Critical companion metals in porphyry deposits in British Columbia: Lithogeochemistry and scanning electron microscopy-mineral liberation analysis (SEM-MLA) from the Schaft Creek, Mount Polley, and New Afton deposits

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Abstract

Porphyry deposits are major sources of Cu, Au, Ag, and Mo and provide many critical metals as byproducts (e.g., Sb, Bi, Te). British Columbia is Canada's largest producer of Cu and only producer of Mo, which occur in porphyry Cu ±Mo ±Au, alkalic Cu-Au, and low-F type Mo ±Cu porphyry deposits. However, the potential for production of critical companion metals from these deposits is poorly understood. Here we present new lithogeochemistry and scanning electron microscopy-mineral liberation analysis (SEM-MLA) results from three Late Triassic porphyry Cu-Au-Ag ±Mo deposits: Schaft Creek, Mount Polley, and New Afton. At Schaft Creek, geochemical data and mineralogy reveal enrichments in Bi and Te that correlate with observed Bi-Te tellurides, native alloys, sulphosalts, and sulphides. The New Afton and Mount Polley alkalic Cu-Au deposits exhibit enrichment of platinum-group elements (PGE), Re, and Te. Enrichment of PGE, particularly Pd, is highest at New Afton, where platinum group minerals (PGM) are identified by quantitative mineralogy. A comparison of geochemical data with similar data from five additional deposits demonstrates variations in critical metal assemblages between subtypes of porphyry deposits in British Columbia.

Keywords: Au-rich porphyry, New Afton, Schaft Creek, Mount Polley, critical minerals, companion metals

1. Introduction

British Columbia is Canada's largest producer of Cu and only producer of Mo, both of which are currently mined exclusively from porphyry deposits (Hickin et al., 2024). Metals that are produced as byproducts are considered 'companion metals' and many are on the critical minerals lists of Canada and allied jurisdictions (Mudd et al., 2014, 2017; Nassar et al., 2015; Hickin et al., 2024; NRCan, 2024). Globally, critical companion metals in porphyry deposits can include Re, Te, W, Sn, Sb, Bi, In, Nb, PGE, and rare earth elements (REE; John and Taylor, 2016; Hofstra and Kreiner, 2020). Although critical companion metals typically occur in relatively low concentrations in mined ore, their production can be feasible due to the large volumes extracted from porphyry deposits (John and Taylor, 2016; Lawley et al., 2025). Positive spatial and mineralogical correlations of potential byproduct metals with primary commodities (Cu, Au, Ag, Mo) increases the likelihood of economically feasible recovery (Mudd et al., 2014). Currently, the potential for production of critical companion metals from porphyry deposits in British Columbia is not well understood, in part due to a lack of information on the concentrations and deportment of these metals (e.g., Lawley et al., 2025).

This study presents new lithogeochemistry and scanning electron microscopy-mineral liberation analysis (SEM-MLA) results from the Schaft Creek Cu-Au-Mo-Ag deposit, and the Mount Polley and New Afton Cu-Au-Ag deposits (Late Triassic; Fig. 1). We compare the geochemical results to data from the Galore Creek (Lawley et al., 2025), Huckleberry and Berg (Orovan et al., 2025), and Kitsault (Orovan et al., 2024) porphyry deposits, and the E&L mafic magmatic Ni-Cu-PGE deposit (Fig. 2; Brzozowski and Zaborniak, 2024; Lawley et al., 2025). This comparison demonstrates variations in critical metal contents between deposit subtypes, which can be used to inform where opportunities may exist for economically viable companion metal production.

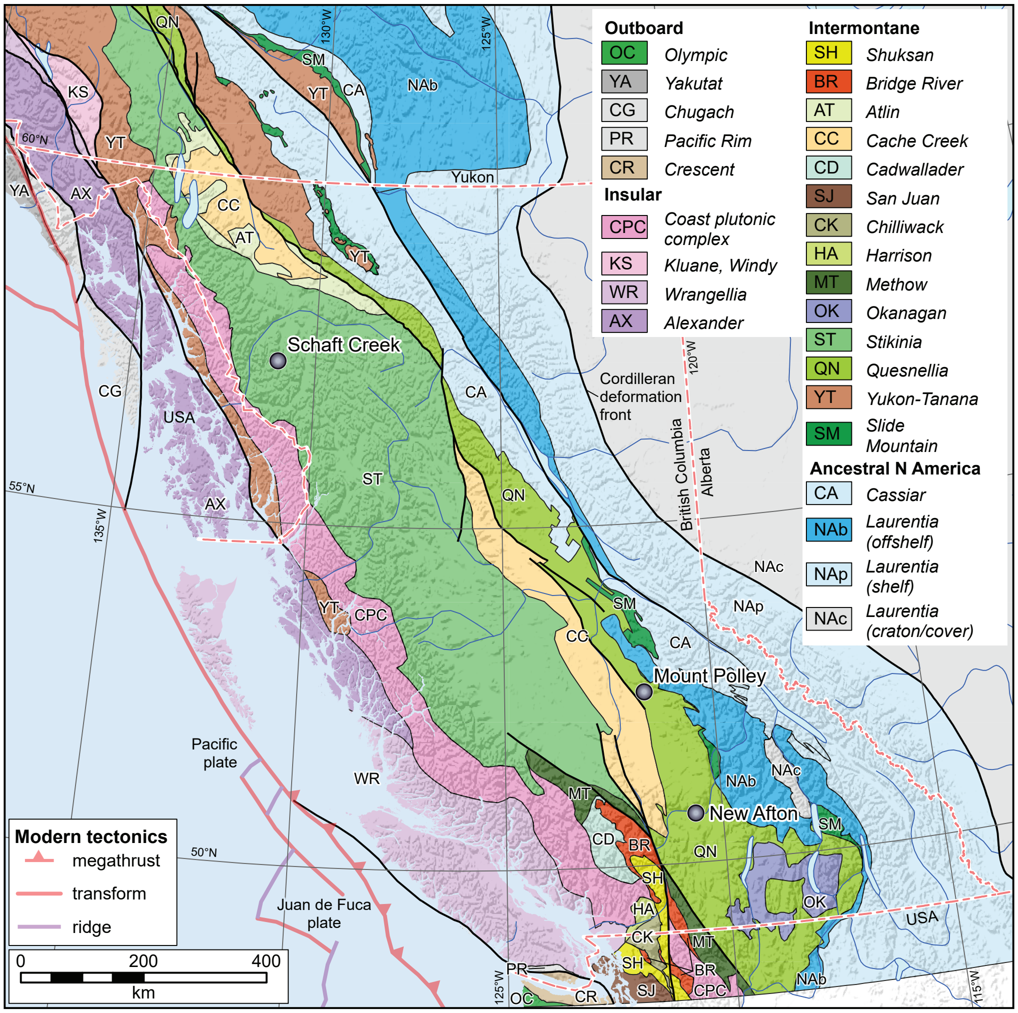

Fig. 1. Locations of Mount Polley, New Afton, and Schaft Creek deposits. Terranes after Colpron (2020).

