Preliminary Investigations of the Metamorphic and Thermochronological Interface between the Purcell Anticlinorium and the Kootenay Arc, Southeastern British Columbia (NTS 082F, G)

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Introduction

The mineralogically rich East Kootenay region encompasses the interface between two major Cordilleran tectonic domains, the Purcell Anticlinorium and the Kootenay Arc. This project is a regional study that seeks to 1) elucidate the nature of differences in metamorphism, structure and cooling history between these two domains; and 2) draw potential links between the tectonic significance of these differences and the mineralization that occurs within the region.

Regional Geology

The study area (Figure 1) includes the region between Creston, Crawford Bay and Kimberley in southeastern British Columbia (BC). The rocks under investigation occur east of the Eocene Purcell Trench fault, an east-side-down extensional normal fault. The eastern portion of this domain is occupied by the Purcell Anticlinorium, a regional-scale, northwest-trending and northwest-plunging anticlinal structure that is cored by Mesoproterozoic rocks of the Belt-Purcell Supergroup. This tectonic domain transitions westward into deformed and metamorphosed Neoproterozoic through Paleozoic pericratonic rocks and accreted island-arc rocks of the Kootenay Arc. Mesozoic deformation and metamorphism within the Kootenay Arc are attributed to Cordilleran orogenic processes spanning the Early Jurassic through the Eocene. The Purcell Anticlinorium is also a Cordilleran structure but preserves, within its core, some of the oldest rock exposures in the Cordillera, as well as evidence for Precambrian deformation and metamorphic events.

The Belt-Purcell Supergroup comprises rift-related clastic rocks and synsedimentary Moyie Sills that are interpreted to have been deposited in an intracratonic rift basin between 1500 and 1350 Ma (Price, 1964; Harrison, 1972; Höy, 1989). The lowermost unit, the Aldridge Formation, comprises predominantly turbiditic deposits and is host to a suite of 1468 Ma dioritic to gabbroic sills, known as the Moyie Sills (Höy, 1989). Belt Purcell strata are unconformably overlain by the Neoproterozoic Windermere Supergroup, exposed on the flanks of the Purcell Anticlinorium. On the west flank of the Purcell Anticlinorium, the Windermere Supergroup occurs in the interface with the Kootenay Arc (Warren, 1997). Farther to the west, within the Kootenay Arc, the Windermere Supergroup is overlain by pericratonic and coarse clastic and carbonate Paleozoic rocks (Bond et al., 1985; Warren, 1997; Colpron et al., 2002).

In addition to this stratigraphic change, the transition between the Purcell Anticlinorium and the Kootenay Arc is marked by a prominent change in structural style, metamorphism, and magmatism. 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 its ancient history, the regional-scale anticlinal structure of the Purcell Anticlinorium is attributed to Mesozoic Cordilleran orogenesis (Price, 1964). The Purcell Anticlinorium is of relatively low metamorphic grade, comprising the chlorite and biotite subzones of the greenschist facies (Leech, 1962; Read et al., 1991). There are rare occurrences of garnet-bearing rocks in the core of its southern part, within rocks of the Aldridge Formation on Mount Olson and Mount Mahon, near the town of Yahk, BC (Read et al., 1991). The garnet-bearing rocks have one of two explanations: they are either domains of locally elevated metamorphic grade, as in the Matthew Creek metamorphic zone (McFarlane and Pattison, 2000); or domains of unusual bulk composition favourable for garnet development, as in the area near the St. Eugene mine (Pattison and Seitz, 2012). The Kootenay Arc is an arcuate belt of rocks that have been ductilely deformed, metamorphosed and intruded in 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, 2017).

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Regional metamorphic grade in the Kootenay Arc ranges from greenschist to amphibolite facies. The higher grade domains are broadly attributed to Barrovian (kyanite-sillimanite–type) metamorphism that locally reaches sillimanite+potassium-feldspar grade (Leclair, 1982; Moynihan and Pattison, 2013; Webster and Pattison, 2017).

The prominent change in deformation styles and metamorphism between the Purcell Anticlinorium and the Kootenay Arc is complemented by a westward decrease in K-Ar and Ar/Ar cooling ages in hornblende and micas (Figure 2). Hunt (1962) and McMechan and Price (1982) reported many K-Ar ages in the range 1084–600 Ma that are indicative of Mesoproterozoic and Neoproterozoic exhumation of the core and eastern flank of the Purcell Anticlinorium. In contrast, metamorphic rocks in the Kootenay Arc, whose protoliths include rocks of the Belt-Purcell and Windermere supergroups, yield K-Ar and Ar/Ar ages in the range of 90–45 Ma, indicating much younger, Mesozoic and Cenozoic, exhumation (Figure 2; Archibald et al., 1983, 1984; Webster and Pattison, 2017).

