Camp Creek Copper-Molybdenum-(Gold) Porphyry-Alteration Mineralogy and Geochemistry: Exploring for Blind Copper Mineralization in Northern British Columbia (NTS 104K/10W)

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Introduction

Porphyry Cu-Mo-(Au) deposits are a significant source of critical metals for technologies required to facilitate a transition toward electricity-based energy systems. Porphyry Cu deposits are the primary source of Cu globally, but the world-class discoveries needed to meet increasing demand are not being made. As most near-surface porphyries have likely been discovered, developing tools for exploring 'blind' subsurface porphyry deposits is vital to meet increasing global resource demand (Sillitoe, 2010).

The Intermontane Belt corresponds to the Intermontane Superterrane, which includes the Quesnel and Stikine island-arc terranes and the Cache Creek ocean-floor terrane (Mihalasky et al., 2010). This belt features postaccretionary porphyry Cu deposits of both calcalkaline porphyry Cu±Mo±Au and alkaline porphyry Cu-Au subtypes. The Camp Creek prospect is a calcalkalic porphyry Cu-Mo prospect located in the northwestern portion of the Canadian Cordillera of British Columbia (BC; Figure 1) with other intermontane island-arc porphyry Cu deposits, including the Highland Valley Copper Mine, the Gibraltar Mine and the Schaft Creek joint venture (Mihalasky et al., 2010). The Camp Creek prospect is part of the Thorn property, which is located approximately 94 km east of Juneau, Alaska, 120 km northwest of Telegraph Creek, BC and 130 km southeast of Atlin, BC (Figure 1a). In 2019, significant zones of porphyry-style veining with Cu and Mo mineralization were intersected at Camp Creek at depths of more than 300 m, with further drilling programs in 2021–2024 focused on discovering extensions of porphyry-style mineralization (Lemiski et al., 2023).

In the early 2000s, a project was initiated by the Mineral Deposit Research Unit (MDRU) at The University of British Columbia to investigate the late Cretaceous igneous complexes in the Taku River area of the Stikine terrane in northwestern BC. This study focused on characterizing intrusions and establishing a geochronology framework for the larger Thorn district (Simmons, 2005; Simmons et al., 2005). More recently, MDRU completed a further geochemical and petrographic study following the discovery of Camp Creek, using data collected in 2021, to help distinguish various intrusive phases at the deposit (Bouzari and Barker, 2021).

[1]*The lead author is a 2024 Geoscience BC Scholarship recipient.*

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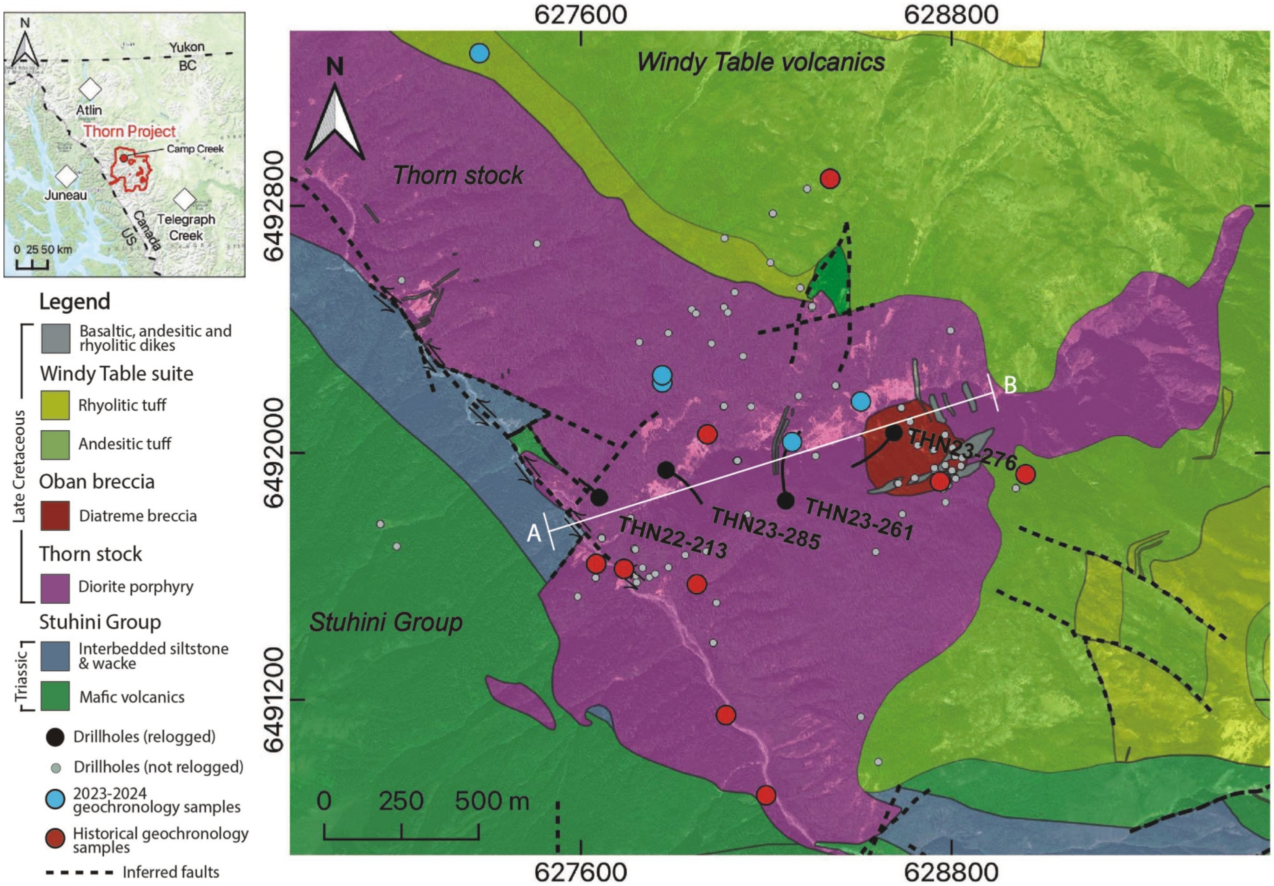