2. Metal enrichments in magmatic and magmatic-hydrothermal environments

Mineral deposits formed in magmatic and magmatic-hydrothermal environments can be classified into mineral systems and deposit types with distinct metal assemblages (Fig. 3; e.g., Hofstra and Kreiner, 2020; Hofstra et al., 2021). Mafic magmatic mineral systems host various types of mafic-ultramafic intrusion-hosted deposits (Fig. 3). These deposits typically form at continental rifts where minerals containing Ni, Cu, Fe, Ti, Cr, and PGE crystallize from immiscible liquids in layered intrusions and conduits (Hofstra and Kreiner, 2020; Hofstra et al., 2021). Less commonly, magmatic Ni-Cu-PGE deposits form at convergent margins or supra-subduction/post-subduction settings (Manor et al., 2016; Nixon et al., 2020). Orthomagmatic Ni-Cu-PGE mineralization in Alaskan-type (i.e., devoid of orthopyroxene) mafic-ultramafic intrusive complexes form an important subclass of arc-related magmatic deposits in British Columbia (Nixon et al., 2019, 2020). Other arc-related magmatic Ni-Cu deposits (e.g., Manor et al., 2016) are classified as tholeiitic-related Ni-Cu-Co (e.g., E&L deposit; Brzozowski and Zaborniak, 2024; British Columbia Geological Survey, 2026).

Porphyry mineral systems typically form in upper crustal magmatic-hydrothermal environments and include porphyry, skarn, epithermal, and replacement deposits (e.g., Hofstra and Kreiner, 2020; Fig. 3). The peripheral deposits (e.g., skarn) can vary widely in metal content and may include critical metals (e.g., Co, Te, W, Sn, In, Ge) in potentially economic concentrations (e.g., Hofstra and Kreiner, 2020; Hickin et al., 2024).

2.1. Metal enrichments in porphyry deposits

Porphyry deposits have been classified according to magmatic affinity (i.e., alkaline or calc-alkaline; Lang et al., 1995; Logan and Mihalynuk, 2014) and by the assemblages of primary commodities Cu, Au, Mo, and Sn (Fig. 3; McMillan et al., 1996; Seedorf et al., 2005; Osatenko et al., 2020). Herein we distinguish between porphyry Mo (±Cu), porphyry Cu ±Mo ±Au, and alkalic Cu-Au deposits, for consistency with some current critical minerals research and MINFILE, the provincial

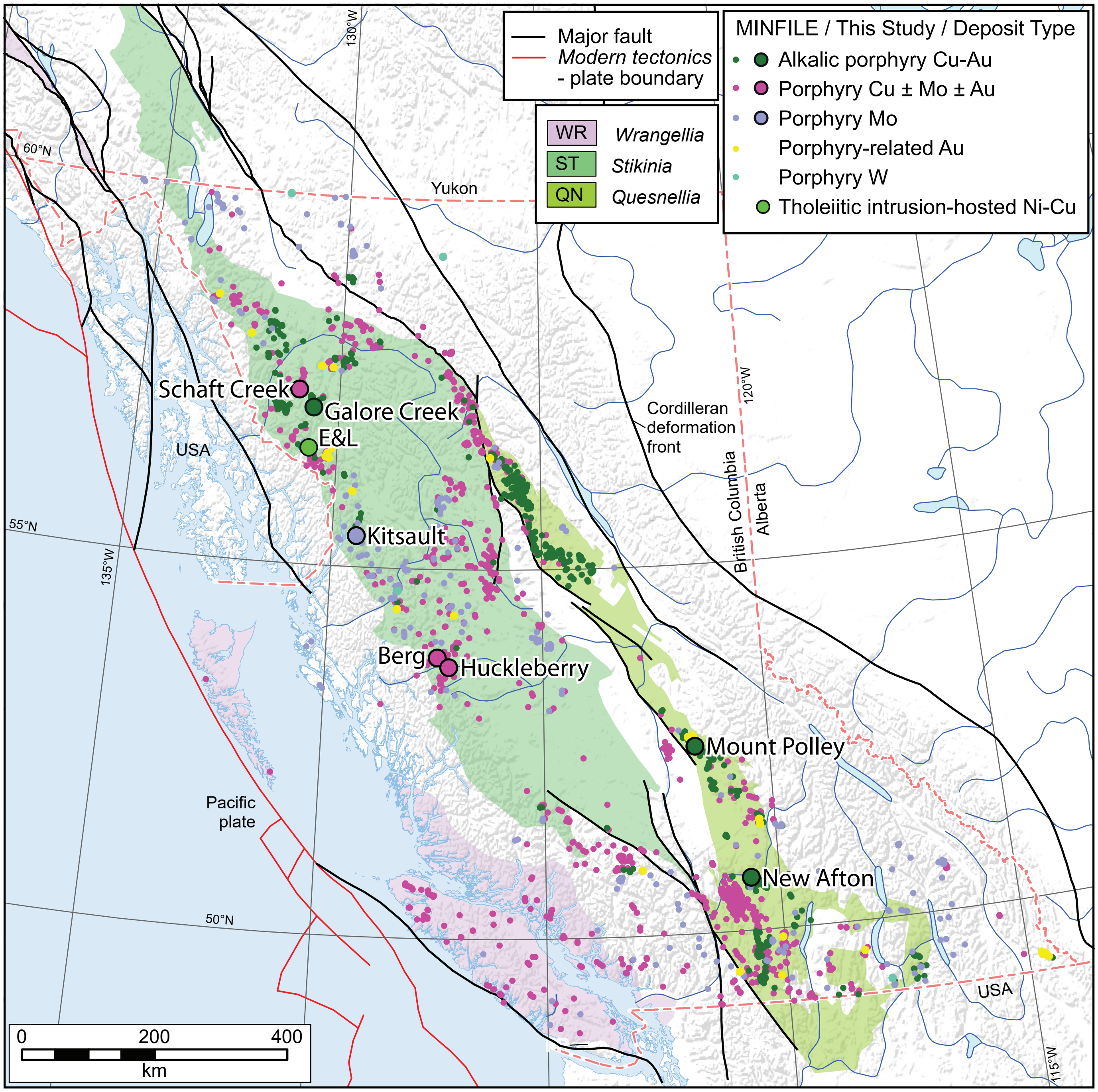

Fig. 2. Locations of deposits discussed herein and porphyry-type occurrences of different deposit sub-types in Quesnel, Stikine, and Wrangell terranes from MINFILE database (British Columbia Geological Survey, 2026). Terranes after Colpron (2020).

mineral occurrence inventory (British Columbia Geological Survey, 2026).

Globally, porphyry Cu ±Mo ±Au deposits are commonly enriched in Te, Re, U, PGE, Sc, Co, and Bi; alkalic porphyry Au ±Cu deposits can contain Bi, Te, and PGE (John and Taylor, 2016; Hofstra and Kreiner, 2020). Porphyry Mo deposits are commonly enriched in Sn, Re, REE, Sc, and W (Sinclair, 2007; Singer et al., 2008; Hofstra and Kreiner, 2020).

Silver is a common co-product of all types of porphyry Cu deposits, where it typically resides in solid solution in chalcopyrite and bornite (John and Taylor, 2016). Rhenium typically occurs as a solid solution in molybdenite and is concentrated in the upper portions of some continental arc deposits (John and Taylor, 2016). Where concentrations of Zn are present, they typically occur in argillic alteration zones at upper and outer parts of deposits and in late-stage veins (John and Taylor, 2016;