Project Goals

The objective of this project is to elucidate the nature and tectonic significance of the transition in structural style, metamorphism and cooling history between the Purcell Anticlinorium and the Kootenay Arc. A comparison of

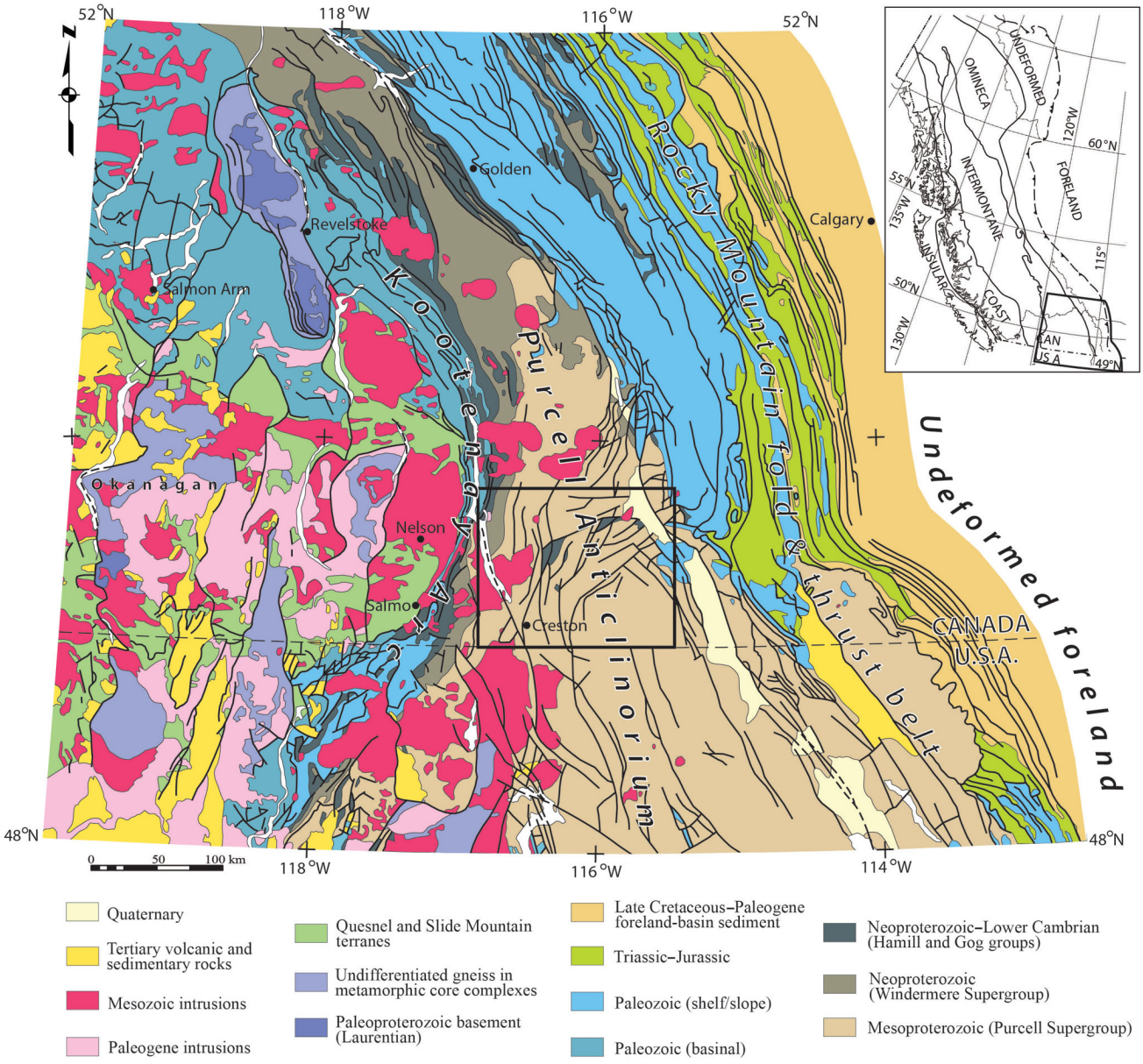

Figure 1. Regional geology of the southeastern Canadian Cordillera in southeastern British Columbia. Study area indicated by black outline. Map modified from Webster and Pattison (2017), originally after Wheeler and McFeely (1991).

structural styles across the Purcell Anticlinorium and into the transition zone with the Kootenay Arc will be complemented by a comprehensive study of metamorphism within the Purcell Anticlinorium and how it relates to that of the Kootenay Arc. Both of these studies will be augmented by thermochronological studies focused on Ar/Ar cooling ages in biotite, muscovite and hornblende. This three-step approach will enhance the understanding of the deformational, metamorphic and cooling/exhumation history the Purcell Anticlinorium and Kootenay Arc.