Figure 1. Simplified geology of the Camp Creek porphyry, part of the Thorn property in northwestern British Columbia. The location of the Thorn property is shown on the inset map, outlined in red. All co-ordinates are in UTM Zone 8N (NAD83).

This paper summarizes previous work, discusses preliminary field observations from fieldwork carried out in 2023–2024 and outlines next steps for the coming year. This project, part of the lead author's M.Sc. research, is undertaking the first major geological review of the Late Cretaceous calcalkalic Cu-Mo-(Au) Camp Creek porphyry prospect, focused on characterizing the alteration, mineralization and time scales of magmatism. Ongoing research is integrating petrography, micro X-ray fluorescence (micro-XRF) element mapping, shortwave infrared studies, whole-rock geochemistry and U-Pb geochronology, and will contribute insights into potential geochemical vectors for discovering blind porphyry Cu-Au-(Mo) mineralization.

Regional Geology

The Thorn property is located in the northwest-trending Stikine terrane, the largest and westernmost terrane of the Intermontane Belt in the Canadian Cordillera. The Stikine terrane comprises Triassic island-arc volcanic rocks and related sedimentary sequences of the Stuhini Group, with accretion of the Stikine Arc to western North America being assumed to have taken place in the Middle Jurassic at 172 Ma (Mihalynuk, 1999). Following accretion, Late Cretaceous igneous rocks were emplaced into the Stikine terrane as part of a continental arc, forming a north-northwest-trending belt that extends for 300 km from Yukon into northern BC (Mihalynuk, 1999; Simmons, 2005).

Two distinct periods of Late Cretaceous magmatism have been recognized at the Thorn property, the older magmatic pulse being informally referred to as the Thorn Stock, with exposure of this unit shown in Figure 1 in the study area (Mihalynuk, 1999; Simmons, 2005). The Thorn is composed of dominantly tholeiitic diorite porphyry intrusions, which are the major hostrocks for hydrothermal mineralizing systems at the Thorn property (Awmack, 2002; Simmons, 2005). The Thorn Stock has been constrained to an age of 93.3 ±2.4 Ma by U-Pb geochronology of zircon from multiple intrusions (Mihalynuk et al., 2003). The younger Windy Table suite was emplaced into the Thorn stock, and is characterized by subaerial, dominantly felsic volcanic rocks and associated calcalkaline, equigranular monzonite to granodiorite (Awmack, 2002). Windy Table suite volcanic rocks nonconformably overlie the Thorn stock (Figure 2). The tuff overlying this unconformity has a U-Pb SHRIMP-RG zircon age of 84.7 ±0.8 Ma, providing an age constraint for the onset of Windy Table volcanism (Simmons, 2005).

