aldridge Formation (Höy, 1989). On the flanks of the Purcell Anticlinorium, Belt-Purcell strata are unconformably overlain by a Neoproterozoic sequence of sandstone and conglomerate interbedded with pelitic and carbonate rocks known as the Windermere Supergroup (WSG). On the western flank of the Purcell Anticlinorium, where it transitions into the Kootenay Arc, the WSG is unconformably overlain by pericratonic, coarse clastic and carbonate Paleozoic rocks that are part of the Kootenay Arc (Bond et al., 1985; Warren, 1997; Colpron et al., 2002).

In addition to a younging of stratigraphy, the westward transition from the Purcell Anticlinorium into the Kootenay Arc is marked by a change in structural style, metamorphic grade, and cooling history. The Purcell Anticlinorium contains some of the oldest rock exposures in the Cordillera and preserves evidence of structures and metamorphism that are stratigraphically restricted to rocks of Mesoproterozoic age. The Purcell Anticlinorium was affected by three cryptic, Proterozoic orogenic events, the ca. 1350–1300 Ma East Kootenay orogeny, a ca. 1050 Ma Grenville-age event and the ca. 900–800 Ma Goat River orogeny (Leech, 1962; McMechan and Price, 1982; McFarlane and Pattison, 2000; McFarlane, 2015). Despite this orogenic history, and the later effects of Cordilleran deformation that created the Purcell Anticlinorium, Belt–Purcell rocks in the core of the Purcell Anticlinorium preserve primary sedimentary structures and appear to be generally undeformed.

One of the primary features of the transition from the Purcell Anticlinorium to the Kootenay Arc is a change in structural style. The Kootenay Arc preserves evidence of at least three phases of intense structural modification regionally, and up to five locally, which took place during the Mesozoic (Moynihan and Pattison, 2013; Webster and Pattison, 2018). These rocks are characterized by more ductile deformation and higher grades of metamorphism attributed to Cordilleran orogenic processes spanning the Early Jurassic

This publication is also available, free of charge, as colour digital files in Adobe Acrobat® PDF format from the Geoscience BC website: http://www.geosciencebc.com/s/SummaryofActivities.asp.

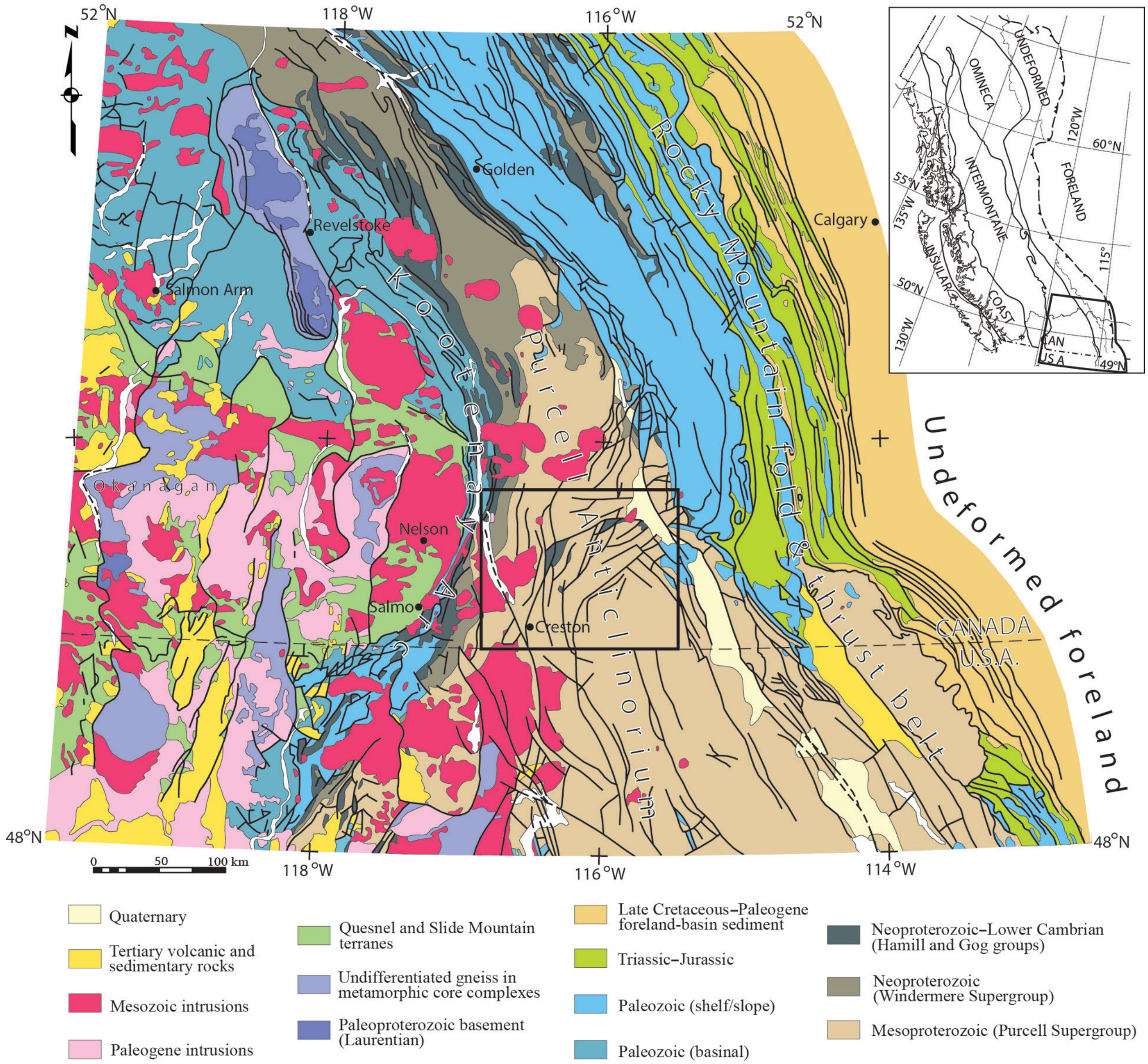

Figure 1. Regional geology of the southeastern Canadian Cordillera in southeastern British Columbia. Study area indicated by black outline. Map modified from Webster and Pattison (2018), originally after Wheeler and McFeely (1991).

through Eocene. The extent to which Mesozoic deformation and metamorphism associated with the Kootenay Arc impinged upon the Purcell Anticlinorium is poorly understood and is the focus of this study.

The metamorphic grade of BPSG rocks within the Purcell Anticlinorium is relatively low, within the chlorite and biotite subzones of the greenschist and lower amphibolite facies (Leech, 1962; Read et al., 1991; Pattison and Seitz, 2012). High grade rocks (andalusite-sillimanite zone) within the Purcell Anticlinorium are restricted to the Matthew Creek metamorphic zone (MCMZ), a fault bounded domain west of Kimberley, BC. These rocks are interpreted to have resulted from a local thermal perturbation, likely associated with mafic intrusions during the East Kootenay orogeny (McMechan and Price, 1982; McFarlane and Pattison, 2000; McFarlane, 2015). Westward into the Kootenay Arc, there is a contrasting metamorphic history, in which the rocks were ductilely deformed, metamorphosed and intruded over several pulses between 180 and 50 Ma (Archibald et al., 1983, 1984; Klepacki, 1985; Leclair et al., 1993; Moynihan and Pattison, 2013; Webster and Pattison, 2018). Regional metamorphic grade within the Kootenay Arc ranges from greenschist to middle amphibolite facies. Evidence of amphibolite-grade metamorphism is represented by Barrovian (kyanite-sillimanite–type) metamor-