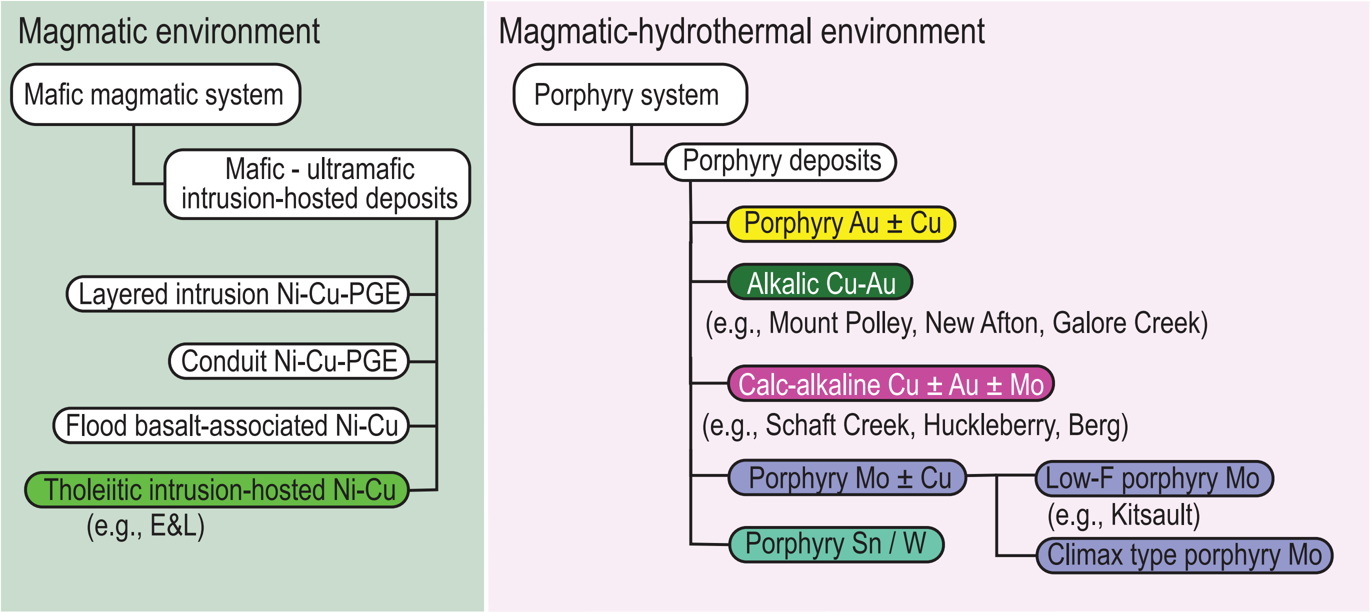

Fig. 3. Selected mineral systems and deposit types in the magmatic and magmatic-hydrothermal mineralizing environments. Deposit types discussed herein are coloured as in Figure 2. Simplified after Hofstra and Kreiner (2020), Hofstra et al. (2021), and British Columbia Geological Survey (2026).

Halley, 2020). Platinum group elements can form potentially economic byproduct concentrations in solid solution in hypogene bornite (Thompson et al., 2001), Ni-Co-rich pyrite (Boucher et al., 2023; Robb et al., 2023), or as discrete platinum group minerals (PGM) in late-stage hydrothermal veins (LeFort et al., 2011; Eliopoulos et al., 2014). Enrichment of PGE is commonly paragenetically associated with a complex semi-metal assemblage and is more common in porphyry deposits formed in island arc environments associated with alkaline magmas (Eliopoulos et al., 2014; McFall et al., 2021; Karatas Ahmadli, 2025).

3. British Columbia porphyry deposits

3.1. Geologic setting

Most porphyry deposits in British Columbia were formed either: 1) in the Late Triassic through Middle Jurassic in Stikine terrane (Stikinia), Quesnel terrane (Quesnellia), and Wrangell terrane (Wrangellia) island arcs before or during their accretion to Ancestral North America; or 2) in the Cretaceous through Eocene, after accretion of the Insular superterrane to the Intermontane superterrane (Figs. 1, 2; Nelson and Colpron, 2007; Nelson et al., 2013; Logan and Mihalynuk, 2014; Colpron et al., 2022).

The Stikine and Quesnel island arc terranes are thought to share similar Devonian through Early Jurassic histories (Nelson and Colpron, 2007; Nelson et al., 2013; Logan and Mihalynuk, 2014). The oldest island arc volcanic and coeval intrusive rocks are Devonian to Permian and are now preserved as the stratigraphic basement to Stikinia (Stikine assemblage, e.g., Logan and Koyanagi, 1994) and Quesnellia (e.g., Lay Range assemblage, Asitka Group; Ootes et al., 2022a, b). The second major episode of arc magmatism was during the Late Triassic, forming the mafic to intermediate volcanosedimentary (e.g., Stuhini Group in Stikinia; Takla Group and Nicola Group in Quesnellia) and allied plutonic rocks that commonly host porphyry deposits (Logan and Mihalynuk, 2014). Late Triassic to Early Jurassic magmatism followed, resulting in deposition of Hazelton Group volcanosedimentary rocks in Stikine terrane (e.g., Nelson and Colpron, 2007; Nelson et al., 2018).

During the Cretaceous, the orogen was subjected to crustal shortening and transpression, and intrusions with local porphyry Cu ±Mo mineralization were emplaced in deformation zones (Nelson et al., 2013). Porphyry Mo (±Cu) deposits associated with crustal extension-driven magmatism formed during the Eocene (e.g., Gehrels et al., 2009).

3.2. Mineralization characteristics and metal enrichments

Most porphyry deposits in British Columbia have been classified based on magmatic affinity and metal contents as porphyry Cu ±Mo ±Au, alkalic Cu-Au, or low-F Mo deposits (Osatenko et al., 2020; British Columbia Geological Survey, 2026). Herein we refer to deposits as 'pre-accretionary' (formed in an island arc setting) and 'post-accretionary' (formed in a continental setting).

During the Late Triassic through Early Jurassic, both alkalic Cu-Au and Cu ±Mo ±Au deposits formed in Quesnel and Stikine terranes (Figs. 1-3). A particularly prolific epoch of porphyry deposit formation was during an approximately 15-million-year period spanning the Triassic-Jurassic boundary (Logan and Mihalynuk, 2014). Porphyry Cu ±Mo ±Au deposits that formed during this time are typically associated with calc-alkaline magmatism, exhibit potassic, phyllic, and propylitic alteration assemblages and mineralization styles including hypogene quartz-sulphide vein stockwork (Logan and Mihalynuk, 2014; Lawley et al., 2025). They commonly host Ag and Mo coproducts, but little is known about potential critical mineral byproducts (e.g., Lawley et al., 2025).

The alkalic Cu-Au porphyry deposits typically display early, predominantly magnetite alteration near a potassic (K-feldspar-biotite-magnetite) core, and peripheral calc-potassic (garnet-diopside-biotite-K-feldspar) and calc-sodic (albite-diopside) alteration. These deposits contain Au-rich metal assemblages, and geologic features (e.g., hydrothermal breccias and dike swarms) implying relatively shallow (i.e., subvolcanic) formation (Tosdal et al., 2009; Murakami et al., 2010; Osatenko et al., 2020; Chiaradia, 2021; Thompson et al., 2021). A subset of these deposits is associated with silica-undersaturated magma series (e.g., Galore Creek; Lang et al., 1995; Thompson et al., 2001). Previous workers identified significant enrichment of PGE (100s of ppb to 10s of ppm locally), particularly Pd, in many of British Columbia's Cu-Au porphyry deposits (Thompson et al., 2001; Nixon, 2004; LeFort et al., 2011; Hanley et al., 2020; Boucher et al., 2023; Robb et al., 2023; Karatas Ahmadli, 2025).

Post-accretionary porphyry deposits include Cretaceous Cu-Mo ±Au (e.g., Huckleberry) and Eocene porphyry Mo-rich deposits (i.e., Mo ±Cu). These Eocene Mo-bearing mineralized systems are classified as both low-F Mo porphyry deposits (e.g., Kitsault), and calc-alkalic Cu-Mo (e.g., Berg; Figs. 2, 3). The Kitsault and Berg deposits host elevated Ag, Te, Bi, Sn, Zn, and In predominantly in late-stage transitional veins (Orovan et al., 2024, 2025).

