Paragenesis and Alteration of the Southeast Zone and Deerhorn Porphyry Deposits, Woodjam Property, Central British Columbia (Parts of 093A)

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Introduction

Porphyry deposits of the Late Triassic to Middle Jurassic (216 to 183 Ma) occur in the Quesnel and Stikine terranes in British Columbia. They are subdivided into calcalkalic and alkalic types on the basis of their hostrock chemistry and styles of alteration and mineralization (Lang et al., 1995; McMillan et al., 1995). Alkalic porphyry deposits such as Mount Milligan (MINFILE 093N 194; BC Geological Survey, 2012), Mount Polley (MINFILE 093A 008) and Lorraine (MINFILE 093N 002), and calcalkalic porphyry deposits such as Brenda (MINFILE 092HNE047), Highland Valley (MINFILE 092ISE001) and Gibraltar (MINFILE 093B 006) are examples of these two classes. These porphyry deposits commonly occur as clusters of several porphyry centres. The metal ratios, alteration assemblages and hostrock intrusive textures of each porphyry deposit can vary within each cluster (e.g., Casselman et al., 1995; Fraser et al., 1995). Such differences are commonly attributed to emplacement at different crustal depths of the now spatially related porphyry stocks (e.g., Panteleyev et al., 1996; Chamberlain et al., 2007). Recently, porphyry clusters such as Red Chris (MINFILE 104H 005; Norris, 2011) and Woodjam (MINFILE 093A 078; Figure 1) have been displaying both alkalic and calcalkalic features. However, the genetic and spatial links between the various deposits in each camp, especially with contrasting assemblages (i.e., calcalkalic and alkalic), are not well understood.

The Woodjam property hosts several discrete porphyry deposits, including the Megabuck (Cu-Au; MINFILE 093A 078), Deerhorn (Cu-Au; MINFILE 093E 019), Takom (Cu-Au; MINFILE 093A 206), Southeast Zone (Cu-Mo; MINFILE 093A 124) and the recently discovered Three Firs (Cu-Au; Figure 2). These deposits display various styles and assemblages of alteration and mineralization. The Southeast Zone Cu-Mo deposit is hosted in variable quartz monzonite intrusive units and displays alteration and mineralization comparable to calcalkalic porphyry deposits, whereas the nearby Deerhorn Cu-Au deposit is mainly associated with narrow (<100 m) monzonite intrusive bodies and hosts mineralization similar to alkalic porphyry deposits. These differences have resulted in the separation of the Southeast Zone (SEZ) from the Megabuck and Deerhorn deposits as a different mineralization event (Logan et al., 2011). However, there are attributes of mineralization and alteration that could indicate that at least some deposits within the Woodjam property may be related.

Recent exploration at the Deerhorn Cu-Au deposit has shown two contrasting alteration assemblages of K-feldspar+magnetite, typical of alkalic systems, and illite+tourmaline and Mo mineralization, typical of calcalkalic systems. The SEZ displays some features not typical of calcalkalic deposits, such as sparse quartz veining, and is located less than 4 km from the Deerhorn deposit. These observations suggest that temporal and paragenetic relationships between the two deposits may exist, thus providing a unique opportunity to study the relationship between alkalic and calcalkalic deposits in BC.

Thus, a research project has been jointly initiated by the Mineral Deposit Research Unit at the University of British Columbia, Gold Fields Canada Exploration and Geoscience BC. The focus of this project is to increase the un-

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Keywords: *alkalic porphyry, calcalkalic porphyry, Woodjam property*

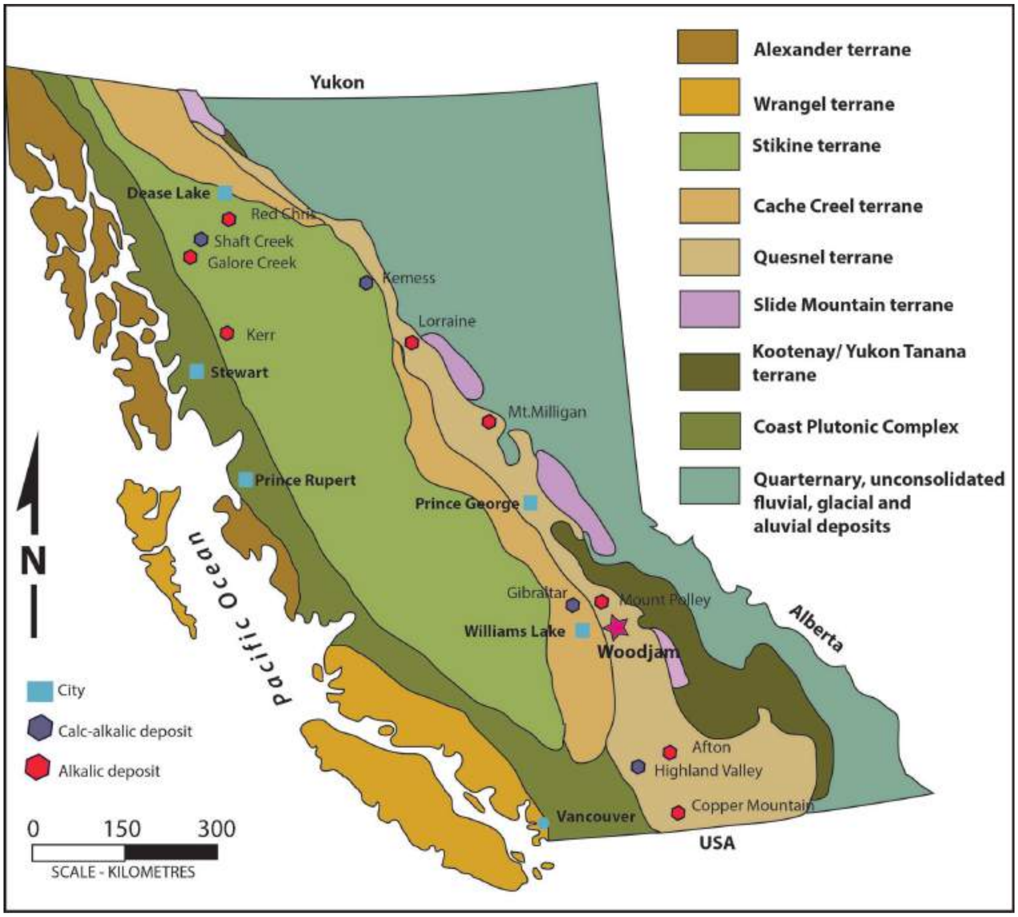

Figure 1. Major tectonic terranes and associated Mesozoic porphyry deposits of the Canadian Cordillera in British Columbia (from McMillan et al., 1995).

derstanding of the paragenesis and alteration of the variable calcalkalic and alkalic deposits and the magmatic evolution in the Woodjam property. Results of this investigation will have important implications in understanding the formation of porphyry clusters and planning the exploration of new targets in known mineralized districts in BC and similar regions worldwide.