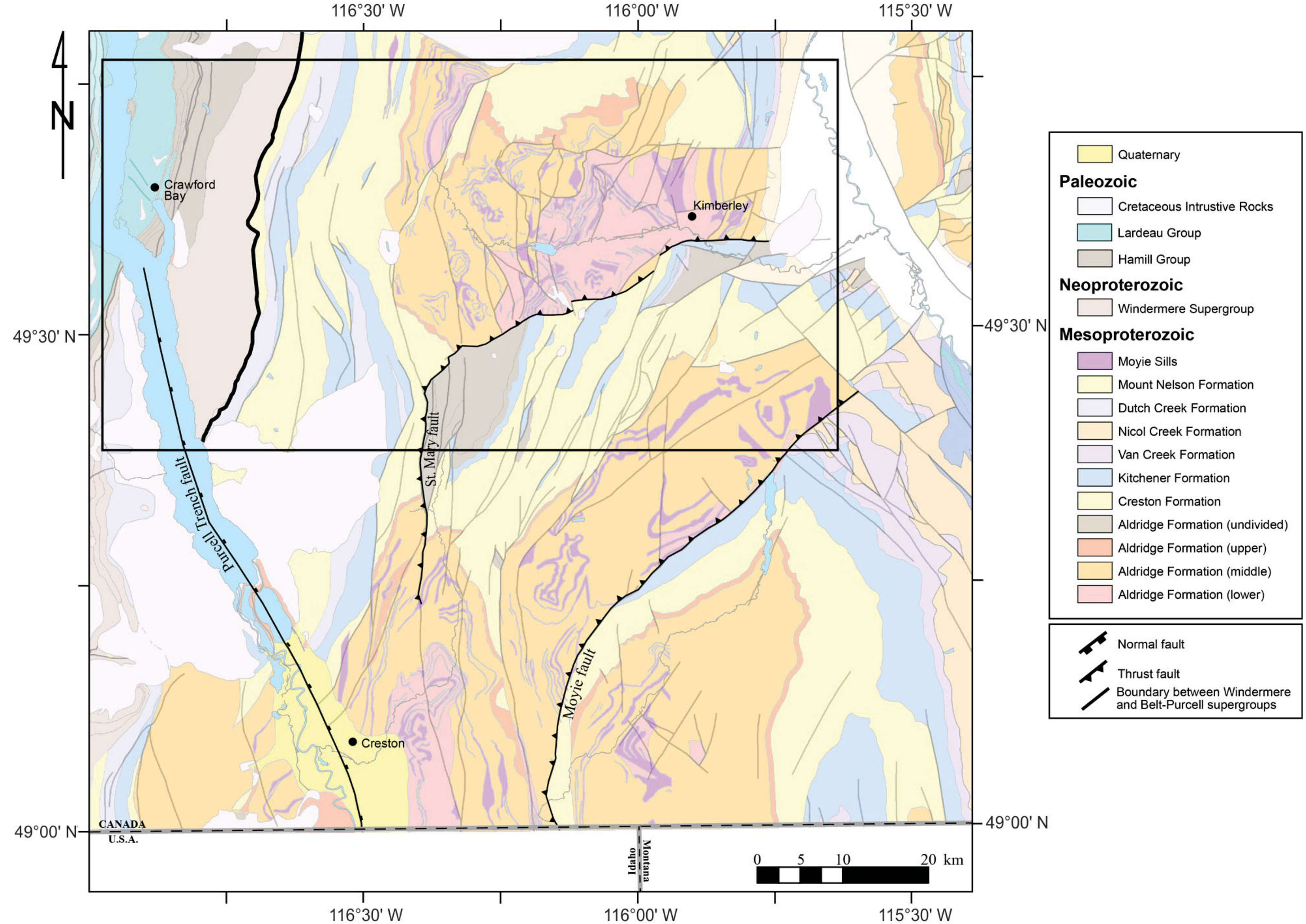

Figure 2. Geological map of the field area, emphasizing the unconformable contact between Belt-Purcell Supergroup (BPSG) and Windermere Supergroup (WSG) and younger rocks. Map modified from Höy et al. (1995). Structure maps in Figure 6 indicated by black outline.

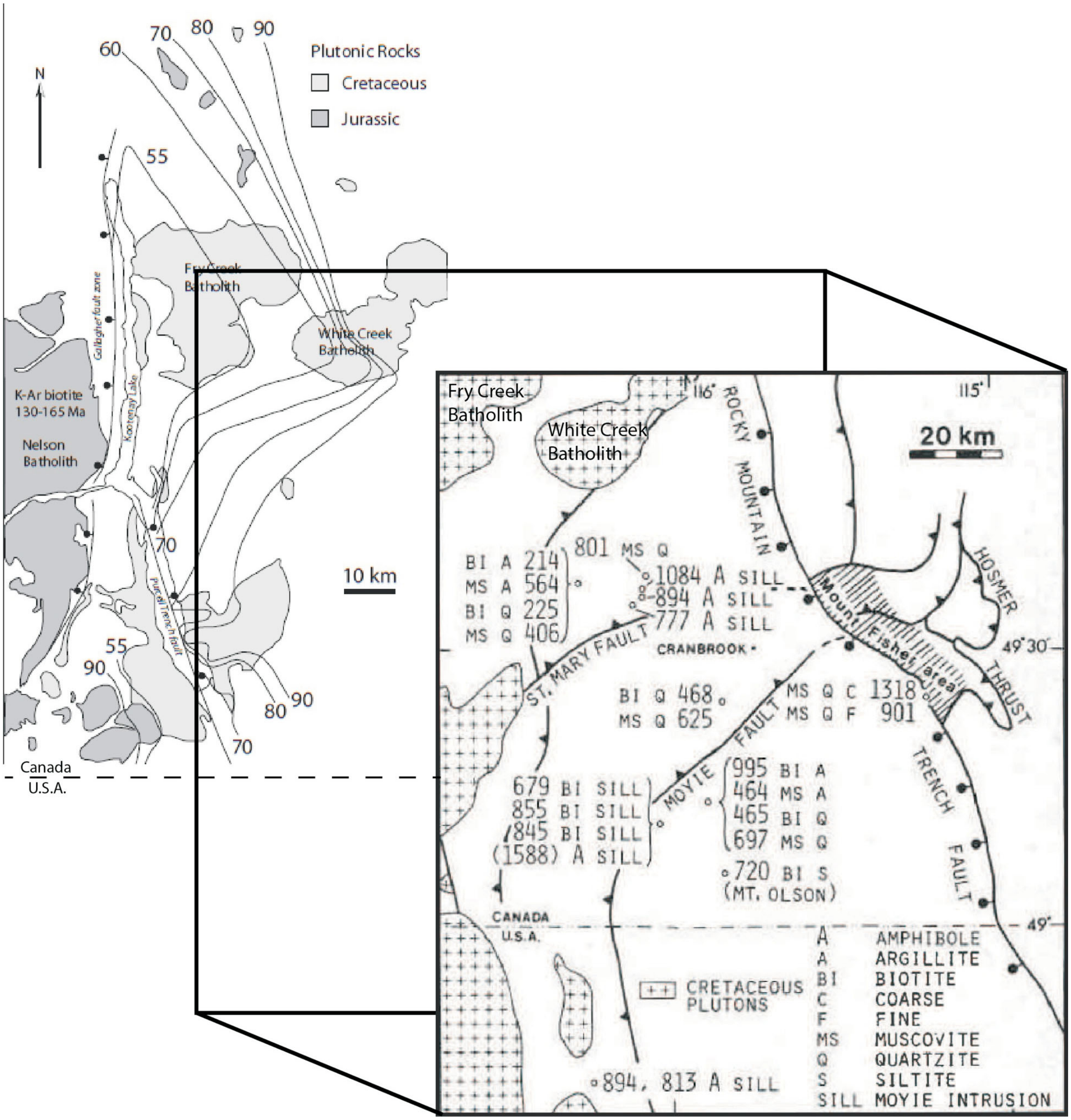

Figure 3. **(Left)** Potassium-argon cooling ages in biotite from the Kootenay Arc (from Archibald et al., 1984); contour interval 10 million years. **(Right)** Potassium-argon cooling ages from the Purcell Anticlinorium (from McMechan and Price, 1982). Location of figures shown on Figure 1, indicated by black outline.

phic zones that locally reach sillimanite+potassium-feldspar grade (Leclair, 1982; Moynihan and Pattison, 2013; Webster and Pattison, 2018).

A prominent westward decrease in K-Ar and Ar/Ar cooling ages in hornblende and micas (Figure 3) indicates that peak metamorphism within the Purcell Anticlinorium is much older than that of the Kootenay Arc. Hunt (1962) and McMechan and Price (1982) reported K-Ar ages in hornblende and micas in the range 1318–600 Ma. Metamorphic mineral growth in the core of the Purcell Anticlinorium must have happened prior to exhumation of these rocks, and therefore is restricted to the Proterozoic. In contrast, metamorphosed Neoproterozoic through Paleozoic strata in the Kootenay Arc, where they interface with the Purcell Anticlinorium, yield K-Ar and Ar/Ar ages in the range of 90–45 Ma, indicating much younger, Mesozoic and Cenozoic, metamorphism and exhumation (Figure 3; Archibald et al., 1983, 1984; Webster and Pattison, 2018).

Structure

There is a change is structural style that occurs across the interface between the Purcell Anticlinorium and the Kootenay Arc. A distinction is made between Purcell Anticlinorium–type structures, which are characteristic of rocks of the BPSG in the core of the Purcell Anticlinorium, and Kootenay Arc–type structures, which are associated with Cordilleran orogenesis. The following sections utilize the subscripts '$_{PA}$' and '$_{KA}$' to differentiate between Purcell Anticlinorium–type and Kootenay Arc–type structures.