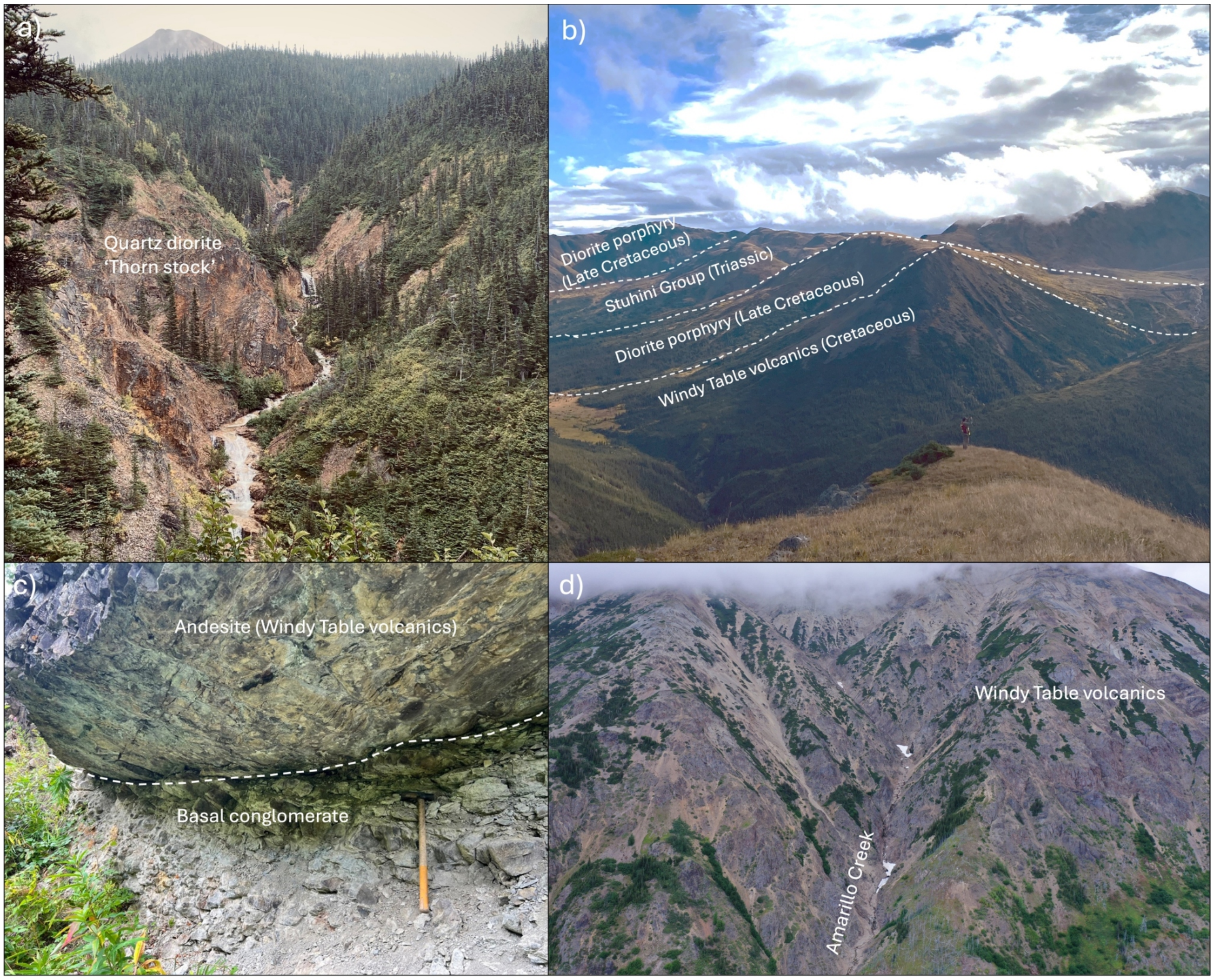

Figure 2. Camp Creek field area: **a)** Camp Creek looking northeast, highlighting quartz diorite (Thorn stock) outcrop; **b)** Camp Creek valley looking east; **c)** unconformity at the base of the Windy Table suite, previously sampled by Simmons (2005); **d)** Windy Table volcanic strata looking east.

Geology of the Camp Creek Property

Initial whole-rock geochemical analysis of core samples from Camp Creek by Bouzari and Barker (2021) revealed the occurrence of at least five porphyry units. These units are geochemically distinct from the Stuhini volcanosedimentary hostrocks, which are characterized by high Sc (>10 ppm). These porphyry units have been termed X, Y, Z, W and V, and are distinguished by different ratios of several trace elements, including Zr, Ti and Sc, as seen in Figure 3. Petrography by Bouzari and Barker (2021) provided an initial correlation between mineralogy and geochemistry, providing preliminary criteria for characterizing and distinguishing each of the porphyry units. Representative hostrock samples from drillcore were collected by the author during 2023–2024 fieldwork for further geochemical analysis to improve the previously established characteristics. Examples are shown in Figure 4 and field observations are summarized in the following section. The effective subdivision of the porphyry stocks is critical to refine the geological model of Camp Creek and to understand grade distribution.

Volcanosedimentary Units (Stuhini Group)

The Stuhini Group hostrock at Camp Creek contains siltstone and mafic volcanic rocks with pervasive biotite alteration. It is exposed at surface to the southwest of the study area and is typically first intersected at depths of 500–700 m at Camp Creek. Bedding is occasionally preserved and the unit is crosscut by an intense quartz-vein stockwork when proximal to porphyry X.