4. Overview of the Shaft Creek, Mount Polly, and New Afton deposits

4.1. Schaft Creek porphyry Cu-Mo-Au-Ag deposit

The Schaft Creek deposit is in Stikine terrane, northwest British Columbia (Figs. 1, 2). The mineralization is on the eastern margin of the Hickman batholith where quartz monzodiorite to quartz monzonite dikes (225 to 219 Ma) intrude and locally brecciate Stuhini Group mafic volcanic rocks (Table 1; Jutras and Bailey, 2016; Erbalaban, 2023; Campbell and van Straaten, 2025). Two 'syn-mineral' porphyritic intrusions yielded U-Pb zircon dates of 219.27 ±0.26 and 219.43 ±0.18 Ma (Bailey et al., 2025). The intrusions and mineralization may be related to slight east-west extension across the Hickman batholith during the Late Triassic (Nelson and van Straaten, 2020). Scott et al. (2008) considered that significant syn- and post-mineralization deformation indicates that the deposit may have formed in a crustal-scale shear zone that facilitated multiple pulses of magmatic fluids.

Mineralization comprises bornite, chalcopyrite, and molybdenite as disseminations in intrusions and volcanic wall rock, and within veins and breccias of predominantly quartz and carbonate, veins of predominantly sulphide, and tourmaline veins and breccias (Scott et al., 2008). A secondary phase comprising molybdenite and specular hematite-bearing veins and late quartz-chalcopyrite-galena-sphalerite±pyrite veins has been recognized (Scott et al., 2008).

4.2. Mount Polley alkalic Cu-Au porphyry deposit

Mount Polley is in Quesnel terrane of south-central British Columbia (Figs. 1, 2). Mineralization formed ca. 205 Ma (Table 1) and is associated with diorite, monzonite, plagioclase porphyry, and syenite dikes that were emplaced into mafic volcanic and volcanosedimentary rocks of the Nicola Group (Logan and Mihalynuk, 2005, 2014). The intrusions vary from silica saturated to silica undersaturated; hydrothermal alteration and veining lack quartz (Lang et al., 1995; Rees et al., 2020).

The deposit comprises several mineralized zones and breccia complexes within a north-northwest-trending corridor (Rees et al., 2020). Although no significant faults are recognized, syn-magmatic fabrics localized at vertical contacts between intrusive rocks, dikes, and breccia bodies suggest a structural control and a possible deep feeder structure (Brown et al., 2016). Mineralization comprises chalcopyrite and locally bornite-rich veins and matrix material to hydrothermal and intrusive breccias, and is associated with magnetite (Rees et al., 2020). Native gold is present as inclusions in chalcopyrite and rare tetrahedrite, galena, sphalerite, and molybdenite are present (Rees et al., 2020).

4.3. New Afton alkalic Cu-Au porphyry deposit

New Afton is in Quesnel terrane of south-central British Columbia (Figs. 1, 2) and is related to intrusions of the Iron Mask batholith (ca. 205 Ma; Table 1; Logan and Mihalynuk, 2014). At New Afton, mineralization is associated with silica-saturated porphyritic monzonites that intrude mafic volcanic rocks of the Nicola Group (Hall and May, 2013; Lipske et al., 2020; Mihalynuk and Diakow, 2020). Relatively small volumes of picrite occur and may be associated with metal enrichment, representing a mantle-derived magma within the mineralized system (Logan and Mihalynuk, 2014; Milidragovic and Spence, 2026). A complex structural framework for New Afton includes northwest- and east-trending faults that may have focussed ore-forming fluids and controlled Cu-Au distribution along the north margin of the Iron Mask intrusions (Hall and May, 2013; Lipske et al., 2020). In contrast to Mount Polley and Schaft Creek, magmatic-hydrothermal breccia bodies are not a significant component of the New Afton mineralization (Osatenko et al., 2020).

Mineralization comprises bornite-chalcopyrite with lesser chalcocite-covellite and accessory sulphosalts, and occurs as veins and vein breccias, densely concentrated as replacements of mafic phenocrysts, and as disseminations in intrusions (Hanley et al., 2020). Secondary (Late Jurassic) hypogene mineralization, defined by tennantite-tetrahedrite associated with argillic alteration, overprints primary Cu-Au mineralization (Robb et al., 2023). In the upper portion of the deposit, supergene enrichment consists of chalcocite, native copper, and minor copper oxides (Hanley et al., 2020).

Table 1. Deposits discussed herein with MINFILE database classification (British Columbia Geological Survey, 2026).

Deposit/ MINFILE No.	Deposit type[1]	Primary commodities	Secondary metals	Mineralization age (Ma)	Tectonic setting	Terrane
Schaft Creek 104G 015	Porphyry Cu ±Mo ±Au	Cu, Mo, Au, Ag[2]	Bi, Re, Te, W, Sb[3]	221.2 ±0.3 and 222.4 ±1 Re-Os Mo[4] Late Triassic	Pre-accretionary volcanic arc[2]	Stikine
Galore Creek 104G 090	Alkalic porphyry Cu-Au	Cu, Au, Ag	Bi, Te, Pt, Pd[5]	210-204.5 U-Pb zircon and titanite[4, 6, 7] Late Triassic	Pre-accretionary island arc[2]	Stikine
Mount Polley 093A 008	Alkalic porphyry Cu-Au	Cu, Au, Ag	Mn,[9] Pt, Re, Bi, Te, Pd (Up to 0.32 ppm[10])	205[9] Late Triassic	Pre-accretionary island arc	Quesnel
New Afton 092INE023	Alkalic porphyry Cu-Au	Cu, Au, Ag	Pt, Te, Bi, Pd (Up to 3.8 ppm[11]), Co, Ni, Se, As[12]	204.5 ±0.6 to 201.39 ±0.75[6,8] U-Pb zircon Late Triassic	Pre-accretionary island arc	Quesnel
E&L 104B 006	Tholeiitic intrusion-hosted Ni-Cu	Ni, Cu	Pt, Pd, Au, Ag, Te[5]	180-186[5] Early Jurassic	Island arc	Stikine
Huckleberry 093E 037	Porphyry Cu ±Mo ±Au	Cu, Mo, Au, Ag[13]	Pd, Bi, Te, W, Zn, Sb[13]	85.66 ±0.35[14] Re-Os in Mo Late Cretaceous	Post-accretionary continental arc	Stikine
Kitsault 103P 120	Porphyry Mo (low-F type)	Mo, Ag, Cu	Pb, Zn, Bi, Sb, W, Cd, In, Te, Re[2, 3, 14]	55.84 ±0.23 Re-Os in Mo[14] Eocene	Post-accretionary[14] continental arc	Stikine
Berg 093E 046	Porphyry Cu ±Mo ±Au	Cu, Mo, Ag[13]	Bi, Re, Te, Sb, Pb, Zn, In, As, W[13]	53.16 ±0.21 Re-Os in Mo[14] Eocene	Post-accretionary continental arc	Stikine

1: British Columbia Geological Survey (2026); 2: Osatenko et al. (2020); 3: this study; 4: Bailey et al. (2025); 5: Lawley et al. (2025); 6: Mortensen et al. (1995); 7: van Straaten et al. (2023); 8: Logan and Mihalynuk (2005); 9: Logan and Mihalynuk (2014); 10: Thompson et al. (2001); 11: Nixon (2003); 12: Boucher et al. (2023); 13: Orovan et al. (2025); 14: Graham et al. (2025).

The New Afton deposit is enriched in Co, Ni, and PGE, the transport and deposition of which are distinct from Cu-Au deposition (Boucher et al., 2023). Early hypogene pyrite is enriched in Co-Ni-Pd-Pt-Se-As, with Co and Ni concentrations similar to those in mafic-ultramafic PGE, iron-oxide apatite (IOA), and iron-oxide-Cu-Au (IOCG) deposits (Boucher et al., 2023). According to Robb et al. (2023), secondary hydrothermal alteration remobilized PGE from the early pyrite and re-deposited them as PGM in late-stage polymetallic and carbonate-bearing veins.