Fieldwork and Preliminary Observations

A ten-week field season was undertaken during the summer of 2017. The primary goal was to obtain a suite of biotite- and hornblende-bearing rocks that will provide the basis for metamorphic and thermochronological studies across the Purcell Anticlinorium (Figure 3a). Throughout the Purcell Anticlinorium, biotite occurs within pelitic beds of the Aldridge Formation and the interlayered Moyie Sills, and, along its western flank, within metasedimentary rocks

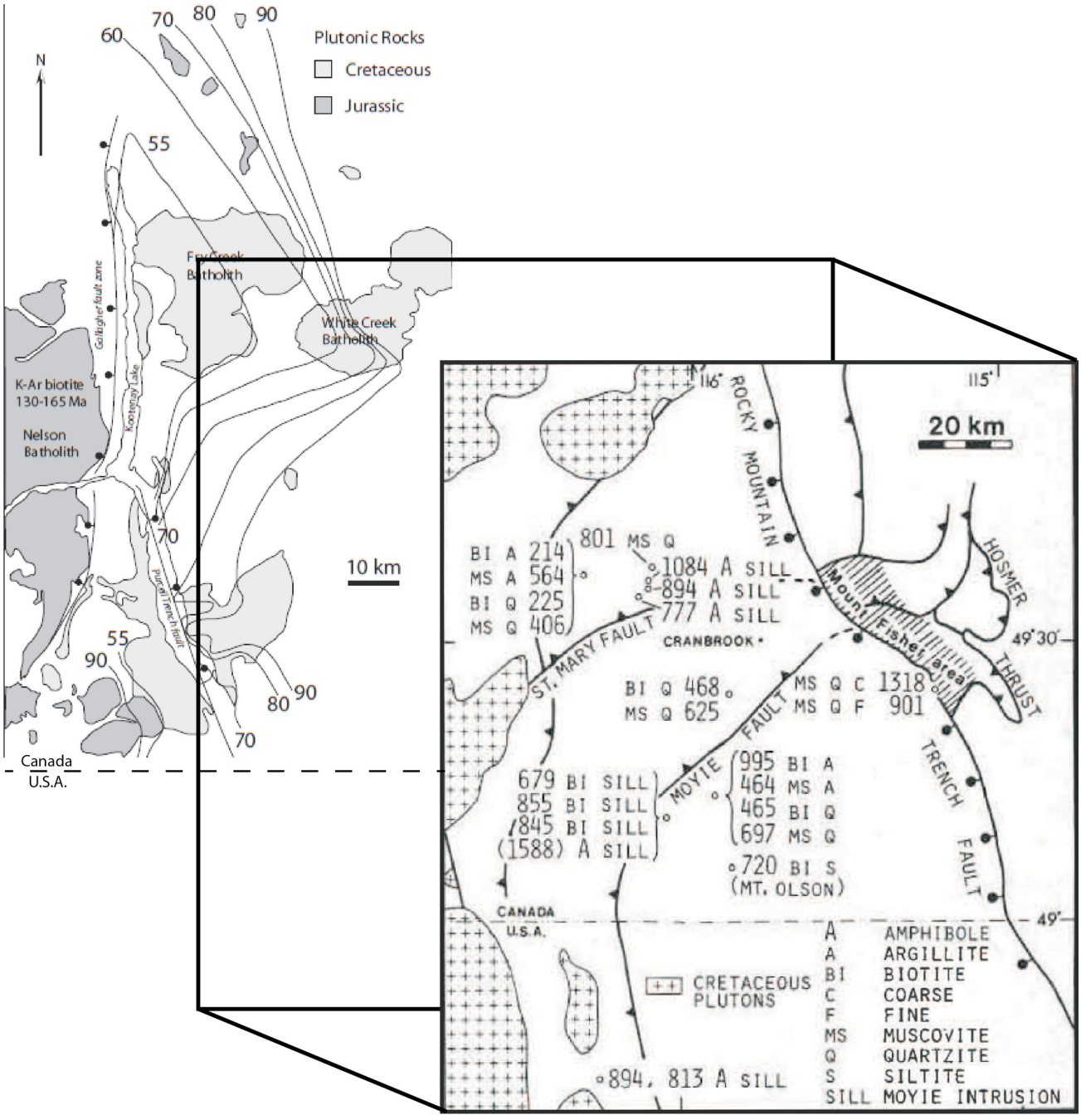

Figure 2. (Left) Potassium-argon cooling ages in biotite (from Archibald et al., 1984); contour interval 10 m. **(Right)** Potassium-argon cooling ages (from McMechan and Price, 1982). Location of figures shown by black outline on Figure 1.