Porphyry Z

Porphyry Z is a quartz-biotite-hornblende-plagioclase porphyry. Diagnostic features of porphyry Z include abundant medium-grained hornblende phenocrysts, medium- to coarse-grained biotite and 1–4 mm rounded quartz pheno-

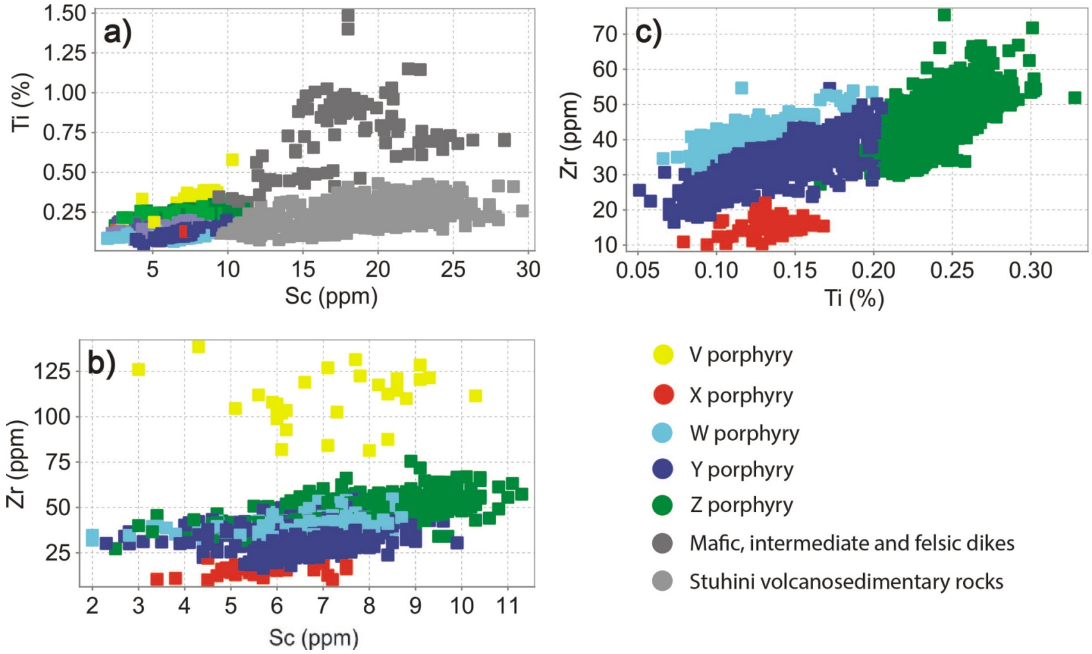

Figure 3. Classification of hostrocks at Camp Creek based on Zr, Ti and Sc trace-element data from whole-rock geochemical analysis: **a)** Sc versus Ti; **b)** Sc versus Zr; **c)** Ti versus Zr (Bouzari and Barker, 2021; reproduced with permission).

crysts. Biotite phenocrysts are 1–4 mm, typically coarse and commonly replaced by fine-grained sericite and rutile. Hornblende is the next most abundant phase after plagioclase, typically tabular and commonly replaced by chlorite. Porphyry Z is distinguished by its high Ti (>0.2%) and Nb (>5 ppm; Bouzari and Barker, 2021), and is the least altered and mineralized of the porphyry phases, dominantly pyrite (1–5%) with trace chalcopyrite (<0.1%).

Porphyry Y

Porphyry Y is a hornblende-quartz-biotite-plagioclase porphyry and is mineralogically and texturally similar to porphyry Z but with significantly less hornblende phenocrysts. Porphyry Y typically has stronger alteration and contains higher amounts of sulphide (5–10%) and Cu grades (>0.1%) when compared to porphyry Z. Geochemically, porphyry Y has lower Ti (<0.2%) and lower Zr (<40 ppm) than porphyry Z (Bouzari and Barker, 2021). Porphyry W was originally distinguished by slightly elevated Zr contents compared to porphyry Y, but is mineralogically and texturally indistinguishable and has been classified as part of porphyry Y during core logging. There were no clear crosscutting relationships observed between porphyries Y and Z.

Porphyry X

Porphyry X is a hornblende-quartz-biotite-plagioclase porphyry. Diagnostic features include coarse biotite books, quartz-rich groundmass and strong K-feldspar alteration, dominantly within the groundmass. It is cut by a stockwork of A-type granular quartz veins and has the highest concentration of Cu mineralization among intrusive units (>0.2%). Geochemically, porphyry X is distinguished by its low Zr (<20 ppm) relative to porphyries Y and Z (Bouzari and Barker, 2021). No clear crosscutting relationships were observed between porphyry X and porphyries Y and Z.

Porphyry V

Porphyry V is a biotite-hornblende-plagioclase porphyry, typically occurring as smaller dikes that crosscut porphyries Z, Y and X. Diagnostic features include fresh to weakly altered biotite phenocrysts, 3–5% disseminated magnetite and rare quartz phenocrysts. It is weakly altered and contains trace pyrite but no Cu-bearing mineralization. Geochemically, porphyry V is characterized by its high Zr concentration (>75 ppm), which is significantly higher than the other porphyry phases observed at Camp Creek (Bouzari and Barker, 2021). Clear crosscutting relationships were observed between porphyry V and porphyries Z, Y and X.