5. Methods

Lithogeochemical samples from Schaft Creek (n=24), Mount Polley (n=36), and New Afton (n=102) were collected from drill core during site visits in 2024. Samples are representative across multiple ore zones and mineralization facies at each deposit. Samples were split, crushed, and pulverized at the BCGS and sent to ALS Canada Ltd. in North Vancouver for geochemical analysis (for method details see Graham et al., 2025). Polished thin sections were examined using scanning electron microscopy-mineral liberation analysis (SEM-MLA) at the CREAIT Microanalysis Facility, Memorial University of Newfoundland, following methods in Graham et al. (2025).

6. Results

Summarized below are geochemical and SEM-MLA results; the complete datasets will be presented elsewhere.

6.1. Metal assemblages in Schaft Creek, Mount Polley, and New Afton deposits

We evaluate the geochemical results from this study by normalizing to average continental crust trace metal values (Fig. 4; Rudnick and Gao, 2014). Only samples with >500 ppm Cu are included. Samples from New Afton (n=79) are very strongly enriched in Cu (interquartile range: 0.53-3.77%).

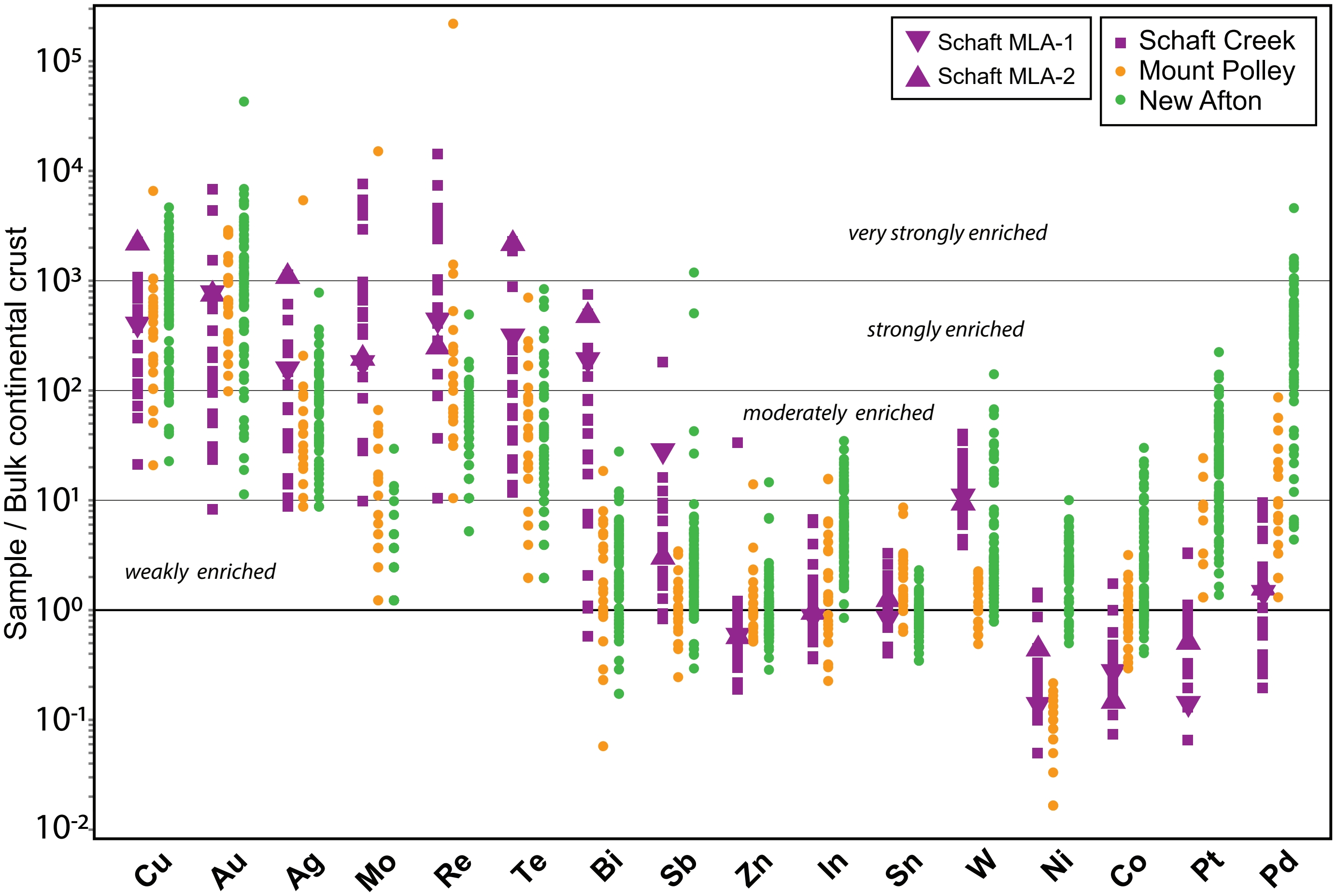

Fig. 4. Lithogeochemical results from Schaft Creek (n=23), Mount Polley (n=25), and New Afton (n=79) samples, filtered by Cu >0.05%. Trace element diagram of primary commodity and potential companion metals normalized to bulk continental crust of Rudnick and Gao (2014). Enrichment levels are defined as weak (1-10x average crust); moderate (10-100x bulk crust); strong (100-1000x bulk crust); very strong (>1000x bulk crust). Selected samples refer to those in Figure 5.

Samples from Mount Polley (n=25) and Schaft Creek (n=23) are similarly strongly enriched in Cu (interquartile ranges: 0.40-1.62% and 0.44-1.93%, respectively).

Samples from all three deposits are moderately to strongly enriched in Au and Ag (Fig. 4). Schaft Creek samples generally have the highest Ag concentrations with a mean of 10.0 and interquartile range of 1.3-13.1 ppm Ag; Ag is positively correlated with Cu in these samples (r=+0.87). Mount Polley samples yielded a mean of 15.6 and interquartile range of 0.6-2.8 ppm Ag, with one sample of massive sulphide breccia yielding 18% Cu, 307 ppm Ag, and 3.56 ppm Te. At New Afton, Ag values are similar (interquartile range: 1.0-6.2 ppm) despite stronger Cu grades (r=+0.65).

Gold values are highest at New Afton (mean: 2624 ppb; interquartile range: 520-2420 ppb), comparable at Mount Polley (mean: 1333 ppb; interquartile range: 430-1953 ppb), and slightly lower at Schaft Creek (mean: 1049 ppb; interquartile range: 72-864 ppb). One sample of iron oxide-clay altered breccia crosscut by a sulphide-bearing quartz-calcite vein at New Afton yielded 56.4 ppm Au and 6.98 ppm Pd.

At Schaft Creek, both Mo (mean: 1133 ppm; interquartile range: 147-759 ppm) and Re (mean: 401 ppb; interquartile range: 49-595 ppb) are strongly to very strongly enriched. Samples from Mount Polley are typically only weakly to moderately enriched in Mo (interquartile range: 3-14 ppm) and moderately to strongly enriched in Re (interquartile range: 10-44 ppb). However, one molybdenite vein sample from Mount Polley yielded 12,250 ppm Mo and 41.7 ppm Re (Fig. 4). Although Mo is only weakly enriched in New Afton samples, Re is moderately to strongly enriched (interquartile range: 4-14 ppb).