Fieldwork was carried out during July and August 2012 and was focused on the Deerhorn and SEZ deposits. Five drillholes along a single cross-section were graphically relogged from each deposit (Figures 2, 3) and sampled. Hostrock texture, alteration assemblages and intensity, vein types, and crosscutting relationships were recorded and form the basis for ongoing detailed petrographic and chemical analyses. Results and discussions presented in this summary are based largely on data and observations collected during this field program.

The Woodjam property is located in the Cariboo Mining Division, central British Columbia, approximately 50 km northeast of Williams Lake (Figure 1). The property is owned by Gold Fields Horsefly Exploration (51%) and Consolidated Woodjam Copper Corporation (49%). The Southeast Zone is the only deposit with a public pit-constrained resource estimated to be 146.5 Mt at 0.33% Cu (Sherlock et al., 2012).

Tectonic Setting

Much of BC comprises several tectonic blocks that were accreted onto the western margin of ancient North America during the Mesozoic. Three of these accreted terranes, the Quesnel (or Quesnellia), Stikine (or Stikinia) and Cache Creek terranes, form most of the Intermontane Belt that composes much of central BC (Figure 1; Monger and Price, 2002). The Stikine and Quesnel volcanic arc terranes have similar compositions and stratigraphy, and are interpreted to have originally been part of the same arc that was folded in counterclockwise rotation, enclosing the Cache Creek terrane (Mihalynuk et al., 1994). Within the Quesnel and Stikine terranes, the emplacement of pre- to synaccretion of both alkalic and calcalkalic Cu±Mo±Au deposits occurred between 216 and 187 Ma (McMillan et al., 1995). The Woodjam porphyry cluster is hosted in the Late Triassic to Early Jurassic arc in the central portion of the Quesnel terrane.

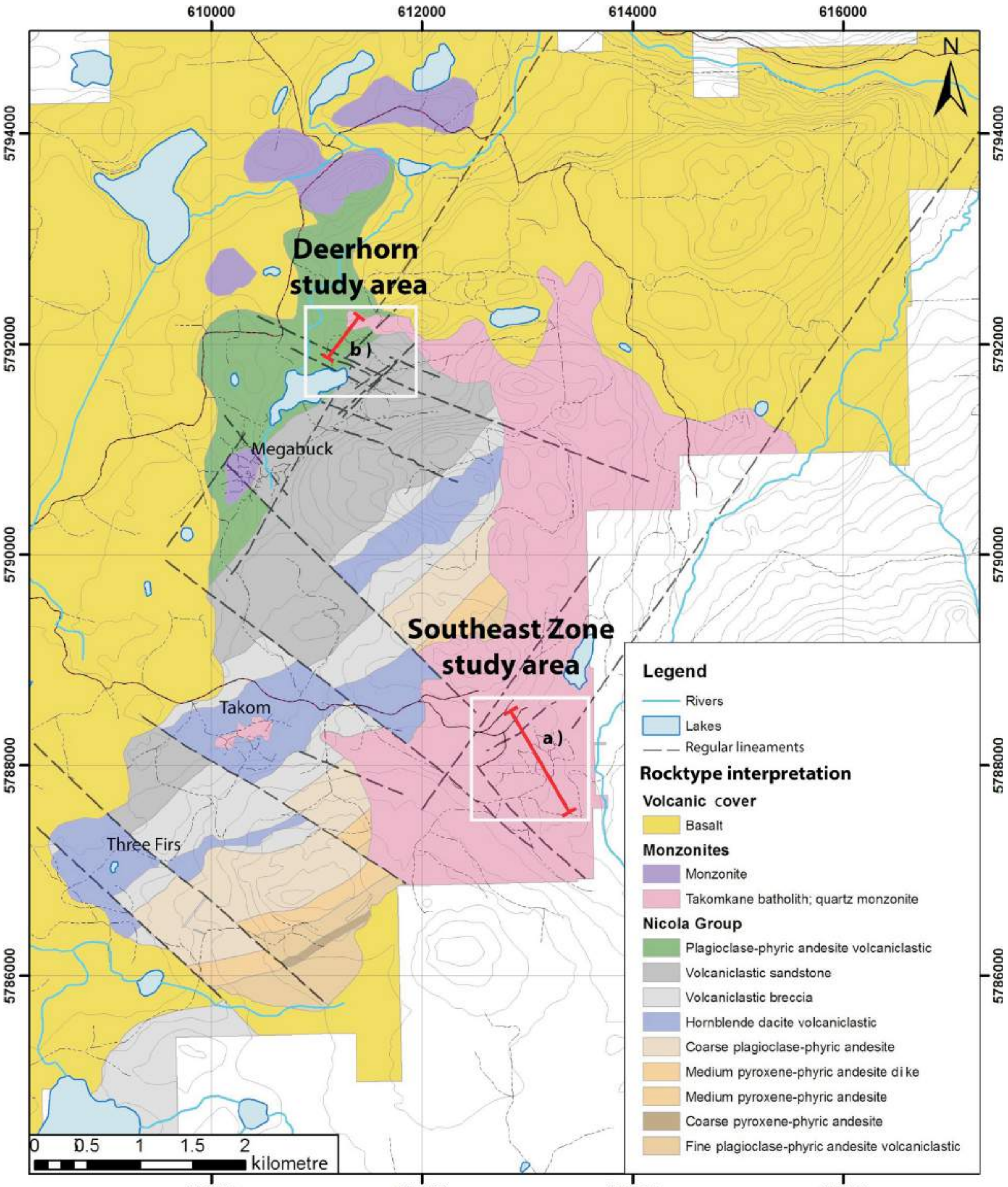

Figure 2. Geology of the Woodjam property. Cross-section lines of drillholes relogged in this study are shown (red line) for the a) Southeast Zone and b) Deerhorn deposits (from Gold Fields Canada Exploration, pers. comm., 2012).