Polymictic Diatreme Breccia (Oban breccia)

The Oban zone is a porphyry-related diatreme breccia hosting polymetallic (Ag-Au-Pb-Zn-Cu) mineralization within the breccia matrix. The Oban breccia varies significantly, and typically contains subangular and well-rounded fragments of fine- to medium-grained quartz-diorite porphyry with altered biotite-feldspar-quartz phenocrysts. Porphyry clasts host quartz veins with remnants of K-feldspar alteration that resemble A-type quartz veins, which suggests the presence of porphyry mineralization at depth. Weakly al-

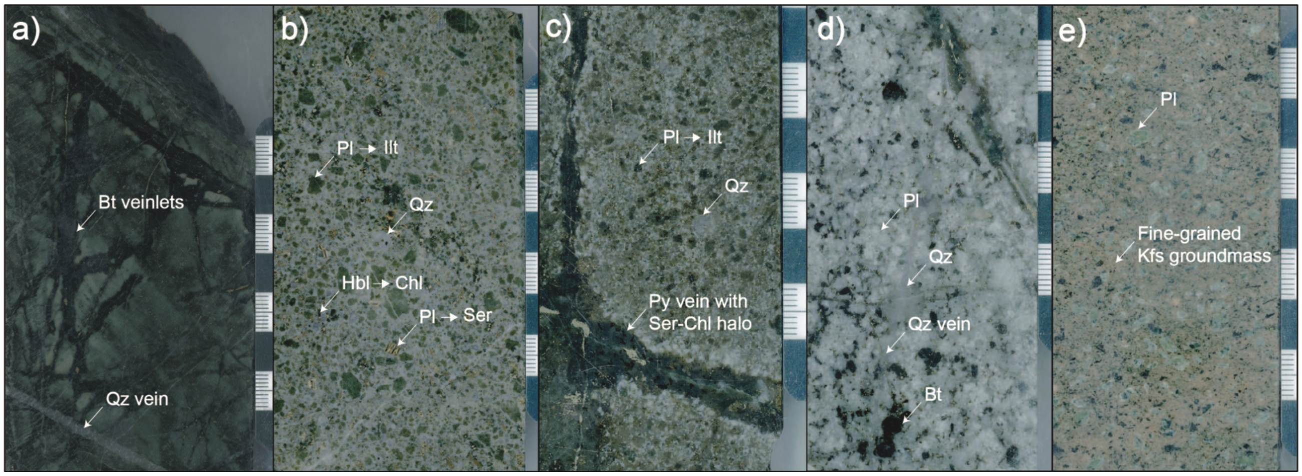

Figure 4. Examples of hostrocks observed at Camp Creek, with corresponding scale card shown to the right of each sample: **a)** siltstone with pervasive and veinlet-controlled biotite alteration overprinted by chlorite and sericite, THN23-261 841.20 m; **b)** quartz-biotite-hornblende-plagioclase porphyry (porphyry Z) with pervasive and phenocryst-replacement sericite alteration, THN23-277 348.60 m; **c)** hornblende-quartz-biotite-plagioclase porphyry (porphyry Y) with pervasive and phenocryst-replacement sericite alteration, overprinted by chlorite, THN23-276 875.25 m; **d)** hornblende-quartz-biotite-plagioclase-porphyry (porphyry X) with pervasive K-feldspar alteration and quartz-vein stockwork, THN23-276 1235.80 m; **e)** biotite-hornblende-plagioclase porphyry (porphyry V), THN22-201 845.97 m. Mineral abbreviations: Bt, biotite; Chl, chlorite; Hbl, hornblende; Ilt, illite; Pl, plagioclase; Py, pyrite; Qz, quartz; Ser, sericite.

tered volcanic and sedimentary clasts are hosted within rock flour, and fractures are commonly filled with sulphides and sulphosalts. Generally, the contact of the Oban diatreme breccia with the hostrock is poorly constrained. Dominant alteration minerals include sericite and pyrophyllite with minor diaspore, suggesting shallower depths of a porphyry environment. The breccia is heterogeneously altered and locally contains fragments that have variable degrees of sericite-pyrophyllite-diaspore alteration (Lemiski et al., 2023). Minerals such as pyrophyllite and diaspore indicate an initially hot, acidic hydrothermal system on the order of 250 °C or greater (Hedenquist et al., 2000; Simmons, 2005).