Purcell Anticlinorium–Type Structures

Rocks of the lower, middle and upper Aldridge Formation occur as thick, planar-bedded, turbiditic deposits. These strata consist predominantly of massive sandy units, which range from 0.5–1 m in thickness, and are irregularly interbedded with thinner (5–10 cm) silty layers (Figure 4a). The Moyie Sills occur mainly in lower and middle Aldridge rocks; they are typically massive and commonly preserve ophitic, igneous textures (Figure 4b). These units are typically on the order of 6–10 m thick.

Bedding (S_0), as well as primary sedimentary structures, are well preserved within Belt–Purcell rocks in the core of the Purcell Anticlinorium (Figure 4c). An S_1 penetrative, slaty cleavage (Figure 4d) is present throughout the pelitic portions of the Aldridge Formation. This cleavage is referred to as S_{1PA}, and generally dips within a range of 15–30° from that of S_0. The S_{1PA} cleavage is stratigraphically restricted to rocks of the Belt-Purcell Supergroup, indicating that cleavage development occurred prior to deposition of the Windermere Supergroup. Leech (1962) noted that there is a lack of recognizable fold structures that can be related to S_{1PA}. Although referred to here as S_{1PA}, this cleavage is a structure that is intrinsic to rocks of the Belt-Purcell Supergroup in parts of the Purcell Anticlinorium that have not been overprinted by Kootenay Arc–type structures.

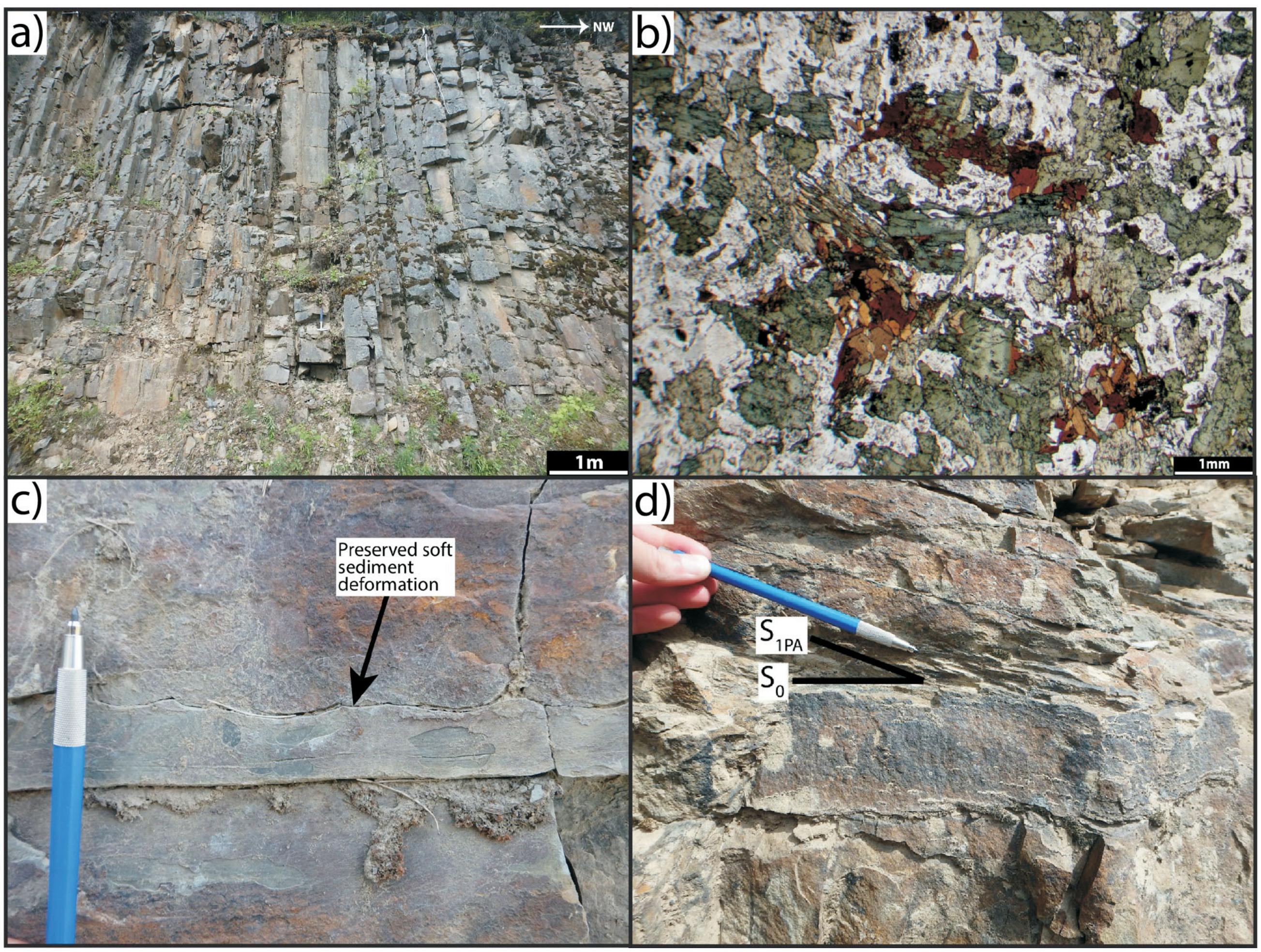

Figure 4. Photos and photomicrographs of representative units and structures in the study area: **a)** exposure of the Aldridge Formation from within the core of the Purcell Anticlinorium near Kitchener, BC; **b)** photomicrograph of a typical Moyie Sills sample collected near St. Mary Lake, BC; **c)** soft-sediment deformation observed near Lumberton, BC; **d)** S_{1PA} cleavage developed within the pelitic interbeds of the Aldridge Formation near Yahk, BC.

Kootenay Arc–Type Structures

Evidence of three deformation events in the Kootenay Arc was observed in rocks of the Windermere Supergroup, as well as in younger, coarse Paleozoic clastic rocks that comprise the easternmost portion of the Kootenay Arc. The primary fabric of these rocks is a steeply dipping, penetrative cleavage (S_{1KA}) that is manifested as a phyllitic fabric, which is subparallel to bedding. The S_{1KA} cleavage is overprinted by a spaced cleavage (S_{2KA}) that dips moderately to the east (Figure 5a) and is axial planar to folds of S_{1KA} (Figure 5b). Sub-horizontal lineations (L_{2KA}) present on the surface of S_{1KA} are generally north trending and are coincident with the constructed F_2 fold axis in both S_0 measured in WSG and younger strata, as well as in S_{1KA} (Figure 5c). A third deformation phase (D_3) resulted in the crenulation of the S_{2KA} surface (Figure 5d), and is manifested as a near-vertical, south-southwest-trending lineation (L_{3KA}) on the surface of S_{1KA} (Figure 5c).

Impingement of Kootenay Arc–Type Structures on the Western Flank of the Purcell Anticlinorium

Kootenay Arc–type structures are restricted to the northern portion of the field area (Figure 6a–c). The Gray Creek Road, which connects the towns of Kimberley and Crawford Bay, BC, allows for an examination of the change in structural style across the interface between the Purcell Anticlinorium, in which S_0 and S_{1PA} (Mesoproterozoic) are the dominant structures, and the Kootenay Arc, which is characterized by a series of three overprinting Mesozoic structures.