Samples from all three deposits are moderately to strongly enriched in Te; Schaft Creek samples tend slightly higher (≤11.55 ppm; Fig. 4). Schaft Creek samples are also weakly to strongly enriched in Bi (mean:19.44 ppm; interquartile range: 1.19-26.70 ppm; ≤130 ppm), whereas Mount Polley and New Afton are weakly enriched (mean values of <0.6 ppm Bi). Schaft Creek has higher concentrations of Sb (interquartile range: 0.4-1.5 ppm) and W (interquartile range: 7.4-20.7 ppm) and lower concentrations of Zn, In, and Sn than Mount Polley; New Afton samples span a larger range, up to strong enrichment of W and Sb (≤143 ppm W; ≤241 ppm Sb; Fig. 4).

New Afton is more enriched in Ni, Co, Pt, and Pd than Schaft Creek and Mount Polley, where Ni is depleted relative to bulk crust (Fig. 4). New Afton is strongly enriched in Pd (mean: 681 ppb; interquartile range: 197-877 ppb; ≤6980 ppb) and Pd is positively correlated with Au (*r*=+0.84) and As (*r*=+0.66). Mount Polley is weakly to moderately enriched in Pt and Pd (≤37 ppb Pt and ≤132 ppb Pd) and Schaft Creek is not. Collectively there is a pattern of Co, Pt, and Pd, where New Afton>Mount Polley>Schaft Creek (Fig. 4).

6.2. SEM-MLA

SEM-MLA quantitative mineralogy indicate that all three deposits contain electrum, Cu (±Fe) sulphides (chalcopyrite, bornite, chalcocite), Fe (±Ni) sulphides (pyrite, pyrrhotite, pentlandite), sphalerite, galena, and tetrahedrite-tennantite (Table 2). Mount Polley has the simplest mineralogy. For example, electrum is the only discrete Ag mineral and cosalite is the only discrete Bi mineral (Table 2). Mount Polley has minor amounts of native Au, enargite, sulphosalts, and scheelite.

Schaft Creek and New Afton contain diverse Ag, Bi, and Te-bearing minerals, where they occur as native metals, tellurides (hessite, tellurobismuthite), sulphides (acanthite, bismuthinite), and sulphosalts (wittichenite). At Schaft Creek, electrum and wittichenite are associated with fine-grained bornite at the margins of chalcopyrite masses (Figs. 5a-d). In another example, a bornite-rich vein (Fig. 5e) contains fine-grained Cu-sulphosalts (bournonite and tetrahedrite), galena, and molybdenite (Fig. 5f). Uniquely, New Afton samples contain platinum group minerals froodite and Pd-Sb alloys (Table 2; Bain et al., 2026).

At Mount Polley, the lack of discrete Te and Ag minerals (excluding electrum) implies they may occur in solid solution in sulphides and/or tetrahedrite (Fig. 4; Table 2). The SEM-MLA method does not resolve trace metals in solid solution; other methods such as µXRF or LA-ICP-MS are required to map elemental distribution of trace metals within minerals (e.g., Ootes et al., 2026).

7. Discussion

7.1. Variations in metal assemblages across deposits

Comparison of geochemical results presented in this study (Fig. 4) with previously published results (Brzozowski and Zaborniak, 2024; Graham et al., 2025; Lawley et al., 2025) shows that different porphyry deposit types in British Columbia contain distinct trends in precious and critical companion metal assemblages (Fig. 6; Table 1). The Eocene Mo-bearing Berg and Kitsault deposits contain the highest concentrations of Ag, Te, Bi, Sb, Zn, and In (Fig. 6a). Among pre-accretionary deposits, Schaft Creek contains higher concentrations of Te and Bi and lower Ni, Co, and PGE than the Mount Polley, New Afton, and Galore Creek Cu-Au deposits (Figs. 4, 6). Nickel, Co, and PGE are highest in the E&L mafic magmatic deposit. The New Afton metal assemblage differs from other porphyry mineralization but is similar to the E&L mafic magmatic deposit with enriched Ni, Co, Pt, and Pd and low Mo, although with an order of magnitude less Ni and higher normalized Pd/Pt (Fig. 6). Platinum group elements, particularly Pd, are more enriched in alkalic Cu-Au than Cu ±Mo ±Au porphyry deposits (Figs. 3, 4, 6). All deposits studied have Pd>Pt, and Pd is positively correlated with Au. Mount Polley and Galore Creek exhibit similar normalized Pd/Pt patterns as New Afton but at lower concentrations.

Positive spatial correlations of potential byproducts with primary commodities improve the potential for their economic extraction. All samples studied have positive correlations of Cu with Au, Ag, Bi, and Te, whereas Mo and Sb are largely decoupled from Cu (Figs. 7a-f). Rhenium is strongly correlated with Mo in all deposits except E&L and New Afton (Fig. 7g). Typically, Re is in solid solution within molybdenite (John and Taylor, 2016; McFall et al., 2021), which is more prevalent in porphyry Cu ±Mo ±Au deposits (Fig. 6). The data in this study show that alkalic Cu-Au deposits contain higher proportions of Re relative to Mo (Fig. 7g) and both E&L and New Afton have moderately enriched Re without the presence of molybdenite (Figs. 6, 7g), implying that Re resides in another mineral (Lawley et al., 2025).

7.2. Sub-epithermal enrichment of precious metals, post-transition metals, and metalloids

Late-stage transitional (post-porphyry, pre-epithermal) veins with high concentrations of critical companion metals have been recognized in several porphyry deposits in British Columbia (LeFort et al., 2011; Robb et al., 2023; Lawley et al., 2025; Orovan et al., 2024, 2025). For example, the high concentrations of semi-metals (Ag, Te, Bi, Sb, Zn, In) identified in the Eocene Berg and Kitsault Cu-Mo deposits are hosted predominantly within sub-epithermal (transitional) veins, as inferred on the basis of spatial and crosscutting relationships, the prevalence of sulphosalts, and carbonate gangue typically associated with low-temperature alteration at relatively shallow depths (Orovan et al., 2024, 2025).

At Schaft Creek, critical companion metals are hosted by sulphosalts (e.g., Bi in wittichenite and Sb in bournonite; Table 2), tellurides (Bi and Te in tellurobismuthite), and spatially associated with carbonate and secondary Cu minerals (e.g., chalcocite; Fig. 5), implying that Bi and Te may be concentrated or upgraded by late-stage mineralizing processes or subsequent hydrothermal activity during repeated deformation (Scott et al., 2008). The presence of fine grains of Bi ±Cu-sulphides, tellurides, and native metals at the margins of chalcopyrite and bornite suggests post-magmatic exsolution from original solid solution in the Cu-Fe sulphides. Alternatively, Bi and Te may have precipitated from the same fluids as the Cu-sulphides during slow cooling of the magmatic-hydrothermal system but formed discrete minerals after saturation of the sulphides (McFall et al., 2021; Karatas Ahmadli, 2025).

Analogous veins in alkalic igneous environments host PGM, deposited from Au-PGE-As-Sb-Bi-Te-B-rich fluids in late (post-porphyry, pre-epithermal) stages of the magmatic-

Table 2. Minerals identified by SEM-MLA.