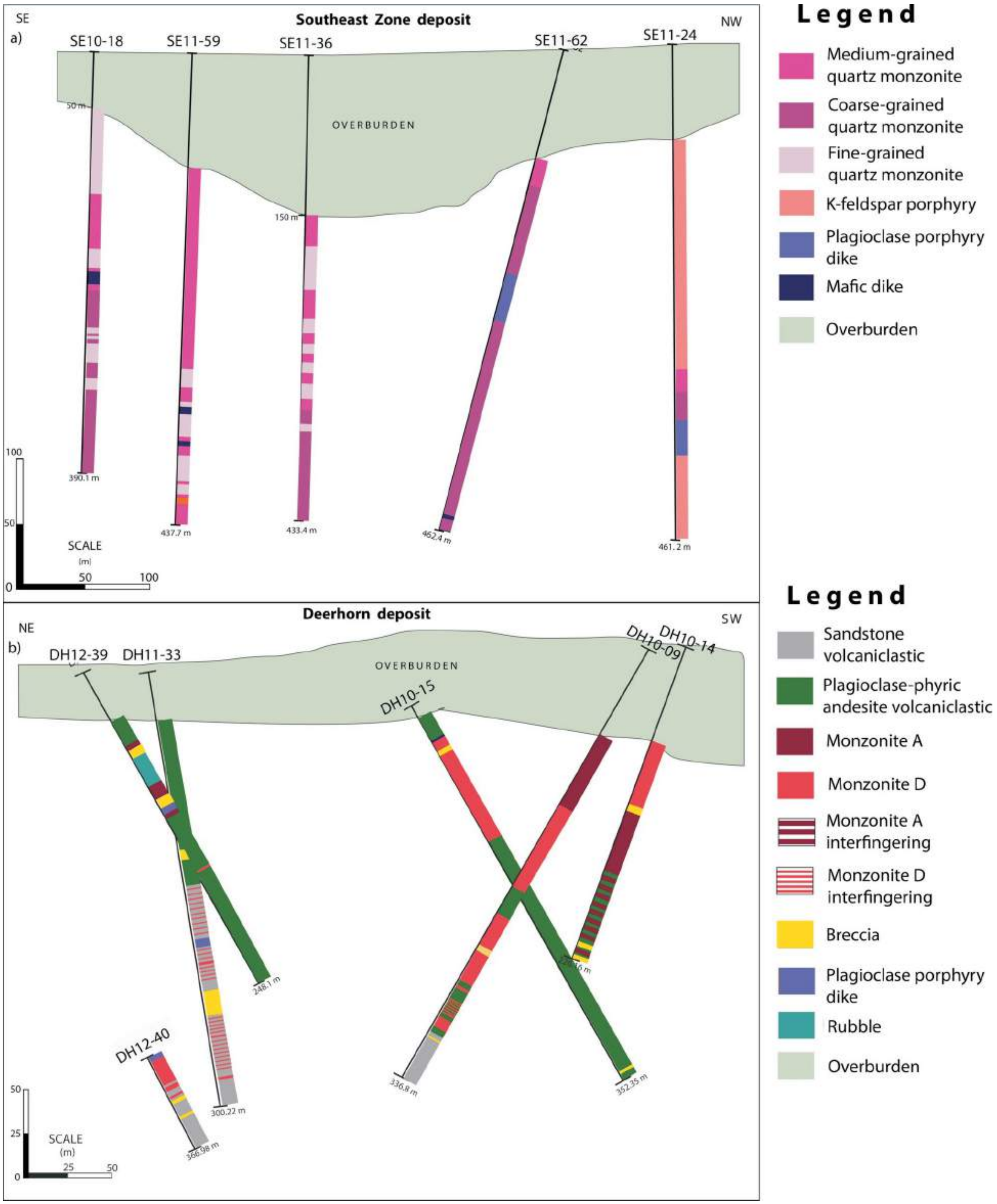

Figure 3. a) Southeast cross-section along the line 613160E, 5788000N, NAD 83, UTM Zone 10 (28.5 m thickness) across the Southeast Zone deposit; **b)** northeast cross section along the line 611230E, 5792020N, NAD 83, UTM Zone 10 (62.5 m thickness) across the Deerhorn deposit.

Regional Geology

The Quesnel terrane consists of upper Paleozoic and lower Mesozoic volcanic, sedimentary and plutonic rocks. The Paleozoic components are unconformably overlain by the Late Triassic and Early Jurassic island arc volcanic and sedimentary strata of the Nicola Group and its northern continuation, the Takla Group (McMillan et al., 1995). The Nicola Group is composed of submarine basaltic to andesitic augite±plagioclase–phyric lava and volcaniclastic and sedimentary units (Mortimer, 1987; Schiarizza et al., 2009; Vaca, 2012). This sequence extends throughout south-central BC.

These rocks were intruded by the Takomkane batholith, a large composite calcalkalic intrusion of largely granitoid composition with a surface expression of approximately 40 by 50 km. The Woodjam Creek unit of the Takomkane batholith occurs on the Woodjam property and comprises granodiorite, monzogranite and quartz monzonite (Schiarizza et al., 2009). The Nicola and Takomkane units are overlain by the Early Miocene to Early Pleistocene basalt of the Chilcotin Group.