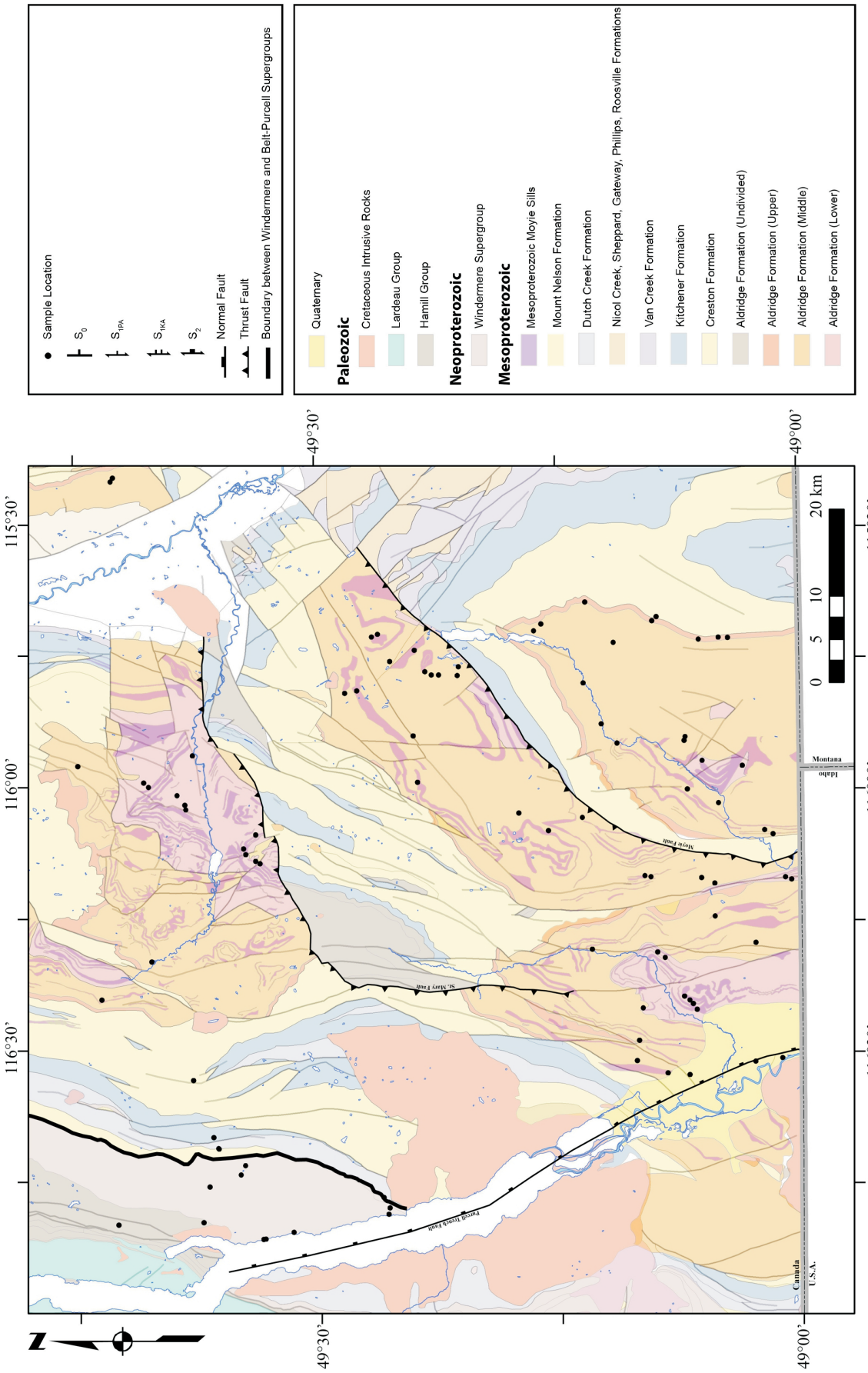

Figure 3. Sample locations in the study area (geology after Höy et al., 1995).

of the Windermere Supergroup. These rocks were targeted during sampling, as biotite-bearing rocks are essential for future metamorphic and thermochronological analysis. Measurements of bedding, foliation(s), lineation(s) and folding were collected to identify changes in structural style between the Purcell Anticlinorium and the Kootenay Arc, complementing the results of metamorphic and thermochronological studies.

Rocks of the lower, middle and upper Aldridge Formation occur as thick, planar-bedded, turbiditic deposits that range from sandy to silty in composition. These strata consist predominantly of massive sandy units, ranging from 0.5–1 m in thickness, with thinner (5–10 cm) silty interbeds (Figure 4a). The Moyie Sills occur mainly in lower and middle Aldridge rocks and are typically massive, with common preservation of ophitic igneous texture (Figure 4b). These units are typically on the order of 6–10 m thick.