Alteration

Observations from drilling in the Camp Creek porphyry indicate multiple distinct types of alteration that are evident in the classic porphyry-alteration model of Sillitoe (2010). At Camp Creek, pyrophyllite with rare diaspore occurs at the roots of the preserved advanced argillic zone (see Figure 5), with residual quartz and quartz-kaolinite occurring at higher levels. Zones of advanced argillic alteration occur in the upper part of porphyry Cu deposits that can form a large near-surface footprint of the hydrothermal system, providing a vectoring tool toward concealed porphyry Cu mineralization at depth (Bouzari et al., 2022). A challenge to establishing alteration zoning is the subtle mineralogical changes across porphyritic units that can be difficult to identify (Bouzari et al., 2022). MicroXRF is an effective tool to gauge modal abundances and review mineralogy by element mapping, particularly when phases are difficult to distinguish by eye. Based on previously analyzed short-wave infrared (SWIR) data, a variety of downhole alteration trends and observations is shown in Figure 5 (from Bouzari et al., 2023).

Sericite alteration increases in intensity with depth, being weaker in porphyry Z and typically increasing in porphyry Y before transitioning to a dominantly K-silicate alteration in porphyry X (Bouzari et al., 2023). Sericitic assemblages are typically classified by a quartz-sericite-pyrite assemblage, which transitions into zones of intense chlorite replacement of biotite and hornblende with depth. K-silicate alteration is classified by pervasive fine-grained K-feldspar alteration (Figure 6), common 1–3 mm K-feldspar haloes and occasional biotite alteration. Propylitic alteration is characterized by abundant epidote and chlorite occurring distally to Camp Creek.

Mineralization

Camp Creek is a blind porphyry target, and exploration drilling intersected porphyry-style mineralization in 2019. Drill programs from 2021 to 2024 aimed to push holes beyond 1000 m depth, targeting deeper Cu-Au-Ag-Mo mineralization (Lemiski et al., 2023). Copper mineralization is predominantly hosted by a coarse-grained feldspar-quartz-biotite porphyry, with intervals of Stuhini intermediate volcanic and sedimentary rocks. Porphyry-type vein density, following the model of Gustafson and Hunt (1975), increases gradually with depth. An example interval with higher grade mineralization occurred in hole THN22-201 from 335 m to 1302.71 m, with 967.71 m of 0.25% Cu, 0.09 g/t Au, 2.39 g/t Ag and 186 ppm Mo (Lemiski et al., 2023). Mineralization assemblages comprise mainly chalcopyrite, pyrite and molybdenite within porphyry-style