Geology of the Woodjam Property

The Woodjam property is hosted by a succession of Triassic–Jurassic Nicola volcanic and volcanosedimentary rocks that are intruded by several Jurassic monzonite to syenite stocks. The Takomkane batholith occurs in the eastern and southern parts of the property (Figure 2) and mainly consists of light-grey to pinkish to white hornblende-biotite granodiorite, monzogranite, quartz monzonite and quartz monzodiorite (Schiarizza et al., 2009). Nicola Group rock units comprise a sequence of plagioclase±pyroxene–phyric andesitic rocks, monomictic and polymictic volcanic breccias, and volcanic mudstones and sandstones, all of which dip moderately to the northwest (Gold Fields, pers. comm., 2012).

Locally, extensive olivine-phyric basalt flows of the Chilcotin Group are characterized by dark grey, aphanitic and vesicular basalt (Schiarizza et al., 2009). The flows have thicknesses of less than 20 m to more than 100 m and they overlie the Nicola stratigraphy.

Several zones of porphyry-type mineralization occur within and around porphyry stocks that intruded the strata of the Nicola Group. The Deerhorn deposit is hosted by multiple monzonite intrusions and volcanic rocks of the Nicola Group, whereas the SEZ deposit is hosted entirely in quartz monzonites of the Takomkane batholith (Gold Fields, pers. comm., 2012; Sherlock et al., 2012).

Hostrock Geology

Southeast Zone Deposit

The SEZ deposit is hosted by a series of texturally variable quartz monzonite intrusive units that strike ~220° and dip ~65–80° to the northwest (Rainbow, 2010). The quartz monzonites are divided texturally into fine-, medium- and coarse-grained units (Figures 3a, 4a; Rainbow, 2010). Fine-grained quartz monzonite cut both medium- and coarse-grained intrusive rocks. Aplite dikes cut all quartz monzonites with sharp contact. All quartz monzonite units are largely equigranular, white-grey to pink and comprise interlocking crystals of plagioclase, potassium feldspar and quartz. Mafic minerals are typically hornblende and less abundant fine-grained biotite. Quartz monzonites are intruded by K-feldspar porphyry (FP) bodies characterized by a phaneritic medium- to coarse-grained groundmass and large euhedral and elongated K-feldspar phenocrysts that occur sporadically throughout the unit. The FP forms a wide (>250 m) intrusion that strikes northeast (Rainbow, 2010; Sherlock et al., 2012). It cuts the quartz monzonite and has a chilled margin in the contact. All quartz monzonites were emplaced pre- to synmineralization and are affected by intense alteration, whereas the FP was probably emplaced during final stages of hydrothermal activity and is typically weakly altered. All of these units were intruded by late postmineralization plagioclase porphyry mafic and andesitic dikes (Rainbow, 2010; Sherlock et al., 2012).

Deerhorn Deposit

The Deerhorn deposit is hosted in both the volcanosedimentary rocks of the Nicola Group and the monzonitic rocks that intrude the Nicola strata (Figure 3b; Gold Fields, pers. comm., 2012; Scott, 2012). The host Nicola Group stratigraphy consists of volcaniclastic sandstone overlain by a plagioclase-phyric andesite with local clast breccia facies (Gold Fields, pers. comm., 2012). These units dip ~25°N in the deposit area and were intruded by at least two monzonite bodies. Monzonite A occurs as pencil-shaped intrusive bodies with irregular margins that intrude the volcanosedimentary rocks of the Nicola Group (Gold Fields, pers. comm., 2012). Intense alteration obliterated much of the primary texture of monzonite A but remnants of plagioclase and biotite phenocrysts are locally preserved. Monzonite D is characterized by plagioclase and hornblende phenocrysts (Gold Fields, pers. comm., 2012) and occurs as dikes with sharp contacts that crosscut monzonite A and Nicola Group stratigraphy (Gold Fields, pers. comm., 2012; Scott, 2012). The highest Cu and Au values occur in monzonite A and in the surrounding volcanic sandstone where grades are locally <1.5 g/t Au and <0.75% Cu (Gold Fields, pers. comm., 2012). Mineralization in monzonite D is mainly pyrite and subordinate chalcopyrite with Cu grades between 0.1 and 0.3% (Gold Fields, pers. comm., 2012). Postmineralization mafic and andesitic dikes crosscut all the Deerhorn hostrocks and phases of mineralization (Gold Fields, pers. comm., 2012).

Alteration

Hydrothermal alteration in both the Deerhorn and SEZ affected all hostrocks except postmineralization mafic and andesitic dikes. Several alteration assemblages are recognized in each deposit.

Southeast Zone

Potassium feldspar+biotite+magnetite (Table 1) is the earliest alteration assemblage in the SEZ deposit and typically occurs as pervasive alteration of K-feldspar replacing feldspar phenocrysts and biotite with minor magnetite replacing mafic minerals (Figure 4a). Potassium feldspar+biotite+magnetite alteration varies from very intense (i.e., nearly all texture and original minerals are destroyed) in the centre of the deposit to weak (i.e., only secondary biotite and K-feldspar flooding) at the margins of the deposit. Albite alteration is recognized at the northern extent of the deposit where it is juxtaposed against K-feldspar+biotite+magnetite alteration by a large northeast-striking fault. Albite alteration has a distinct bleached appearance and locally obliterates original rock textures (Figure 4b). Both K-feldspar+biotite+magnetite and albite alterations are overprinted by chlorite±epidote±pyrite, illite and hematite alterations (Table 1). At least some of chlorite and epidote occur with albite alteration. The intensity and distribution of chlorite±epidote± pyrite alteration is weakly inversely proportional to the K-feldspar+biotite+magnetite alteration. The former occurs more commonly at the margins of the deposit and is very weak to absent in the core of the deposit. Illite occurs as three visually and possibly paragenetically distinct types: dark green illite that replaces plagioclase phenocrysts, white illite that is fracture controlled and has locally patchy distribution, and apple green illite that overprints albite and K-feldspar alterations (Figure 4c).