Map patterns and structural observations of bedding from within the central part of the field area indicate broad large-scale folding, likely associated with the anticlinal structure formed during Cordilleran orogenesis (Figure 5). The development of an S_1 penetrative slaty cleavage is present throughout the pelitic portions of the Aldridge Formation. This cleavage is referred to as S_{1PA}. In the field, it was observed that the dip of S_{1PA} consistently falls within a range of 15–30º from that of S_0 (bedding; Figures 4c, 6).

Within the Kootenay Arc, the dominant rock fabrics developed (S_1 and S_2) are attributed to two deformation events, D_1 and D_2, respectively. Within the central part of the arc, an S_1 schistosity is axial planar to F_1 folds developed during D_1, a Middle Jurassic metamorphic event responsible for low-grade, regional metamorphism (Moynihan and Pattison, 2013). Moynihan and Pattison (2013) described a second phase of deformation within the Kootenay Arc that is attributed to Early Cretaceous D_2 deformation and is responsible for the development of F_2 folds. An S_2 schistosity that is axial planar to F_2 folds steepens eastward from within the central Kootenay Arc toward the Purcell Anticlinorium (Moynihan and Pattison, 2013). These are Mesozoic fabrics related to the structural and metamorphic evolution of the Kootenay Arc that, in this discussion, will be referred to as S_{1KA} and S_{2KA}.

One of the aims of this project is to understand the nature of overprinting of Proterozoic Belt-Purcell structures by the Mesozoic structures documented above as the Purcell Anticlinorium transitions into the Kootenay Arc. An east to west transect through the northern part of the field area was made possible via the Gray Creek Road, which connects the towns of Crawford Bay and Kimberley, BC. This transect allows for an examination of the change in the structural style of rocks from the core of the Purcell Anticlinorium to the Kootenay Arc. Along this transect, there is a westward transition in structural style. The eastern portion of the transect exposes rocks with a Purcell Anticlinorium–type S_{1PA} fabric. Westward, however, it seems as though the dominant fabric is more Kootenay Arc–type S_{1KA} and S_{2KA}. S_{1KA} and S_{2KA} are the dominant fabrics in rocks exposed along the western part of the Grey Creek Road and are developed in rocks of the Windermere and Belt-Purcell supergroups. Within the rocks that were observed, S_{1KA} is difficult to define but generally dips fairly steeply (65–85º) and was affected by later folding responsible for the development of S_{2KA}. The S_{2KA} fabric depicted in Figures 4d–f is a spaced cleavage that is axial planar to the folding of S_{1KA}. Kootenay Arc–type fabrics in this region of the Purcell Anticlinorium are not stratigraphically restricted, implying overprinting of Kootenay Arc–type fabrics in Mesoproterozoic Belt-Purcell rocks of the Purcell Anticlinorium.

Evidence of metamorphic grade in rocks of the Aldridge Formation is restricted to the pelitic interbeds, which have a bulk composition that allows for the growth of index minerals. Biotite porphyroblasts, ranging from 0.1 to 0.3 mm in size, occur in a matrix of predominantly quartz and mica, indicating that peak metamorphic conditions in these rocks did not exceed those of the biotite zone. Garnet from rocks on Mount Olson occurs as 2–4 mm porphyroblasts accompanied by elongate hornblende porphyroblasts that are similar in size. Based on preliminary petrographic observation, the matrix of garnet- and hornblende-bearing rocks is similar to that of more 'typical' biotite-bearing rocks. The Moyie Sills show no detectable variation in metamorphic grade across the Purcell Anticlinorium. These rocks contain combinations of plagioclase, hornblende, actinolite, chlorite, biotite and epidote. This information, which is based on preliminary petrographic work, indicates metamorphic conditions that fall broadly within the lower-amphibolite facies in the Purcell Anticlinorium. West of the Purcell Trench fault, however, Moyie Sills contain amphibolite-facies assemblages (Webster and Pattison, 2017).

Future Work

The next phases of this project will include a more in-depth analysis of the structural and metamorphic characteristics of the Purcell Anticlinorium–Kootenay Arc transition, augmented by thermochronological analysis.

Stereonet analysis will complement the mapped structural variation, allowing for identification of the interplay between structures of the Purcell Anticlinorium and the Kootenay Arc. A follow-up field season during the summer of 2018 will focus more carefully on structural variation in the northwest corner of the field area, where Kootenay Arc–type structures were identified this year.