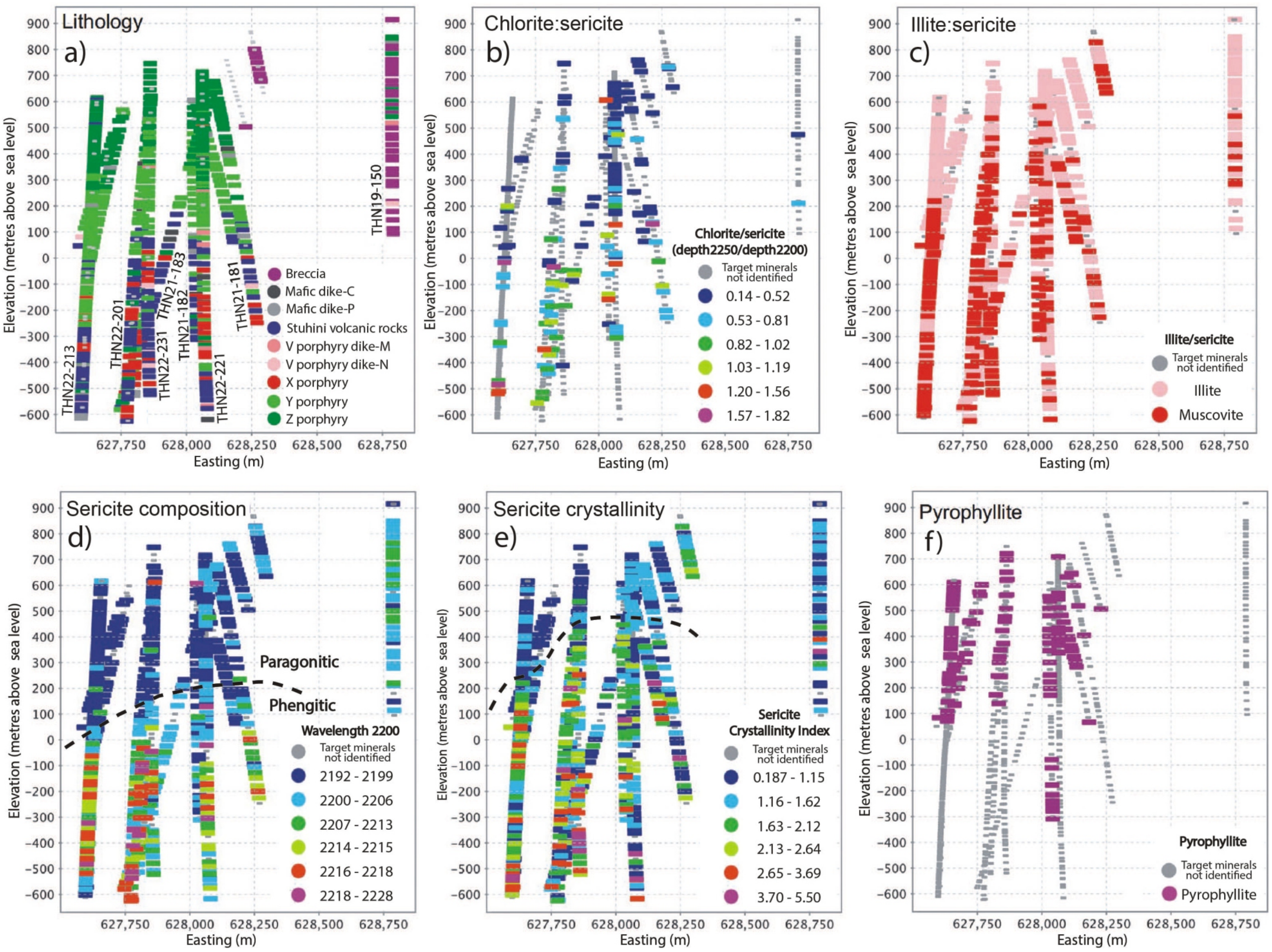

Figure 5. Downhole shortwave infrared data on drillcore samples collected in 2019–2022, plotted along northward-facing drillcore cross-sections (also shown is the corresponding location of the cross-section shown in Figure 1 [modified from Bouzari et al., 2023]): **a)** lithology; **b)** chlorite to sericite ratio, showing the relative abundance of chlorite to sericite using the spectral depth of the minerals; **c)** illite to sericite ratio, with muscovite abundance increasing with depth relative to illite; **d)** sericite composition, dominated by paragonite illite near surface and transitioning to illite and then phengitic illite with depth; **e)** sericite crystallinity increasing with depth toward zones of K-silicate alteration; **f)** pyrophyllite occurring at shallow levels with rare diaspore.

quartz and quartz-anhydrite veins, as well as disseminated sulphides.

Sampling and Analytical Work

Detailed observations of, and sample selection for, further geochemical analysis were completed over two summer field seasons in 2023 and 2024. Four drillholes were relogged to capture additional information on mineralogy, alteration, veining and crosscutting relationships (Table 1). Detailed observations in drillcore have been recorded following logging advice from Williams (2022), aiding in the consistent characterization of intrusive units. As of October 2024, 40 samples have undergone whole-rock geochemical analysis. From this sample set, 20 were selected for petrographic analysis. MicroXRF analysis was completed on 14 samples to assess zircon content prior to U-Pb geochronology and hostrock classification. Four samples of postmineral dikes, each of approximately 2 kg, were submitted for U-Pb geochronology.

More than 400 rocks were sampled from drillcore for follow-up analysis. The majority of these samples have been collected at 50 m intervals to be sent for whole-rock geochemical analysis and thin-section preparation. These samples came from the least-altered sections with the least quartz veining and will be used to understand downhole trends and assist in distinguishing intrusive phases. A short fieldwork stint in August 2024 focused on investigating the unconformity between the Thorn stock and the overlying Windy Table volcanics, with three samples collected for U-Pb geochronology (locations in Figure 1). A complete suite of Shortwave Infrared (SWIR) data has been gathered for 14 prioritized drillholes at Camp Creek, and further work will aim to constrain previously identified zones of alteration.