Deerhorn

Alteration assemblages at the Deerhorn deposit are strongly controlled by the distribution of the monzonites (Scott, 2012). Potassium feldspar+biotite+magnetite alteration is very intense in monzonite A and in the volcanic rocks immediately surrounding these intrusions (Table 2, Figure 4d). Monzonite D is only moderately affected by K-feldspar+biotite+magnetite alteration, indicating that it postdated much of main-stage alteration. The K-feldspar+biotite+magnetite alteration is overprinted by chlorite±epidote±pyrite, ankerite, calcite and illite alteration assemblages (Table 2). The chlorite±epidote±pyrite alteration occurs mainly in monzonite D (Figure 4e) and in the surrounding volcanic hostrocks (Figure 3b). Ankerite and calcite veinlets occur throughout all rock types, but are not recognized together. Ankerite occurs in the northeastern extent of the area represented by the cross section, whereas calcite occurs in the centre and southwestern extents. Illite occurs mainly as vein envelope overprinting K-feldspar haloes associated with K-feldspar+biotite+magnetite alteration (Figure 4f).

Tables 1 and 2 summarize the alteration assemblages in both deposits from early to late events, on the basis of field relationships.

Vein Types and Paragenesis

Southeast Zone

The earliest veins in the SEZ deposit are rare magnetite stringers and quartz±chalcopyrite±magnetite veins. These veins occur locally in the core of the porphyry (Figure 5a; i.e., hole SE11-62 in Figure 3a). In the deep central and marginal areas of the SEZ, quartz±chalcopyrite±pyrite±molybdenite±anhydrite (±bornite) veins with K-feld-

Table 1. Description of alteration assemblages at the Southeast Zone deposit, Woodjam property, central British Columbia.

Alteration assemblage	Style	Veinlets	Intensity	Sulphide mineralization	Distribution
K-feldspar+biotite +magnetite	Pervasive replacement, K-feldspar replaces feldspar. biotite and magnetite replace mafic minerals	Magnetite (rare in the SEZ); quartz-chalcopyrite-magnetite; quartz-chalcopyrite-pyrite-molybdenite-(bornite); chalcopyrite±pyrite	Very intense in the core of the porphyry becoming weak in the margins; affects all units except late dikes	Main mineralization occurs with this alteration with py:cpy:mo ratio: core zone: 0.2:3:0; central zone: 1:2:1; marginal zone: 3:1:0.5	Throughout the deposit
Albite	Pervasive, fracture controlled		Very intense to moderate bleach of the rock	Barren	Marginal parts of the deposit
Chlorite±epidote ±pyrite	Patchy, selective, vein controlled and vein envelope	Pyrite-epidote±chalcopyrite	Moderate in the margins of the porphyry becoming very weak in the core.	Pyrite and minor chalcopyrite	Throughout the deposit
Illite	Selective and fracture controlled	Illite	Very intense when is fracture controlled bleaching the rock: affects all units except late dikes.	Barren	Shallow and marginal parts
Hematite	Patchy and fracture controlled	Hematite	Very weak to moderate, affects all rocks including plagioclase porphyry dikes	Barren	Marginal parts of the deposit