Kootenay Arc–type structures are measured in Belt–Purcell rocks on the western flank of the Purcell Anticlinorium. The most easterly indication of Mesozoic structural modification within the Purcell Anticlinorium occurs near St. Mary Lake within the lower Aldridge Formation

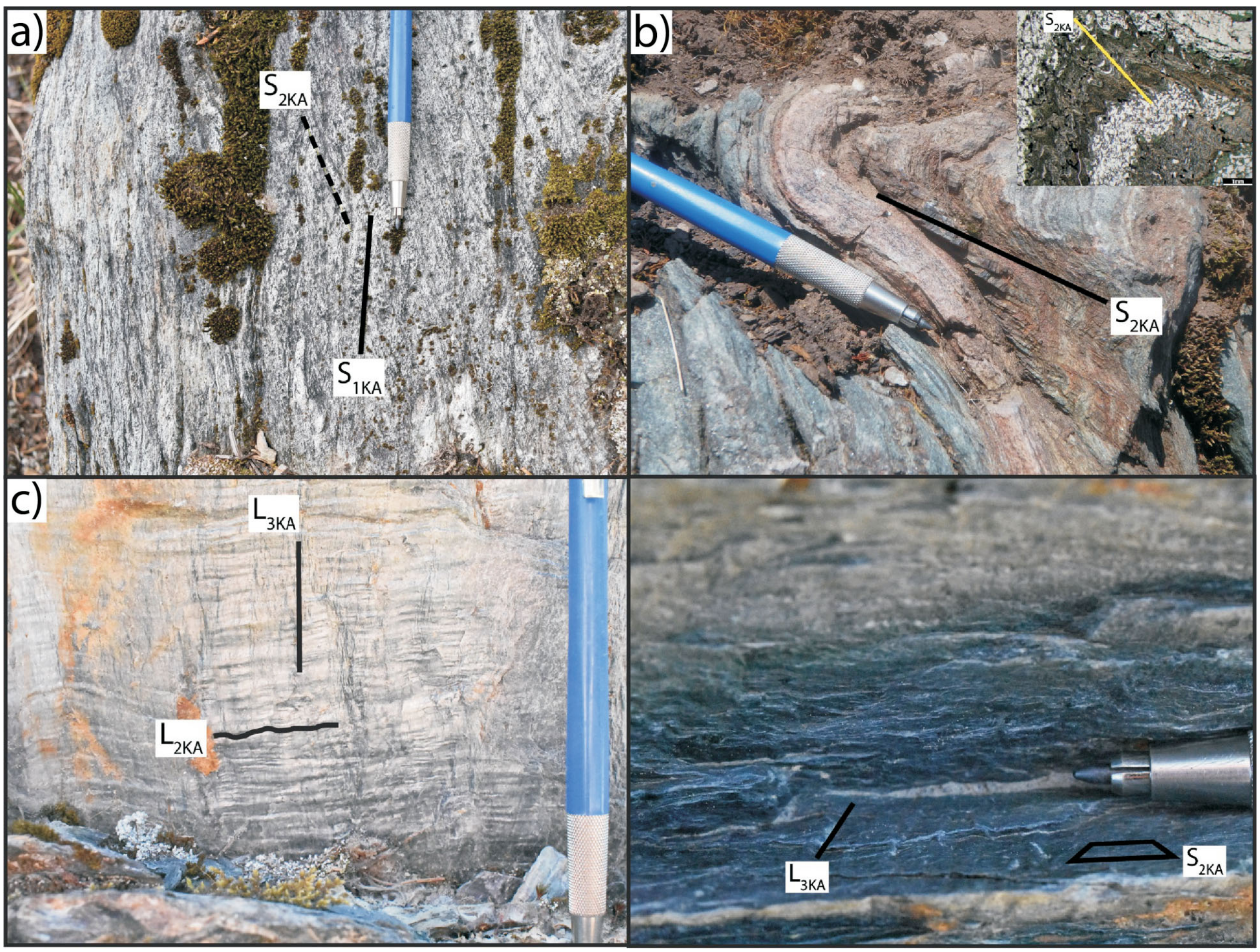

Figure 5. Photos and photomicrographs of representative units and structures in the study area: **a)** relationship between phylitic fabric (S_{1KA}) and spaced cleavage (S_{2KA}) in rocks of the Windermere Supergroup along the western side of the Gray Creek transect near Crawford Bay; **b)** fold in rocks of the Windermere Supergroup along the western side of the Gray Creek transect, with an axial-planar S_{2KA} cleavage (S_{2KA}), and inset of photomicrograph of small-scale fold and S_{2KA} cleavage from the same locality; **c)** exposure of L_{2KA} and L_{3KA} in phylite along the western side of the Gray Creek transect; **d)** crenulation (L_{3KA}) of the S_{2KA} surface along the western side of the Gray Creek transect.

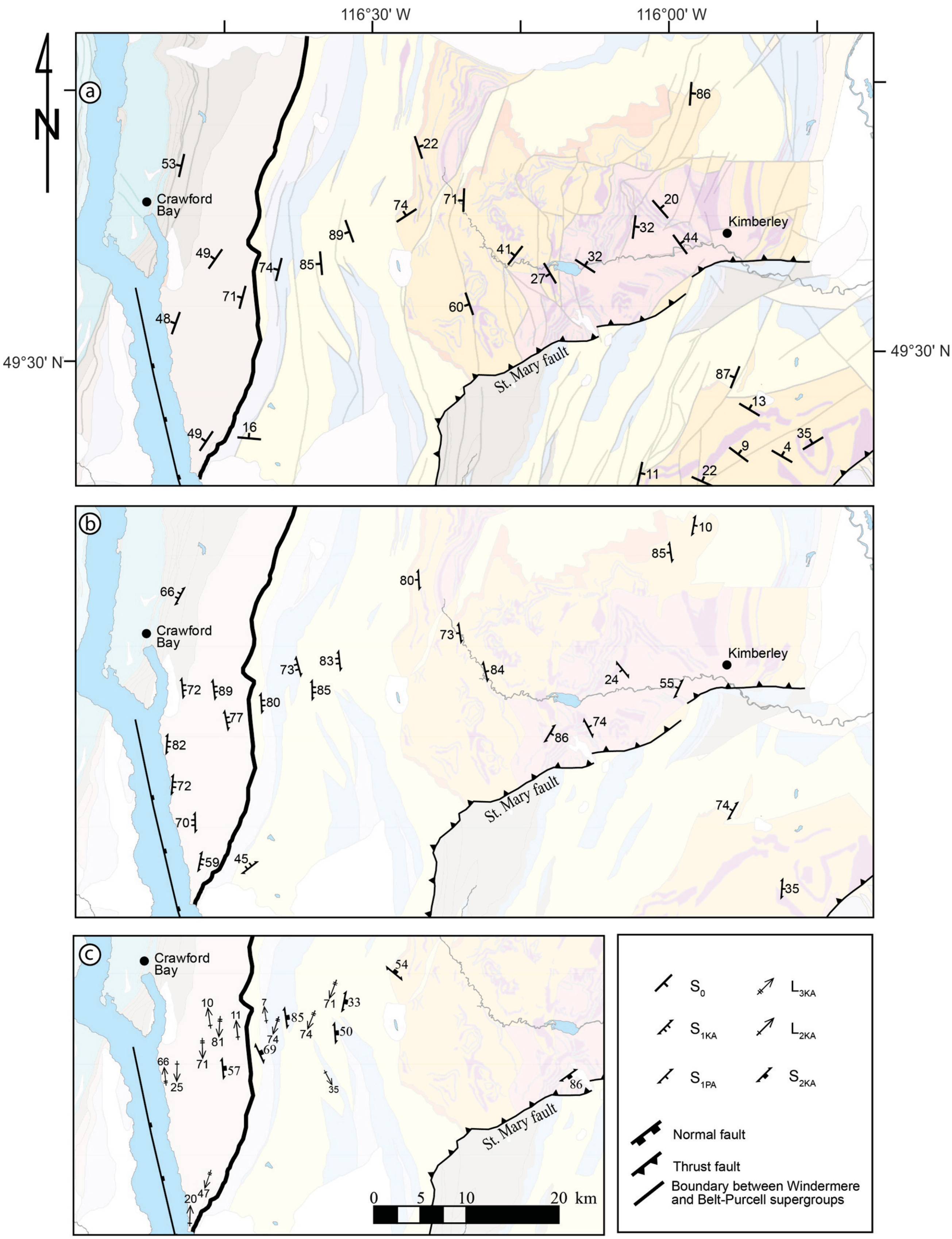

Figure 6. Structures observed across the Purcell Anticlinorium–Kootenay Arc transition in the study area. Maps show **a)** bedding orientations; **b)** fabrics S_{1PA} (one tick on symbol) and S_{1KA} (two ticks on symbol); **c)** structures associated with D_{2KA} (S_{2KA} and L_{2KA}) and D_3 (L_{3KA}). Map modified after Höy et al. (1995).

where folding and crenulations of S_{1PA} occur, as well as within the MCMZ west of Kimberley (McFarlane and Pattison, 2000). Within the westernmost exposures of the Aldridge Formation, as well as in younger Belt–Purcell rocks, S_{2KA} crenulations are intensified into a pervasive S_{2KA} schistosity. Locally, L_{3KA} is also developed in rocks of both the Belt–Purcell and Windermere Supergroups. Stereonet analysis indicates that large-scale folding of the Purcell Anticlinorium is related to the D_{2KA}, Mesozoic deformation that is responsible for the development of S_{2KA} and L_{2KA}. Constructed fold axes defined by S_0 in Belt–Purcell rocks and S_{1PA} are roughly coincident with the cluster of axes of L_{2KA} crenulations of S_{1PA}. The same is true for constructed fold axes defined by S_0 in WSG and younger rocks, as well as S_{1KA} measured in both BPSG and WSG and younger rocks, although the former plunge shallowly south rather than shallowly north (Figure 7).