Mineral group	Mineral	Chemical formula	Schaft Creek	Mount Polley	New Afton
Native element and alloy	Native gold	Au		x	
	Electrum	(Ag, Au)	x	x	x
	Native silver	Ag	x		
	Native bismuth	Bi	x		
Telluride	Hessite	Ag_2Te	x		
	AgTe	AgTe			x
	Tellurobismuthite	Bi_2Te	x		
Oxide	Gossanized chalcopyrite				x
	Cuprite	Cu_2O	x		x
Sulpharsenide	Cobaltite	CoAsS	x		x
	Enargite	Cu_3AsS_4	x	x	
Sulphide	Acanthite (argentite)	Ag_2S	x		
	Bismuthinite	Bi_2S_3	x		
	Molybdenite	MoS_2	x	x	
	Bornite	Cu_5FeS_4	x	x	x
	Chalcopyrite	$CuFeS_2$	x	x	x
	Chalcocite	Cu_2S	x	x	x
	Covellite	CuS	x		
	Sphalerite	ZnS	x	x	x
	Galena	PbS	x	x	x
	Pentlandite	$(Fe,Ni)_9S_8$	x	x	x
	Pyrite	FeS_2	x	x	x
	Pyrrhotite	FeS	x	x	x
	Arsenopyrite	FeAsS			x
Sulphosalt	Wittichenite	Cu_3BiS_3	x		
	Cosalite	$Pb_2Bi_2S_5$		x	
	Tetrahedrite-tennantite	$(Cu,Fe)_{12}(Sb, As)_4S_{13}$	x	x	x
	Bournonite	$PbCuSbS_3$	x		
	Cd-Cu-Fe-S				x
Tungstate	Scheelite	$CaWO_4$		x	
Platinum group mineral	Froodite	$PdBi_2$			x
	Pd Sb	Alloys			x

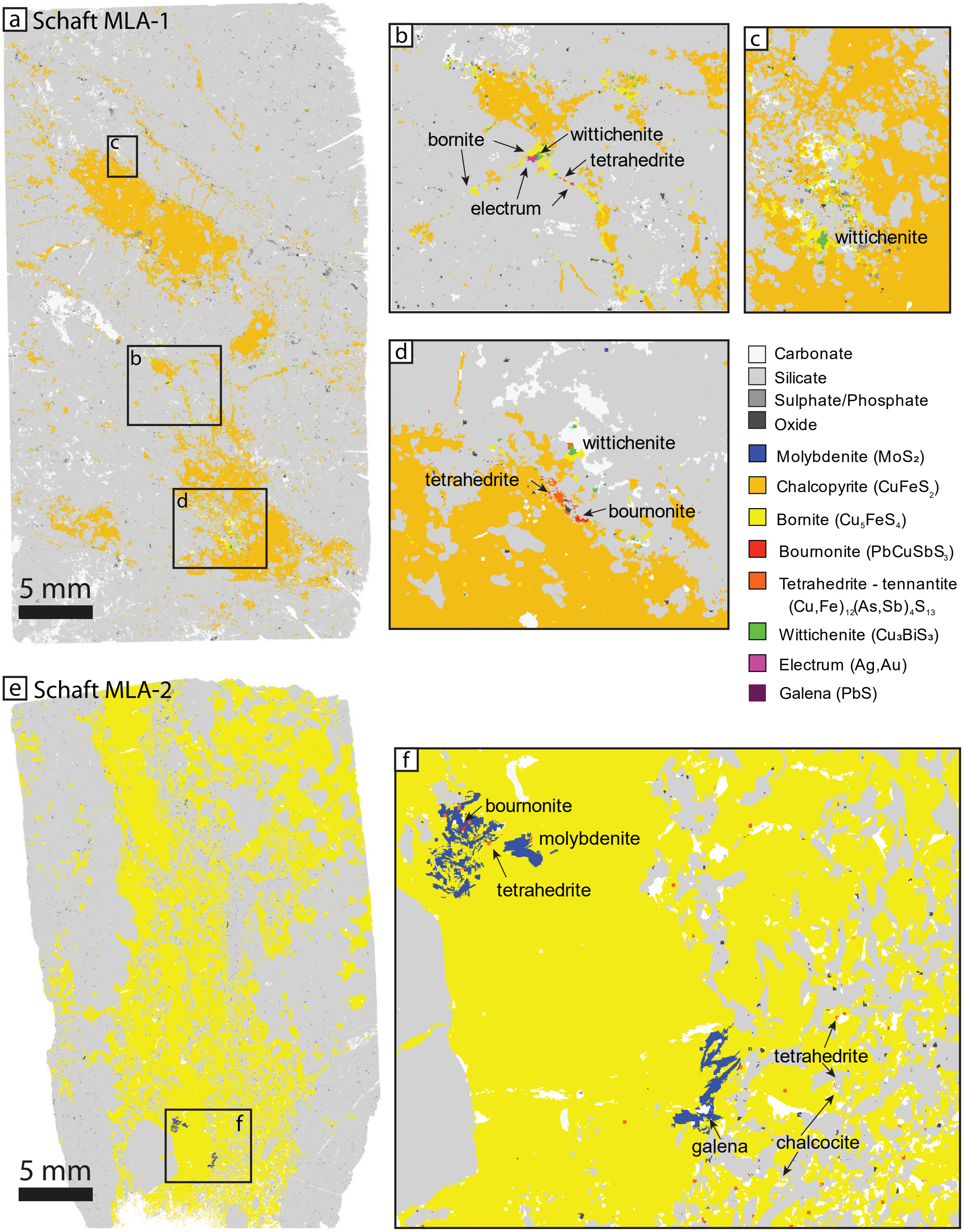

Fig. 5. SEM-MLA images from two Schaft Creek sample thin sections. **a)** False-colour mineralogy of Schaft MLA-1 (sample 24RCA-197-73a) showing locations of insets b-d. **b)** Wittichenite, electrum, and tetrahedrite in bornite veinlet at margin of chalcopyrite. **c)** Wittichenite in bornite with carbonate at margins of chalcopyrite clot. **d)** Wittichenite, tetrahedrite, and bournonite at margins of chalcopyrite vein. **e)** False-colour mineralogy of Schaft MLA-2 (sample 24RCA-195-55b) showing location of inset f. **f)** Bournonite, tetrahedrite, and galena as fine grains within and at margins of molybdenite clusters in bornite vein and tetrahedrite-chalcocite with carbonate at bornite margins.