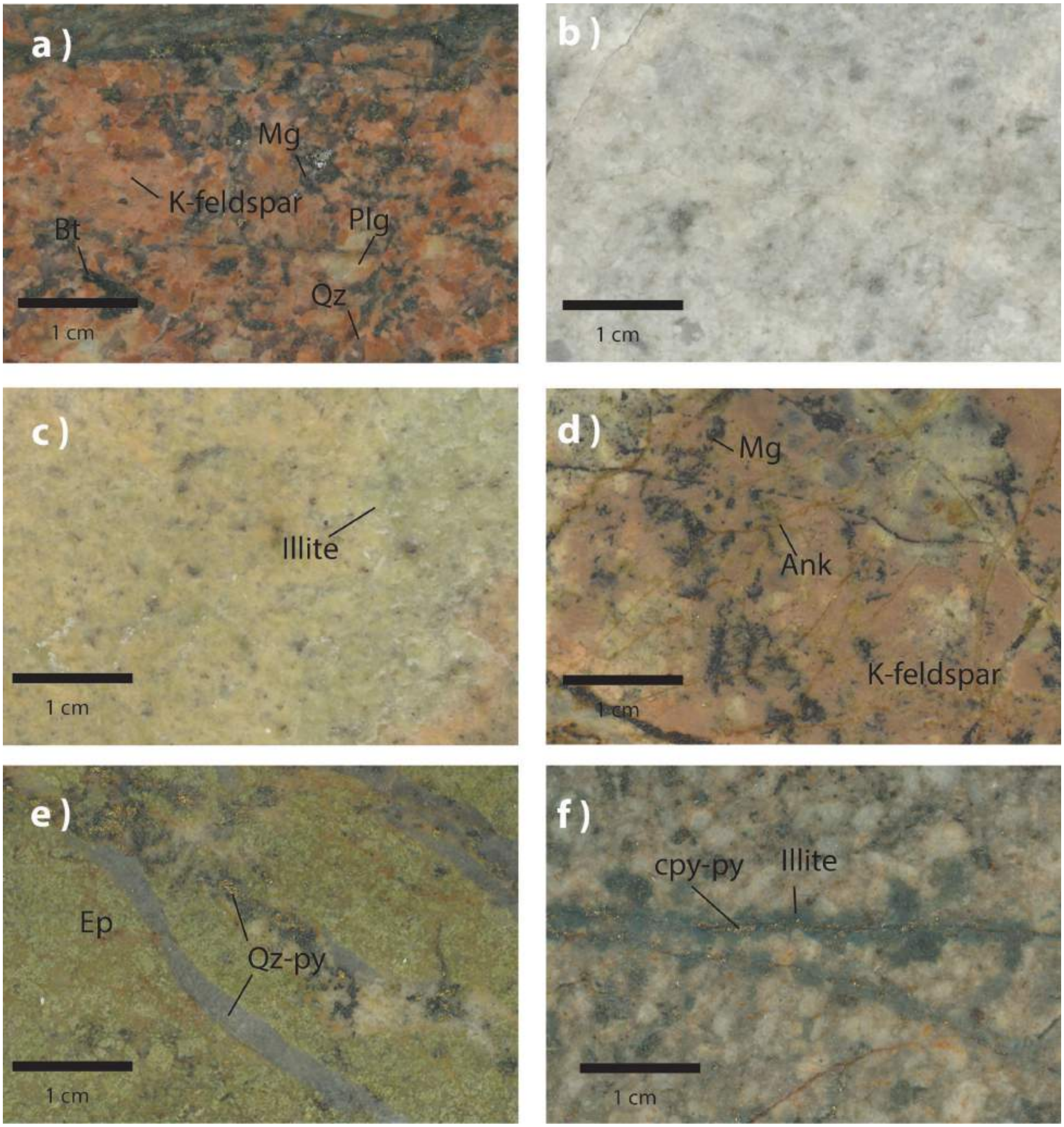

Figure 4. Alteration in the Southeast Zone (a, b, c) and Deerhorn (d, e, f) deposits (sample numbers represent drillhole numbers followed by depth): **a)** intense pervasive K-feldspar+biotite+magnetite alteration in coarse-grained quartz monzonite (SE11-62; 256.6 m); **b)** intense albite alteration of fine-grained quartz monzonite (SE11-36; 352.35 m); **c)** apple green illite alteration overprinting albite and K-feldspar+biotite+magnetite alteration in fine-grained quartz monzonite (SE10-18; 73.15 m); **d)** intense K-feldspar+biotite+magnetite alteration in the volcanic hostrock near the contact with monzonite A, with ankerite veins cutting the alteration (DH10-09; 202.85 m); **e)** epidote alteration halo to quartz-pyrite vein in the andesite volcaniclastic hostrock (DH10-09; 280.25 m); **f)** illite vein envelope of a chalcopyrite-pyrite stringer in monzonite D (DH10-09; 291.2 m). Abbreviations: Ank, ankerite; Bt, biotite; cpy, chalcopyrite; Ep, epidote; Mg, magnetite; Plg, plagioclase; py, pyrite; Qz, quartz.

Table 2. Description of alteration assemblages at the Deerhorn deposit, Woodjam property, central British Columbia.

Alteration assemblage	Style	Veinlets	Intensity	Sulphide mineralization	Distribution
K-feldspar+biotite+ magnetite	Pervasive, K-feldspar affects the groundmass and replaces feldspar phenocrysts, biotite and magnetite replace mafic minerals	Magnetite stockwork, quartz-chalcopyrite-magnetite-hematite, quartz-chalcopyrite-pyrite(±molybdenite)	Very intense in monzonite A, moderate in monzonite D, very intense where the volcanic hostrock is in contact with monzonite A, weak in the distal volcanic hostrock	Main mineralization occurs with this alteration with average py:cpy:au ratios of monzonite A: 1:2:4, monzonite D: 2:1:0, volcanic host rock: 4:2:1	Throughout the deposit
Chlorite±epidote± pyrite(±magnetite)	Vein envelope, selective and vein controlled	Quartz–chlorite–magnetite± K-feldspar±sulphides	Weak in monzonites A and D, moderate to intense in volcanic hostrock.	Pyrite associated with this alteration	Throughout the deposit
Ankerite or calcite	Vein controlled	Pyrite-quartz±chlorite ±carbonate±ankerite	Moderate to weak throughout all units	Barren	Ankerite in the northeast part of the section (DH10-09 and DH10-14); calcite in the centre and southwest part.
Illite	Vein envelope for Sulphide–epidote± hematite (±tourmaline), selective and fracture controlled	~	Very weak to strong when is fracture controlled; affects all units	Barren	Throughout the deposit

spar haloes also occur (Figure 5b). The timing relationship of these veins with magnetite-bearing veins is not known. Quartz±chalcopyrite±pyrite±molybdenite±anhydrite veins, with coarse quartz but without a K-feldspar halo (Figure 5c), cut quartz±sulphides±anhydrite veins with a K-feldspar halo; these last two types of veins do not occur with a frequency greater than four veins per metre. Pyrite±epidote±chlorite veins with epidote±hematite±illite haloes are the youngest veins that host pyrite with minor chalcopyrite and cut all earlier veins. Quartz±chalcopyrite±pyrite±molybdenite±anhydrite veins with and without K-feldspar haloes dominate areas with stronger K-feldspar+biotite+magnetite alteration but progressively become less abundant toward the margins of the deposit. Pyrite-epidote-chlorite veins occur most commonly at the margins of the deposit, and are associated with the intense chlorite±epidote±pyrite alteration assemblage of the hostrocks. They are rare to absent in the central parts of deposit. Pre- to synmineralization veins such as magnetite, quartz± magnetite±chalcopyrite and quartz±sulphides±anhydrite veins with and without K-feldspar haloes commonly occur in all quartz monzonite units but are less abundant in the K-feldspar porphyry unit. This unit is largely cut by late pyrite±epidote±chlorite veins. This relationship indicates that the K-feldspar porphyry unit is younger than the quartz monzonites and postdates at least part of the main phase of mineralization.

Deerhorn Deposit

In the Deerhorn deposit, early magnetite stockwork and Au-bearing quartz–magnetite±hematite±sulphide veins (Figure 5d; Scott, 2012) with banded texture commonly occur in monzonite A and the adjacent volcanic hostrock. Monzonite D cuts monzonite A and the early Au-bearing quartz-magnetite-sulphide veins. Quartz±sulphide veins occur throughout all rock types and cut the early quartz–magnetite±sulphide veins (Figure 5d). Locally, quartz±sulphide veins have an illite overprint of a K-feldspar halo, which is interpreted as a later event (Figure 4f). Quartz–magnetite–chlorite–K-feldspar veins occur in the volcanic hostrock (hole DH11-33 in Figure 3b; Figure 5e); however, crosscutting relationships with the veins described above are not observed. Pyrite–quartz±hematite±epidote±tourmaline veins with a white illite halo occur throughout all rock units, cutting early veins and pyrite–chlorite±calcite±ankerite veins (Figure 5f). Late carbonate and hematite veins occur throughout all hostrocks including late mafic dikes. These observations indicate that pre- to synmineralization veins such as the Au-bearing quartz–magnetite±sulphide occur mainly in monzonite A and in the volcanic hostrock adjacent to it, whereas monzonite D is commonly cut by late veins.