The occurrence of overprinting Mesozoic structures characteristic of the Kootenay Arc within Belt-Purcell Supergroup rocks in the western margin of the Purcell Anticlinorium suggests that Kootenay Arc–type deformation propagated across the Windermere–Belt-Purcell unconformity into these older rocks. Although Kootenay Arc–type crenulations (S_{2KA}) are found near the St. Mary Lake area, the structural interface between the Purcell Anticlinorium and the Kootenay Arc is interpreted as the easternmost development of S_{1KA}, which occurs farther west, within 10–15 km east of the Windermere–Belt-Purcell unconformity. Here, $S_{1KA,}$ the penetrative phyllitic schistosity that is characteristic of Kootenay Arc–type deformation, is the dominant fabric in rocks of the uppermost units of the Belt-Purcell Supergroup. By contrast, S_{2KA}, is developed throughout the region and overprints both S_{1KA} and S_{1PA}.

Metamorphism

Evidence of metamorphic grade across the interface is primarily restricted to argillaceous rocks of the Belt–Purcell and Windermere supergroups, whose bulk compositions are favourable for porphyroblast growth. Metamorphic grade in the Purcell Anticlinorium falls within the chlorite and biotite subzones of the greenschist and lower amphibolite facies (Figure 8), rocks are characterized by the assemblage plagioclase+quartz±muscovite±chlorite±biotite. There is no significant variation in the distribution of mineral assemblages across the Purcell Anticlinorium, indicating that the five samples that lack biotite are the result of restricted bulk compositions rather than a lower metamorphic grade. Similarly, the Moyie Sills, which are restricted to the lower and middle Aldridge Formation, do not show any significant variation in metamorphic grade across the Purcell Anticlinorium, and are characterized by the mineral assemblage plagioclase+quartz±chlorite±biotite±hornblende±actinolite±epidote. Variable occurrences of garnet in the Purcell Anticlinorium will be discussed in more detail below.

The Kootenay Arc is characterized by three distinct episodes of metamorphism spanning the Middle Jurassic to the Late Cretaceous (Moynihan and Pattison, 2013; Webster and Pattison, 2018). The easternmost edge of the Kootenay Arc, where it interfaces with the Purcell Anticlinorium, is characterized by an elongate belt of regional, Barrovian metamorphism (Figure 8). East of Kootenay Lake, metamorphic grade decreases eastward from sillimanite+potassium-feldspar to biotite zone within Windermere and younger rocks. Peak metamorphic grade is about the same (biotite zone) as that of older metamorphic rocks of the BPSG beneath the Windermere unconformity (Moynihan and Pattison, 2013). For this reason, an investigation of mineral growth with respect to microstructures is necessary to determine the timing of metamorphism across the region.

Metamorphism with Respect to Deformation

Within the northern portion of the field area, consisting of argillaceous rocks of the Aldridge Formation, porphyroblasts of chlorite show evidence of internal deformation, as well as alignment within the plane of the S_{1PA} foliation (Figure 9a, b). These fabrics indicate that porphyroblast growth occurred prior to the development of S_{1PA}; metamorphic conditions responsible for the growth of these minerals must have occurred during the Proterozoic. The last occurrence of porphyroblasts in Belt–Purcell rocks that predate the development of S_{1PA} roughly coincides with the first signs of Kootenay Arc–type structures. Within rocks of both the Belt–Purcell (Figure 9c), and Windermere supergroups (Figure 9d, e) that exhibit Kootenay Arc–type deformation, porphyroblast growth appears to be intertectonic, between D_{1KA} and D_{2KA}, meaning biotite of this type cannot be Mesoproterozoic. The S_{1KA} cleavage is folded into microlithons between the cleavage planes of S_{2KA}. Straight inclusion trails in biotite porphyroblasts indicate that mineral development preceded folding associated with S_{2KA}. Additionally, the spaced S_{2KA} cleavage wraps biotite porphyroblasts (Figure 9c–e). In the westernmost portion of the field area, along the eastern shoreline of Kootenay Lake, pre-S_{2KA} biotite occurs both as large porphyroblasts that are wrapped by S_{2KA} (Figure 9e), and as finer grains that were folded with S_{1KA} (Figure 9f). In both cases, biotite growth preceded the development of S_{2KA}. Microstructural analysis implies that some of the biotite in Belt–Purcell rocks, specifically those close to the interface with the Kootenay Arc, developed during the Mesozoic, not the Mesoproterozoic. Therefore, biotite of Mesoproterozoic age does not extend westward all the way to the Windermere unconformity and Mesozoic metamorphism affected Belt–Purcell rocks in the Purcell Anticlinorium.

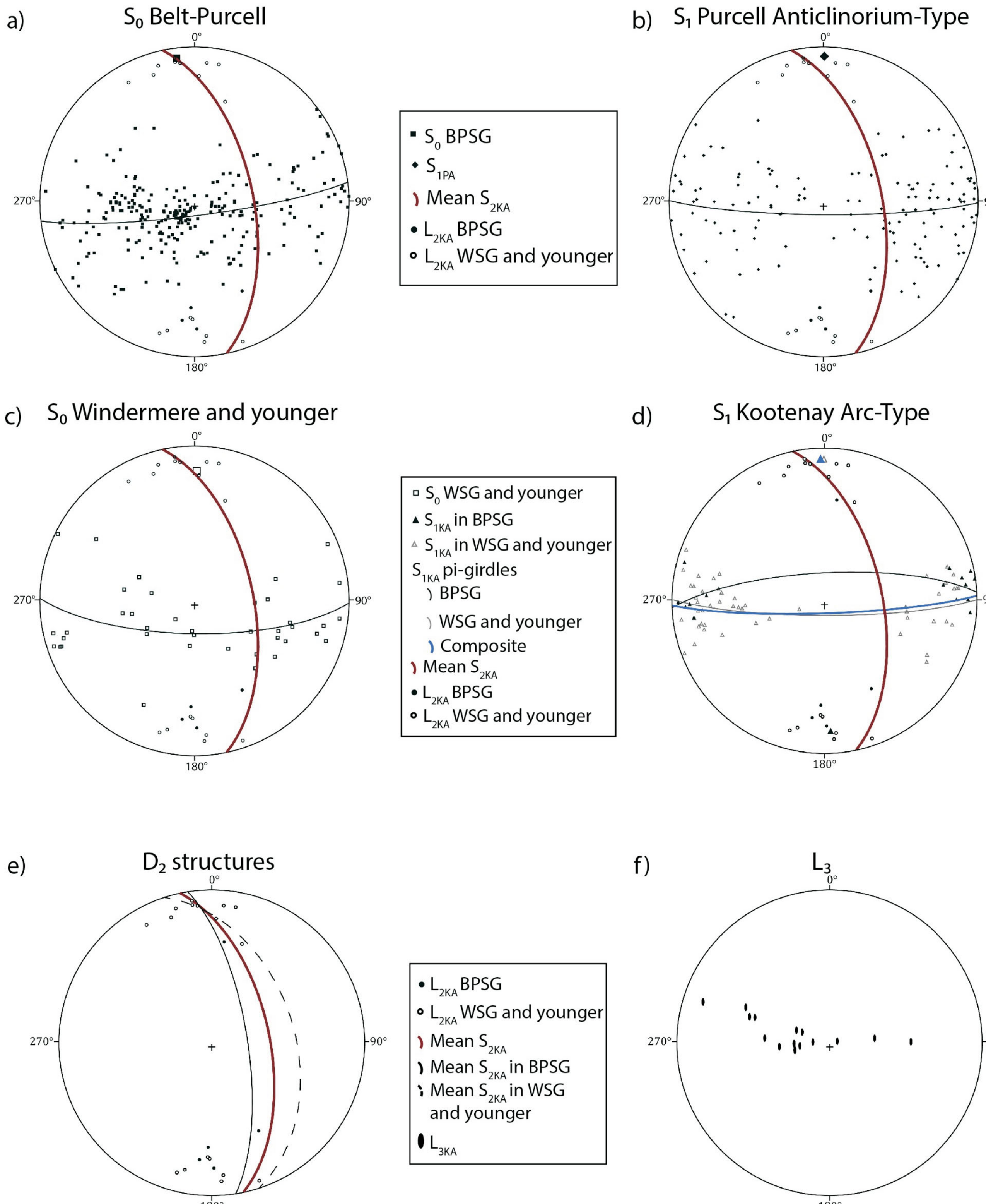

Figure 7. Stereonet analysis of all measured structures (equal angle projections, lower hemisphere): **a)** poles to S_0 in Belt-Purcell rocks with associated D_{2KA} structures; **b)** poles to S_{1PA} with associated D_{2KA} structures; **c)** poles to S_0 in Windermere and younger strata with associated D_{2KA} structures; **d)** poles to S_{1KA} with associated D_{2KA} structures; **e)** D_{2KA} structures: overall mean S_{2KA}, mean S_{2KA} measured in the Belt–Purcell Supergroup (BPSG), mean S_{2KA} measured in the Windermere Supergroup (WSG) and younger rocks, and L_{2KA} lineations; **f)** D_3 lineations.