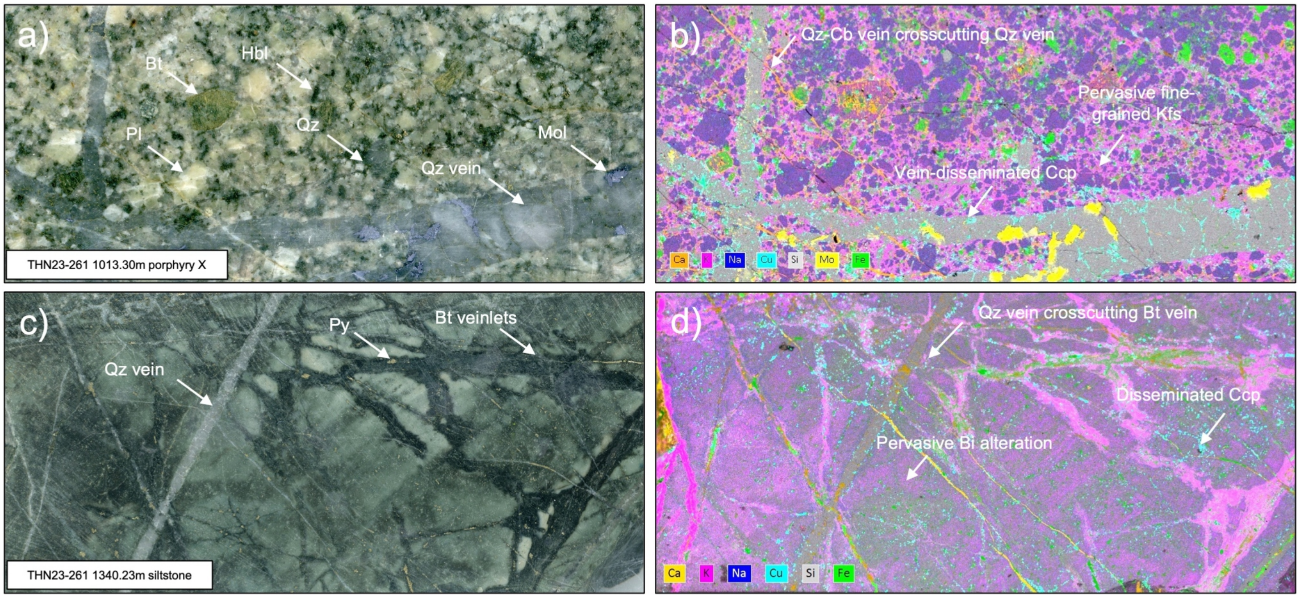

Figure 6. Flatbed optical scans and microXRF element maps of hostrocks at Camp Creek: **a)** scan of porphyry X at 1013.30 m in drillhole THN23-261; **b)** microXRF element map of porphyry X at 1013.30 m in drillhole THN23-261, with a legend showing elements and their corresponding colours; **c)** scan of siltstone at 1340.23 m in drillhole THN23-261; **d)** microXRF element map of siltstone at 1340.23 m in drillhole THN23-261, with a legend showing elements and their corresponding colours; Mineral abbreviations: Bt, biotite; Pl, plagioclase; Hbl, hornblende; Qz, quartz; Mol, molybdenite; Py, pyrite; Ccp, chalcopyrite; Cb, carbonate.

Future Work

Ongoing studies will utilize a range of techniques to investigate the evolution of the Camp Creek porphyry prospect. A subsequent detailed petrographic study will provide insight into the textural, mineralogical and alteration variations of the different porphyry phases downhole. Additional samples have been selected for whole-rock geochemistry, and a complete geochemical analysis will be performed on the collected data. Further SWIR data will be processed to build an understanding of the alteration model. More microXRF scans will be collected from existing samples to gain insight into modal abundance of mineralogy and textural relationships. Further U-Pb dating will be completed for intrusive phases, to better constrain the timing and formation of the porphyry stocks at Camp Creek. Research outputs will focus on establishing the evolutionary model of the system, as well as developing an alteration model of the different porphyry phases.

This project will inform mineral-exploration development by adding vectoring tools to assist in more efficient exploration programs, enabling more effective exploration of subsurface cryptic and ‘blind’ mineralization that may constitute future high-grade Cu-Mo-(Au) discoveries. Feasible programs may help to boost investment in British Columbia’s mineral-exploration industry and enable more rapid, cost-effective exploration across the province. Furthermore, understanding the geometry of these porphyries and the spatial association of intrusive phases can help predict where mineralizing phases are likely to be encountered at the deposit scale, increasing the likelihood of exploration success. Alteration footprints can be linked to multiple porphyry phases and help distinguish the paragenetic evolution of intrusive phases at Camp Creek.

Conclusions

Mineralization is hosted primarily as disseminated and vein-hosted chalcopyrite in porphyry X, as well as siltstone and mafic volcanic rocks of the Stuhini Group. Porphyry Z has the weakest sericite alteration, transitioning to more intense sericite alteration and overprinting chlorite alteration in porphyry Y, and weak sericite alteration in shallower zones

Table 1. Diamond-drill hole data for THN22-213, THN23-161, THN23-276 and THN23-285 (Lemiski et al., 2023). All co-ordinates are in UTM Zone 8N (NAD83).

Drillhole ID	Year Completed	Easting	Northing	Azimuth (°)	Dip (°)	Depth (m)
THN22-213	2022	627659.34	6491855.06	319.72	-85.21	1243
THN23-261	2023	628263.704	6491844.726	353	-81	1650
THN23-276	2023	628613.622	6492065.301	216	-82	1470
THN23-285	2023	627876	6491944	110	-84	1602

of porphyry X. These porphyry units overlap in time, based on U-Pb dating, and further analytical work will be needed to resolve uncertainties on timing. Additionally, crosscutting relationships do not provide information on the relative ages of porphyries Z, Y and X through evidence gathered to date. Porphyry V clearly postdates porphyries Z, Y and X, with observed postmineral dikes clearly postdating all other intrusive phases. SWIR data show multiple alteration zones, with mineralogy dominated by pyrophyllite at shallow levels, transitioning to illite and then muscovite at greater depths, and eventually to K-feldspar in porphyry X. Future characterization work will aim to constrain field observations by detailed petrography, additional SWIR analysis and geochemical analysis.

Acknowledgments

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