Tables 3 and 4 summarize various vein types observed at the SEZ and Deerhorn deposits, and give their analogies with common vein types (i.e., M, A, B and D veins) in porphyry copper deposits (Gustafson and Hunt, 1975; Arancibia and Clark, 1996; Sillitoe, 2000, 2010).

Mineralization

Copper, gold and molybdenum mineralization in the Woodjam property are controlled by the rock type, alteration, density of veining and location (margins or central area) within the porphyry system. In the SEZ deposit, Cu occurs dominantly in chalcopyrite with subordinate bornite disseminated but more commonly in veins (Figure 5a–c). Molybdenite is observed mainly in veins (Figure 5b). Sulphide minerals occur in quartz veins and chalcopyrite±py-

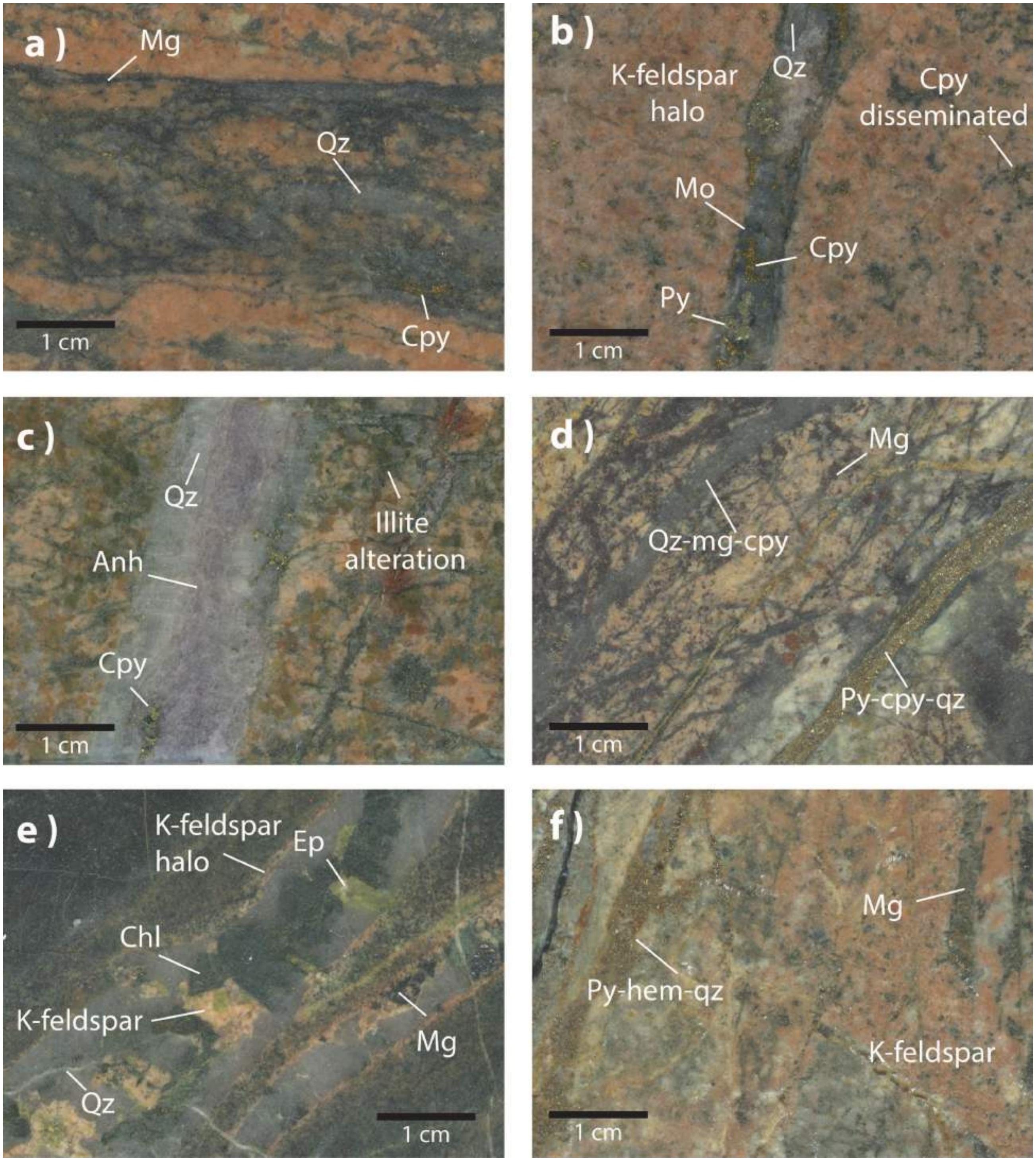

Figure 5. Examples of veining in the Southeast Zone (a, b, c) and Deerhorn (d, e, f) deposits, Woodjam property, central British Columbia (sample numbers represent drillhole numbers followed by depth): **a)** quartz-magnetite-chalcopyrite veining with very intense K-feldspar+biotite+magnetite alteration in coarse-grained quartz monzonite (SE11-62; 185.08 m); **b)** quartz-chalcopyrite-molybdenite-pyrite vein with a K-feldspar halo in the medium-grained quartz monzonite, disseminated chalcopyrite in a mafic mineral (SE11-59; 310.25 m); **c)** quartz-chalcopyrite-anhydrite centreline vein, with selective replacement of plagioclase by illite (SE11-36; 399 m); **d)** quartz-magnetite-chalcopyrite and magnetite veinlets are cut by a pyrite-chalcopyrite-quartz vein (DH12-39; 94.42 m); **e)** quartz–K-feldspar–magnetite–chlorite vein with a K-feldspar halo in the volcaniclastic sandstone (DH11-33; 248.2 m); **f)** K-feldspar vein-cut magnetite vein, which is itself cut by a pyrite-hematite-quartz vein (DH10-15; 210.35 m). Abbreviations: Anh, anhydrite; Chl, chlorite; Cpy, chalcopyrite; Ep, epidote; hem, hematite; Mg, magnetite; Mo, molybdenite; Qz, quartz; Py, pyrite.

Table 3. Southeast Zone vein descriptions, Woodjam property, central British Columbia.