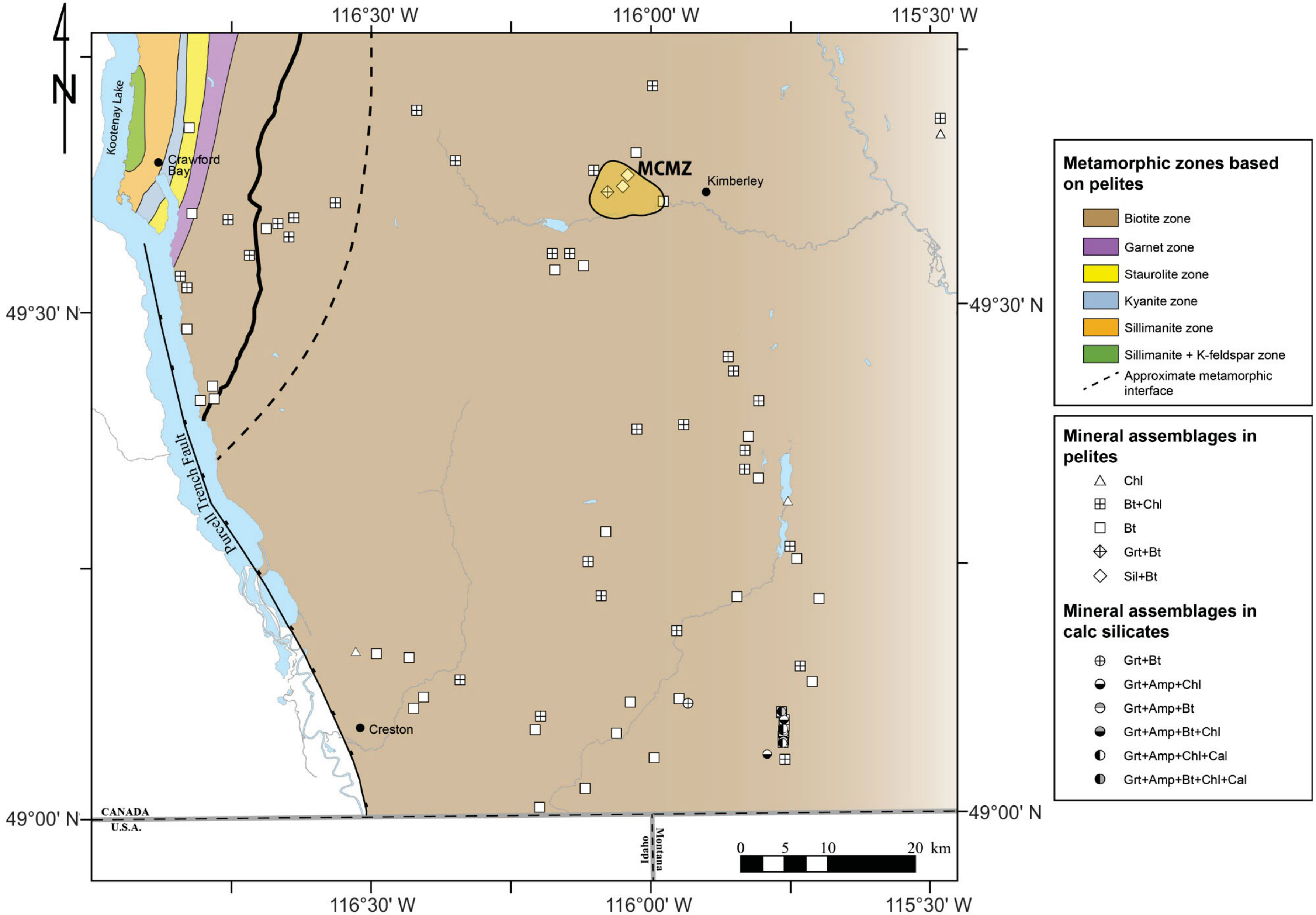

Figure 8. Map of mineral assemblages in sedimentary rocks across the Purcell Anticlinorium in the study area, with metamorphic zones from Moynihan and Pattison (2013). Abbreviation: MCMZ, Matthew Creek metamorphic zone.

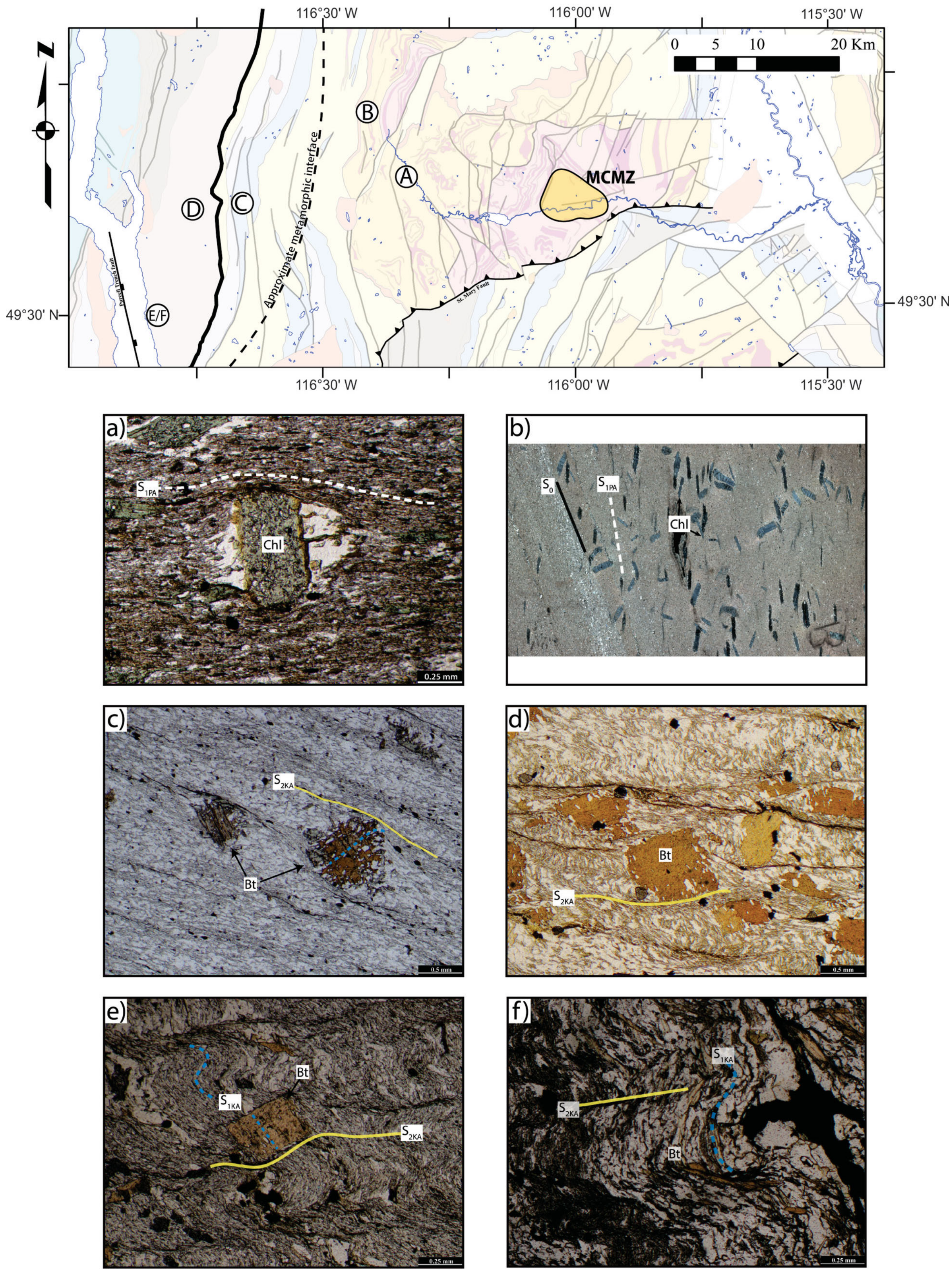

Figure 9. Photomicrographs indicating the relationship between porphyroblasts and rock fabrics, along with a map indicating sample locations (letters match those identifying the photomicrographs) in the study area: **a)** pretectonic chlorite from the Aldridge Formation; **b)** pretectonic chlorite from the Aldridge Formation; **c)** intertectonic biotite from the uppermost units of the Belt–Purcell Supergroup; **d)** intertectonic biotite from the Windermere Supergroup; **e)** intertectonic biotite from the Windermere Supergroup; **f)** pre S_{2KA} biotite from the Windermere Supergroup. Abbreviations: Bt, biotite; Chl, chlorite; MCMZ, Matthew Creek metamorphic zone.