The metamorphic portion of the study requires a multifaceted approach, involving 1) petrographic work to identify

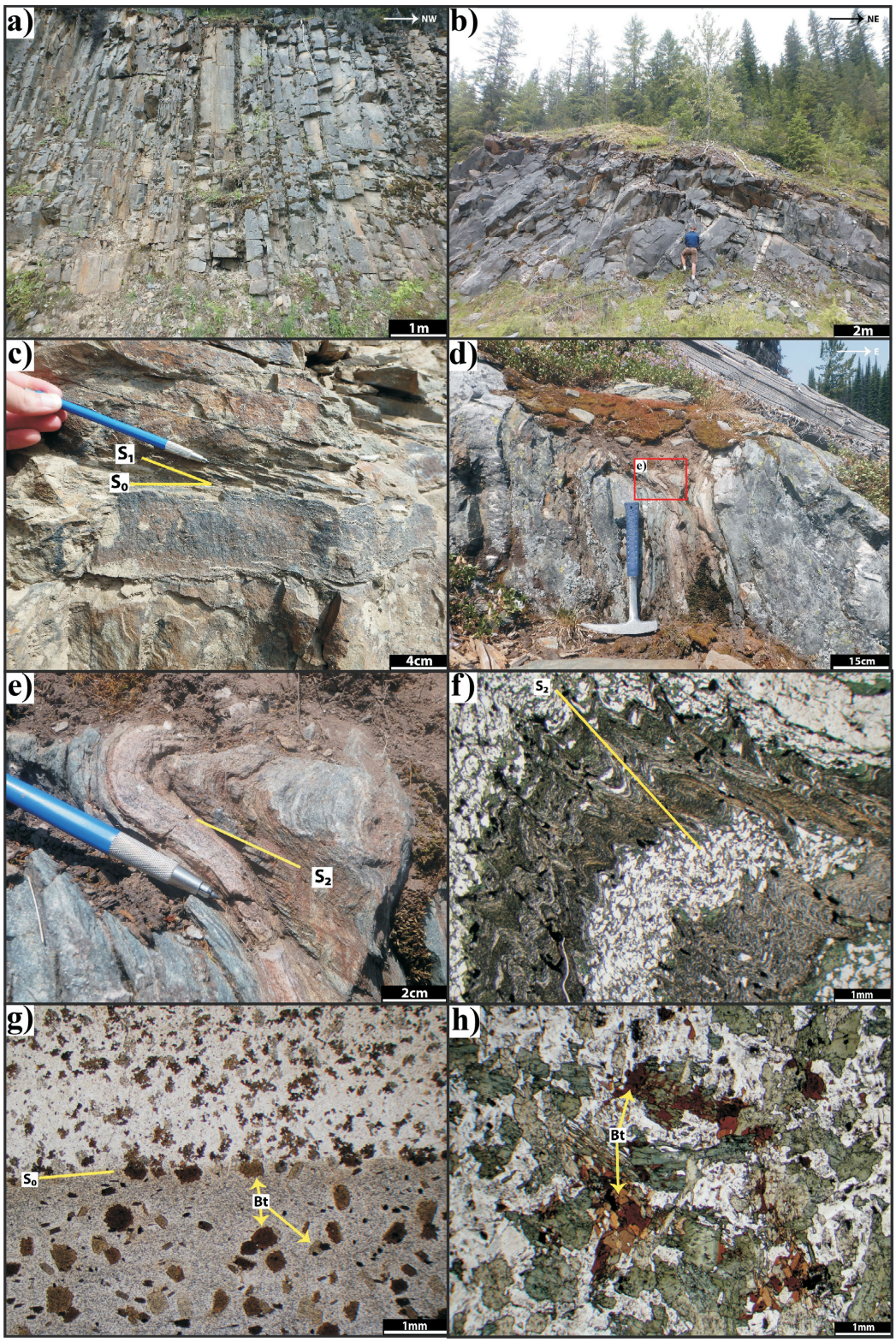

Figure 4. Photos and photomicrographs of representative units, structures and mineralogy in the study area: **a)** exposure of the Aldridge Formation from within the core of the Purcell Anticlinorium near Kitchener, BC; **b)** outcrop of a Moyie Sill as it appears within the core of the Purcell Anticlinorium near Creston, BC; **c)** S_1 cleavage developed within the pelitic interbeds of the Aldridge Formation near Yahk, BC; **d)** fold in rocks of the Windermere Supergroup along the western side of the Gray Creek transect; **e)** close-up of fold shown in part 4d, with an axial-planar S_2 cleavage; **f)** photomicrograph of small-scale fold and S_2 cleavage from the same locality as Figure 2d and e; **g)** photomicrograph of biotite-bearing rock of the Aldridge Formation from Mt. Olson, near Yahk, BC; **h)** photomicrograph of biotite in a Moyie Sill near St. Mary Lake.