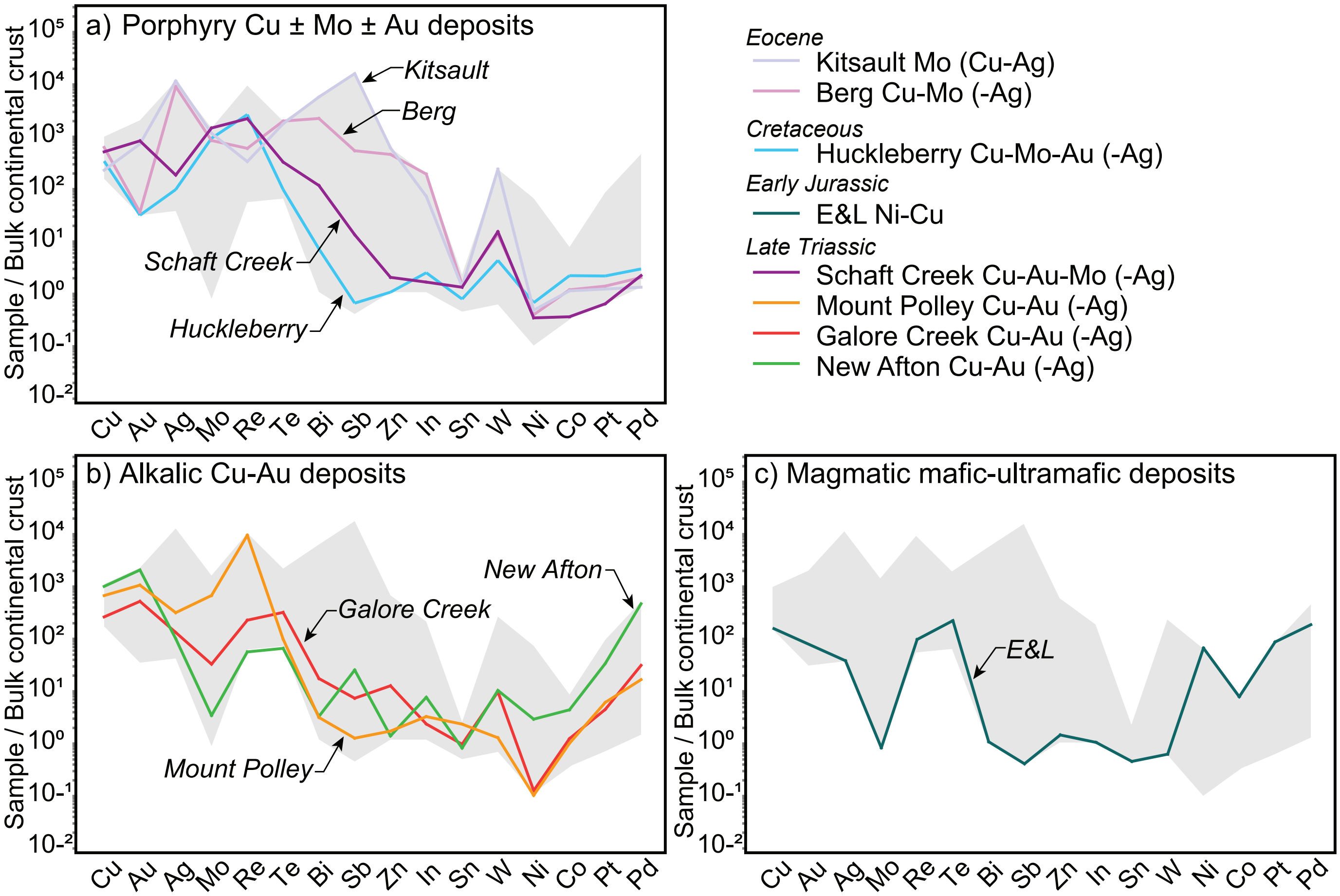

Fig. 6. Bulk continental crust-normalized mean commodity and potential companion metals. **a)** Porphyry Cu ±Mo ±Au deposits, including pre- and post-accretionary examples. **b)** Alkalic porphyry Cu-Au deposits. **c)** Mafic magmatic E&L deposit. Light grey shaded background represents the range of results for all data. Galore Creek data from Lawley et al. (2025), E&L data from Brzozowski and Zaborniak (2024).

hydrothermal system (LeFort et al., 2011; Robb et al., 2023). This results in a low- to intermediate-sulfidation epithermal-like style of mineralization of complex polymetallic but Cu-poor mineralization adjacent to Cu-Au ore (LeFort et al., 2011).

8. Conclusion

Bulk rock geochemical data and automated SEM-MLA mineralogy have revealed critical metal enrichment in mineralized rock samples from the Schaft Creek, Mount Polley, and New Afton porphyry deposits. The Schaft Creek Cu-Au-Mo-Ag deposit is enriched in Bi and Te, which is confirmed by the presence of Bi and Te within tellurides, native alloys, sulphosalts, and sulphides. The New Afton and Mount Polley Cu-Au deposits have PGE enrichment, and concentrations of Co and Pd at New Afton are similar to those at the E&L mafic magmatic deposit. Comparison with other British Columbia deposits highlights a variety of metal assemblages and critical companion metals.

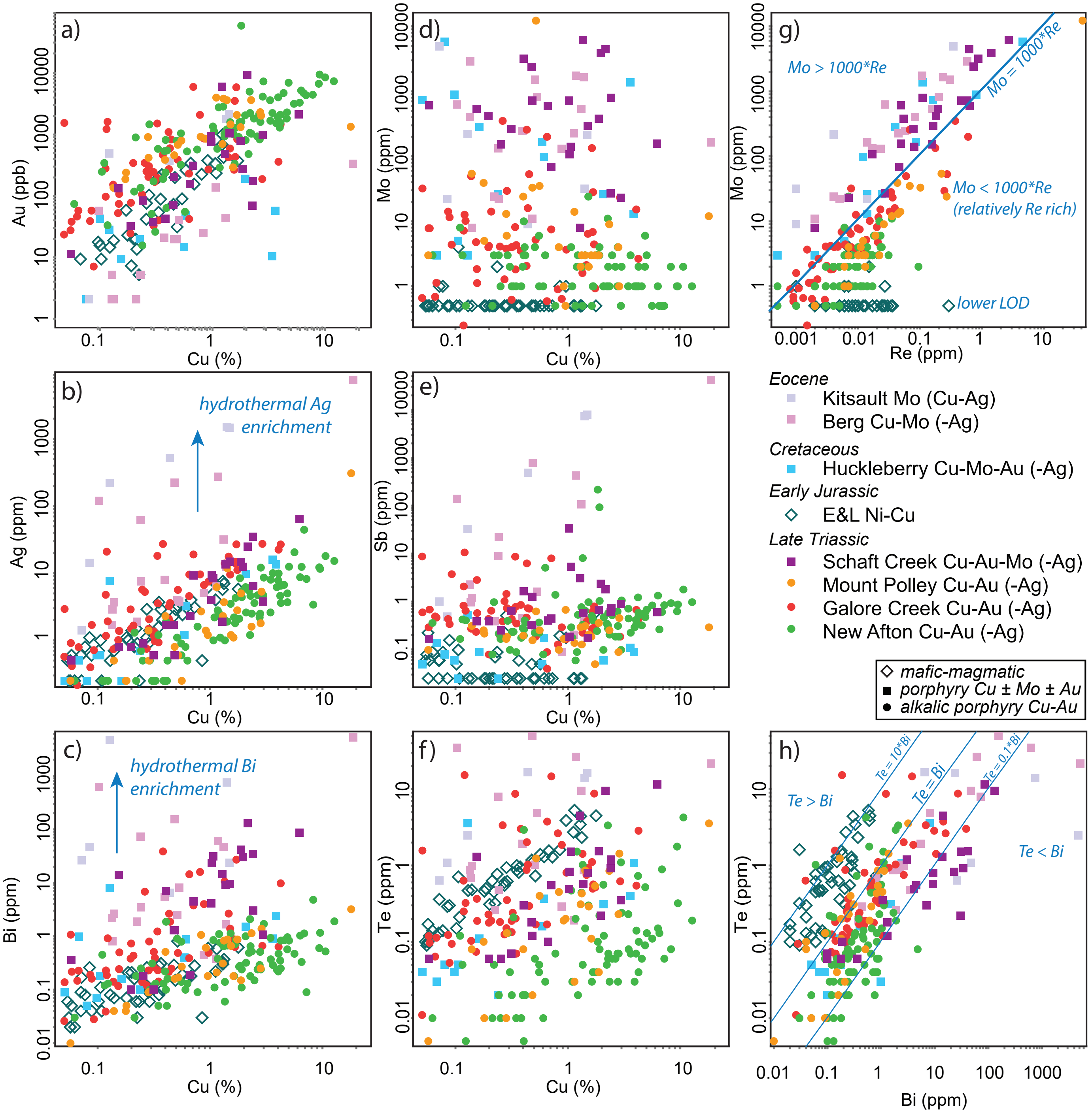

Fig. 7. Co-variation between Cu (wt.%) and **a)** Au (ppb), **b)** Ag (ppm), **c)** Bi (ppm), **d)** Mo (ppm), **e)** Sb (ppm), and **f)** Te (ppm). **g)** Co-variation between Re (ppm) and Mo (ppm). **h)** Co-variation between Bi (ppm) and Te (ppm). Galore Creek data from Lawley et al. (2025), E&L data from Brzozowski and Zaborniak (2024).

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