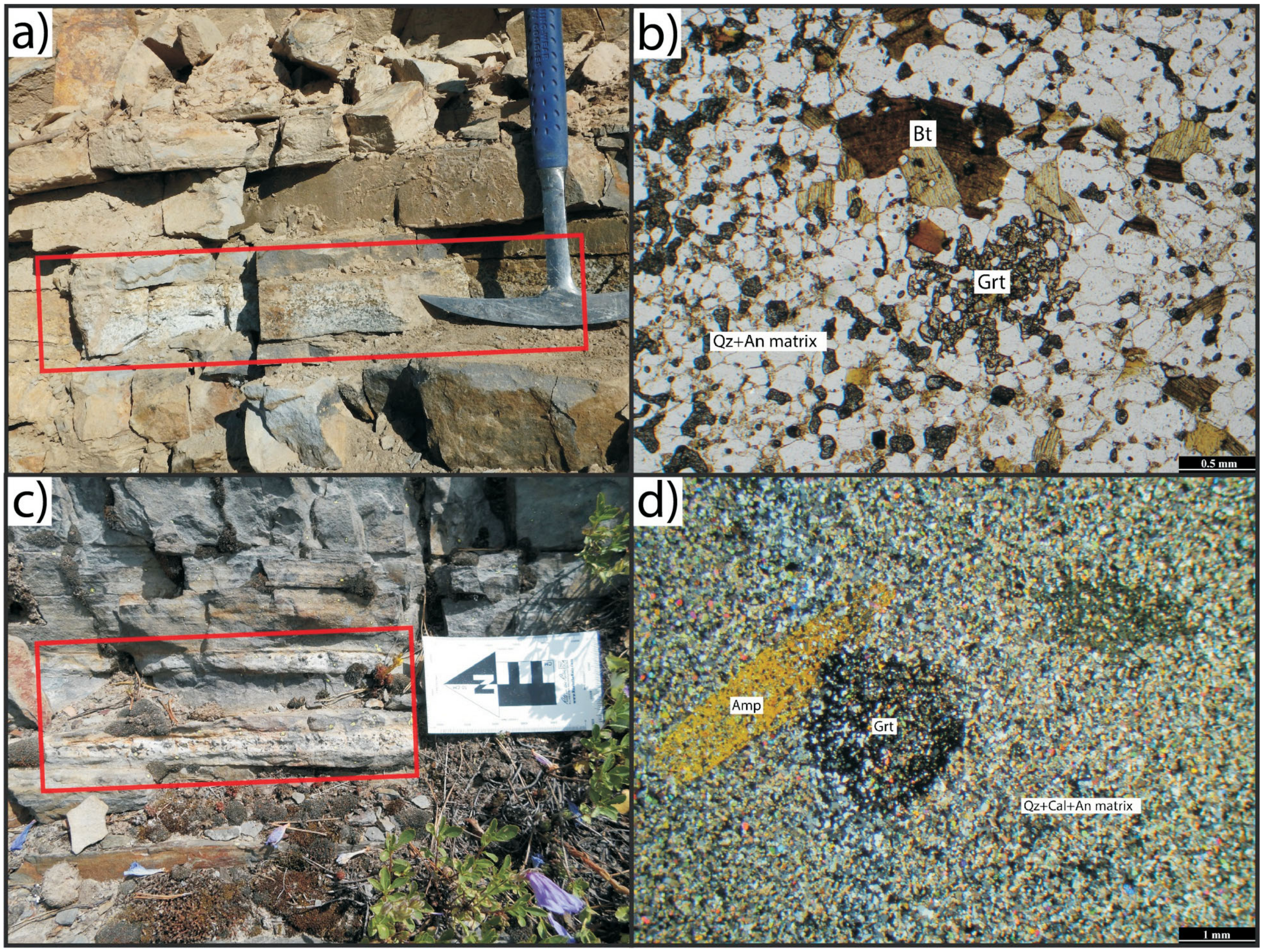

Figure 10. Garnet-bearing rocks in the Purcell Anticlinorium in the study area: **a)** field setting of garnet-bearing rocks on Mount Mahon; **b)** photomicrograph of garnet-biotite rock from Mount Mahon; **c)** field setting of garnet-amphibole rocks near Mount Olson; **d)** photomicrograph of garnet-amphibole rock near Mount Olson. Abbreviations: Amp, amphibole; An, anorthite; Bt, biotite; Cal, calcite; Grt, garnet; Qz, quartz.

Garnet in the Purcell Anticlinorium

Five occurrences of garnet-bearing rocks have been identified within the Purcell Anticlinorium. They include: 1) the MCMZ west of Kimberley (McFarlane and Pattison, 2000), 2) the Sullivan mine northwest of Kimberley (DePaoli and Pattison, 2000), 3) the St. Eugene mine in Moyie (Pattison and Seitz, 2012), 4) Mount Mahon west of Yahk (Read et al., 1991; Brown and Stinson, 1995), and 5) near Mount Olson east of Yahk (Leech, 1967; Read et al., 1991). Previous studies indicate that garnet-bearing mineral assemblages within the Purcell Anticlinorium are due to either unusual bulk compositions favourable to garnet growth (DePaoli and Pattison, 2000; Pattison and Seitz, 2012) or domains of higher metamorphic grade (e.g., MCMZ; cf. McFarlane and Pattison, 2000). The presence of garnet within the Purcell Anticlinorium is of interest because anomalous garnet-bearing assemblages in metasedimentary rocks of low metamorphic grade have been associated with prolific mineral deposits within the area (e.g., Sullivan and St. Eugene deposits).

Garnet-bearing rocks in the middle Aldridge Formation at Mount Mahon were identified in a single (though there may be more) layer ~10 cm thick (Figure 10a) and contain the mineral assemblage garnet+biotite+quartz+plagioclase+clay as an alteration product (Figure 10b). Near Mount Olson, within the lower Aldridge Formation, garnet-bearing layers ranging in thickness from 5 to 30 cm and with a maximum stratigraphic separation of ~15 m were identified in the field (Figure 10c). These rocks contain garnet+amphibole+plagioclase+quartz+ilmenite, with either calcite or chlorite (Figure 10d). A reaction that accounts for garnet growth at Mount Mahon and Mount Olson is:

$$\text{muscovite+quartz+calcite+chlorite+}H_2O = \text{anorthite+garnet+amphibole+}CO_2$$

In both localities, garnet-bearing layers are interlayered with typical biotite-bearing argillaceous rocks of the Aldridge Formation. Therefore, localized garnet growth is not the result of higher metamorphic grade and is instead attributed to unusual calcareous bulk compositions. There is no evidence of mineralization associated with these layers.

Summary

Difficulty in defining the interface between the western edge of the Purcell Anticlinorium, and the eastern edge of the Kootenay Arc within the study area is attributed to the fact that the boundary between the two domains can be described in terms of stratigraphy, structure, metamorphism and exhumation history. Overall, there is a younging of stratigraphy as the Kootenay Arc is entered, from Mesoproterozoic BPSG rocks in the core of the Purcell Anticlinorium to Neoproterozoic and Paleozoic strata in the Kootenay Arc. However, structurally the interface occurs east of the unconformity between the WSG and the BPSG, as indicated by the development of Kootenay Arc–type structures, which are developed within BPSG rocks beneath the unconformity. In terms of metamorphism, there is no discernable change in metamorphic grade across the unconformity between the WSG and BPSG, both regions falling in the biotite zone. Constraining the timing of peak metamorphism in the interface zone is underpinned by the interplay between porphyroblast growth and deformation. Based on these relationships, the metamorphic interface roughly coincides with the structural interface. However, the absence of porphyroblasts makes it difficult to tightly constrain the metamorphic interface within this region. Work in progress on Ar/Ar cooling ages in biotite and muscovite from across the study area will further constrain the location and nature of this multifaceted interface.