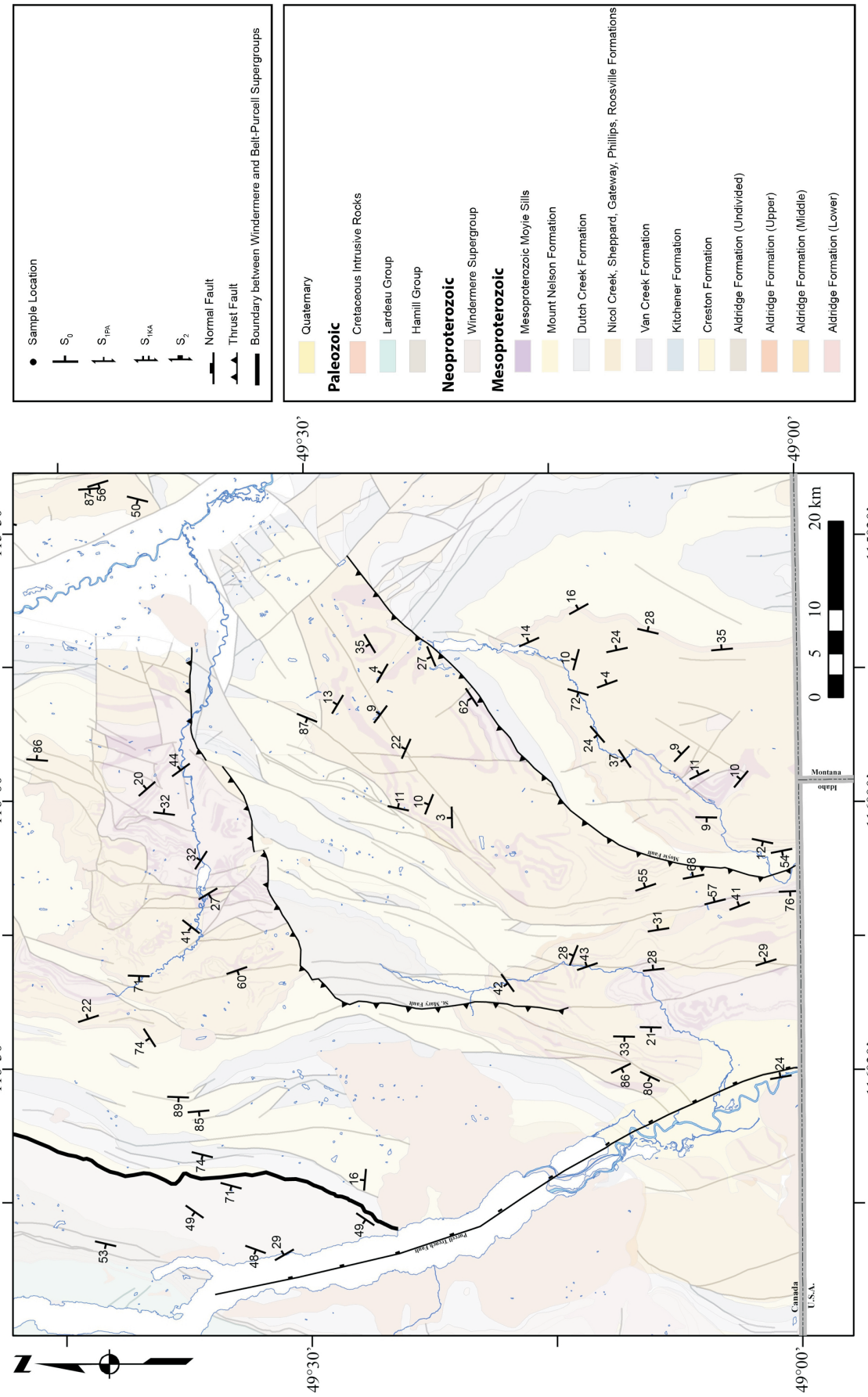

Figure 5. Bedding (S_0) orientations measured during the field season (geology after Höy et al., 1995).