Future Work

Kootenay Arc–type structures observed during fieldwork associated with this project require correlation with structures identified in previous studies of deformation within the Kootenay Arc by Moynihan and Pattison (2013), and Webster and Pattison (2018). Synthesizing observations presented in this paper with those of Moynihan and Pattison (2013), and Webster and Pattison (2018) will more tightly constrain the timing of metamorphism. The aim is to understand the way in which Mesozoic metamorphism affected rocks along the margin of North America at the time of Cordilleran orogenesis. Recently acquired Ar/Ar ages in biotite and muscovite across the field area will allow for an assessment of the marked contrast in exhumation history across the Kootenay Arc–Purcell Anticlinorium interface, and how it relates to the stratigraphic, structural and metamorphic changes across the transition. This improved understanding will provide better constraints on the deformational, metamorphic and cooling histories of these two adjacent, regional-scale structural domains. In turn, elucidating their geological evolution will provide better constraints on the formation of the many mineral deposits in the region and improve the understanding of the different types of mineralization that occur across the interface.

Acknowledgments

The authors would like to thank Geoscience BC for their continued support of this study. This work was funded by a Geoscience BC grant to D. Pattison and N. Rioseco, and a Natural Sciences and Engineering Research Council of Canada (NSERC) Discovery Grant to D. Pattison. They would also like to thank J. Forshaw and C. Padget for reviewing this manuscript, as well as G. Costigan and M. Lazzarotto for additional help and insightful conversation.

References

Archibald, D.A., Glover, J.K., Price, R.A., Farrar, E. and Carmichael, D.M. (1983): Geochronology and tectonic implications of magmatism and metamorphism, southern Kootenay Arc and neighbouring regions, southeastern British Columbia, part I: Jurassic to mid-Cretaceous; Canadian Journal of Earth Sciences, v. 20, p. 1891–1913.

Archibald, D.A., Krough, T.E., Armstrong, R.L. and Farrar, E. (1984): Geochronology and tectonic implications of magmatism and metamorphism, southern Kootenay Arc and neighbouring regions, southeastern British Columbia, part II: Mid-Cretaceous to Eocene; Canadian Journal of Earth Sciences, v. 21, p. 567–583.

Bond, G.C., Christie-Blick, N., Kominz, M.A. and Devlin, W.J. (1985): An early Cambrian rift to post-rift transition in the Cordillera of western North America; Nature, v. 315, p. 742–746.

Brown, D.A. and Stinson, P. (1995): Geological Mapping of the Yahk Map Area, southeastern British Columbia: an update (82F/1); BC Ministry of Energy, Mines and Petroleum Resources, BC Geological Survey, Geological Fieldwork 1994, Paper 1995-1, p. 111–125.

Colpron, M., Logan, J.L. and Mortensen, J.K. (2002): U-Pb zircon age constraint for late Neoproterozoic rifting and initiation of the lower Paleozoic passive margin of western Laurentia; Canadian Journal of Earth Sciences, v. 39, p. 133–143.

De Paoli, G.R. and Pattison, D.R.M. (2000): Thermobarometric calculation of peak metamorphic conditions of the Sullivan deposit; *in* The Geological Environment of the Sullivan Deposit, British Columbia, J.W. Lydon, J.F. Stack, T. Höy and M.E. Knapp (ed.), Geological Association of Canada, Mineral Deposits Division Special Volume No. 1, p. 272–280.

Harrison, J.E. (1972): Precambrian Belt basin of northwestern United States: its geometry, sedimentation and copper occurrences; Geological Society of America Bulletin, v. 83, p. 1215–1240.

Höy, T. (1989): The age, chemistry and tectonic setting of the Middle Proterozoic Moyie sills, Purcell Supergroup, southeastern British Columbia; Canadian Journal of Earth Sciences, v. 26, p. 2305–2317.

Höy, T., Price, R.A., Legun, A., Grant, B. and Brown, D. (1995): Purcell Supergroup, southwestern British Columbia (NTS 82G, F, E; 82J/SW, 82K/SE); BC Ministry of Energy, Mines and Petroleum Resources, BC Geological Survey, Geoscience Map 1995-1, scale 1:250 000.

Hunt, G. (1962): Time of Purcell eruption in southeastern British Columbia and southwestern Alberta; Bulletin of Canadian Petroleum Geology, v. 10, p. 438–442.

Klepacki, D.W. (1985): Stratigraphy and structural geology of the Goat Range area, southeastern British Columbia; Ph.D. thesis, Massachusetts Institute of Technology, Cambridge, Massachusetts, 268 p.

Leclair, A.D. (1982): Preliminary results on the stratigraphy, structure, and metamorphism of central Kootenay Arc rocks, southeastern British Columbia; *in* Current Research, Part A, Geological Survey of Canada, Paper 82-1A, p. 45–49.

Leclair, A.D., Parrish, R.R. and Archibald, D.A. (1993): Evidence for Cretaceous deformation in the Kootenay Arc based on U-Pb and ^{40}Ar/^{39}Ar dating, southeastern British Columbia; *in* Current Research, Part A, Geological Survey of Canada, Paper 93-1A, p. 207–220.

Leech, G.B. (1962): Metamorphism and granitic intrusions of Precambrian age in southeastern British Columbia; Geological Survey of Canada, Paper 62-13, 11 p.

Leech, G.B. (1967): K-Ar Isotopic Ages, Report 7, British Columbia; *in* Age Determinations and Geological Studies, R.K. Wanless, R.D. Stevens, G.R. Lachance, C.M. Edmonds (ed.), Geological Survey of Canada, Paper 66-17, p. 9–10.

McFarlane, C.R.M. (2015): A geochronological framework for sedimentation and Mesoproterozoic tectonomagmatic activity in lower Belt-Purcell rocks exposed west of Kimberley, British Columbia; Canadian Journal of Earth Sciences, v. 52, p. 444–465, URL <https://doi.org/10.1139/cjes-2014-0215> [November 2018].

McFarlane, C.R.M. and Pattison, D.R.M. (2000): Geology of the Matthew Creek metamorphic zone, southeast British Columbia: a window into Middle Proterozoic metamorphism in the Purcell Basin; Canadian Journal of Earth Sciences, v. 37, p. 1073–1092, URL <https://doi.org/10.1139/e00-018> [November 2018].

McMechan, M.E. and Price, R.A. (1982): Superimposed low-grade metamorphism in the Mount Fisher area, southeastern British Columbia–implications for the East Kootenay orogeny; Canadian Journal of Earth Sciences, v. 19, p. 476–489.

Monger, J.W.H., Price, R.A. and Templeman-Kluit, D.J. (1982): Tectonic accretion and the origin of the two major metamorphic and plutonic welts in the Canadian Cordillera; Geology, v. 10, p. 70–75.

Moynihan, D.P. and Pattison, D.R.M. (2013): Barrovian metamorphism in the central Kootenay Arc, British Columbia: petrology and isograd geometry; Canadian Journal of Earth Sciences, v. 50, p. 769–794, URL <https://doi.org/10.1139/cjes-2012-0083> [November 2018].

Pattison, D.R.M. and Seitz, J.D. (2012): Stabilization of garnet in metamorphosed altered turbidites near the St. Eugene lead-zinc deposit, southeastern British Columbia: equilibrium and kinetic controls; Lithos, v. 134–135, p. 221–235, URL <https://doi.org/10.1016/j.lithos.2011.12.007> [November 2018].

Price, R.A. (1964): The Precambrian Purcell system in the Rocky Mountains of southern Alberta and British Columbia; Bulletin of Canadian Petroleum Geology, v. 12, p. 399–426.

Read, P.B., Woodsworth, G.J., Greenwood, H.J., Ghent, E.D. and Evenchick, C.A. (1991): Metamorphic map of the Canadian Cordillera; Geological Survey of Canada, Map 1714A, scale 1:2 000 000.

Unterschutz, J.L.E., Creaser, R.A., Erdmer, P., Thompson, R.I. and Daughtry, K.L. (2002): North American margin origin of Quesnel terrane strata in the southern Canadian Cordillera: inferences from geochemical and Nd isotopic characteristics of Triassic metasedimentary rocks; Geological Society of America Bulletin, v. 114, no. 4, p. 462–475.

Warren, M.J. (1997): Crustal extension and subsequent crustal thickening along the Cordilleran rifted margin of ancestral North America, western Purcell Mountains, southeastern British Columbia; Ph.D. thesis, Queen's University, 477 p.

Webster, E.R. and Pattison, D. (2018): Spatially overlapping episodes of deformation, metamorphism, and magmatism in the southern Omineca belt, southeastern British Columbia; Canadian Journal of Earth Sciences, v. 55, no. 1, p. 84–110, URL <https://doi.org/10.1139/cjes-2017-0036> [November 2018].

Wheeler, J.O. and McFeely, P. (1991): Tectonic assemblage map of the Canadian Cordillera and adjacent parts of the United States of America; Geological Survey of Canada, Map 1712A, scale 1:2 000 000, URL <https://doi.org/10.4095/133549> [November 2018].