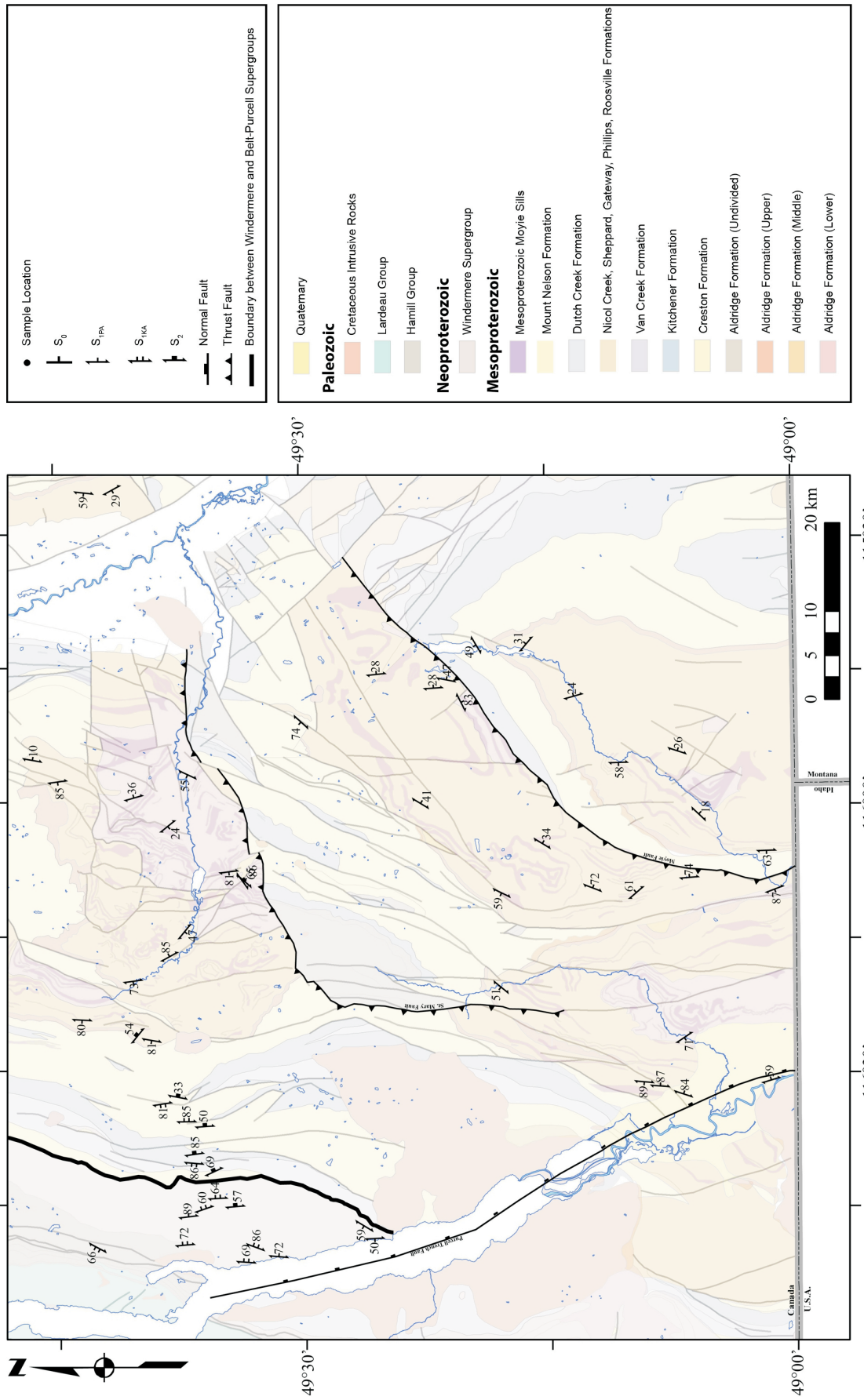

Figure 6. Fabrics S_{1PA} (one tick on symbol), S_{1KA} (two ticks on symbol) and S_{2KA} (thick tick on symbol) measured during the field season (geology after Höy et al., 1995).

mineral assemblages and microstructures that will bear on the variation in grade and timing of metamorphism, especially in the interface between the Purcell Anticlinorium and the Kootenay Arc; 2) microprobe work and X-ray mapping to constrain compositional variations in minerals; and 3) computer-based phase-equilibrium modelling for estimating metamorphic pressure and temperature conditions. Extensive studies of metamorphism within the Kootenay Arc by Moynihan and Pattison (2013) and Webster and Pattison (2017) will serve as the basis for comparison with results from this study. This comparison will aid in elucidating the nature of the metamorphic interface between the two tectonic domains.

Previous thermochronology work in both the Purcell Anticlinorium and the Kootenay Arc has assessed the cooling ages of muscovite, biotite and hornblende using both the K-Ar and Ar/Ar techniques. This study will also focus on the Ar/Ar ages of hornblende, muscovite and biotite east of the Purcell Trench fault, within the Purcell Anticlinorium. Thermochronological studies will focus primarily on biotite, which is present in both pelitic rocks of the Aldridge Formation and the gabbroic Moyie Sills. Figure 4g and 4h show examples of the appearance of biotite within the Aldridge Formation and Moyie Sills, respectively. Mineral separation for thermochronological work will take place during the fall of 2017 at the University of Calgary. Analytical work will take place in 2018 at the University of Manitoba under the guidance of A. Camacho. Biotite and muscovite cooling ages will be compiled on a map that can be compared with that for the Kootenay Arc in Figure 2. Variation in the metamorphic, structural and cooling history of these rocks will provide information on the nature of the tectonic interface between, and exhumation history of, the Purcell Anticlinorium and the Kootenay Arc.

The Purcell Anticlinorium and Kootenay Arc are both host to numerous mineral deposits that reflect the region's diverse geological history. An enhanced understanding of the structural, metamorphic and cooling history of the area will help to place further constraints on the genesis of these deposits. A deeper understanding of the nature of mineral diversity within the region will help to inform mineral exploration in the future.

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