Vein type	Alteration halo	Texture and shape	Sulphides	Related pervasive alteration	Analogies with PCD vein types	Distribution
Magnetite	No halo	1–2 mm wide	No sulphides	Intense K-feldspar, biotite and magnetite	M veins	Rare; core of the deposit (hole SE11-62)
Quartz–sulphides± magnetite	K-feldspar	Banded veins with diffuse edges: 3 mm–1 cm wide	Chalcopyrite(±bornite)	Intense K-feldspar, biotite and magnetite	A veins	Core of the deposit (hole SE11-62)
Quartz± sulphides± anhydrite (±chlorite)	K-feldspar	Diffuse edges; 2 mm–20 cm wide; up to four veins per metre	Chalcopyrite± molybdenite±pyrite (±bornite), more molybdenite-chalcopyrite towards the center, but molybdenite is absent in the core of porphyry; more pyrite to the margins	K-feldspar, biotite and magnetite	A veins	Throughout central part of the system (holes SE11-36, SE11-59 and SE11-62)
Quartz± sulphides± anhydrite	No halo	Sharp edges; coarse-grained quartz, frequently stringer veins; 1–3 mm wide; up to four veins per metre	Chalcopyrite±pyrite±molybdenite	K-feldspar, biotite and magnetite	B veins	Throughout central part of the system
Sulphides± epidote±quartz	Epidote±hematite± white illite	Sharp edges; 1–4 mm wide	Pyrite with minor chalcopyrite	Epidote-chlorite-pyrite	D veins	Marginal and shallower area of the system
Carbonate	No halo	Sharp edges; 1–5 mm wide	No sulphides	Carbonate and hematite	~	Throughout the deposit

* PCD: porphyry copper deposits

rite stringer veins as fine-grained and anhedral grains, whereas disseminations in the hostrock are intimately related to mafic mineral sites. Areas of high Cu grades (~0.5%) are characterized by dense stockworks of thin veins with abundant disseminated chalcopyrite in the hostrock. Copper grades decrease with depth (to amounts less than 0.4%) and copper mineralization becomes more concentrated in quartz veins up to 2 cm wide with K-feldspar haloes. An increase in anhydrite is also observed. Gold mineralization (less than 1 ppm; rarely up to 4 ppm) may be related to banded dark quartz-magnetite-chalcopyrite veins that occur in the core of the porphyry deposit.

Sulphide zoning at the SEZ deposit consists of a chalcopyrite±bornite (±pyrite; hole SE11-62) assemblage in the core of the deposit, which changes upward and outward to chal-

Table 4. Deerhorn vein descriptions, Woodjam property, central British Columbia.

Vein type	Alteration halo	Texture and shape	Sulphides	Related pervasive alteration	Analogies with PCD vein types	Distribution
Magnetite	No halo	density up to 30% of the rock; 1–2 mm wide	No sulphides	Intense K-feldspar, biotite and magnetite	M veins	In monzonite A and volcanic hostrock in areas near the contact with the intrusive body
Quartz-magnetite± hematite± sulphides	K-feldspar	laminated veins with indistinct margins; up to a 70% of the rock; 3 mm–2 cm wide	Chalcopyrite-bornite	Intense K-feldspar, biotite and magnetite	A veins	In monzonite A and the volcanic hostrock in areas near the contact with the intrusive body
Quartz±sulphides	No halo	Sharp edges; 1–4 mm wide	Chalcopyrite-pyrite (in monzonite A); pyrite± chalcopyrite (±molybdenite: in monzonite D)	K-feldspar, biotite and magnetite	A veins	Monzonite A, monzonite D and the volcanic hostrock in areas near the contact with the intrusive body
Quartz–magnetite–chlorite±K-feldspar± sulphides	K-feldspar	Sharp edges; 4 mm–1 cm wide	Chalcopyrite-pyrite	Chlorite–magnetite–K-feldspar–epidote	A veins	Volcanic hostrock, mainly in hole DH11-33
Sulphide–epidote± hematite(±tourmaline)	White illite	Sharp edges; 2–5 mm wide	Pyrite	Pyrite-epidote-hematite-illite	D veins	Mainly in the volcanic host rock and in monzonite D
Pyrite-quartz±chlorite ±carbonate/ankerite	White illite	Sharp edges; 1–3 mm wide	Pyrite	Pyrite-chlorite-carbonate-illite	D vein	Monzonite A, monzonite D and volcanic hostrock; ankerite occurs northeast of the area
Carbonate-hematite-gypsum	No halo	1–5 mm wide	No sulphides	Carbonate and hematite	~	Throughout the whole deposit

* PCD: porphyry copper deposits

copyrite±molybdenite±pyrite (holes SE11-59 and SE11-36) and finally, a pyrite-dominated assemblage in the periphery of the deposit (holes SE10-18 and SE11-24). However, mineralization is not symmetric through the system. For example, the northeast area was intruded by the late or synmineralized K-feldspar porphyry intrusion in which pyrite is the dominant sulphide with Cu grading less than 0.4%.

Mineralization at the Deerhorn deposit differs from the SEZ deposit in that it has significantly higher Au grades associated with Cu mineralization (up to <1.5 ppm Au and <0.75% Cu). Mineralization is hosted dominantly in monzonite A (Figure 5d) and the adjacent volcanic hostrocks and occurs as disseminated in both the early quartz-magnetite-chalcopyrite veins and in later quartz-sulphide veins. Monzonite D hosts lower grades of Cu mineralization (~0.1–0.3% Cu) but does not host significant Au. Trace amounts of molybdenite have been observed in the later-stage quartz sulphide veins in monzonite D.

Discussion

The characteristics of the hostrock, alteration and mineralization of the Deerhorn and SEZ deposits were documented on the basis of field observations in order to understand their similarities, differences and possible genetic relationships.

The Southeast Zone deposit is hosted in texturally variable quartz monzonite intrusive rocks that are inferred to be part of the Takomkane batholith. Alteration is zoned from intense K-feldspar+biotite+magnetite in the centre, which becomes weaker toward the margins and is laterally surrounded by albite alteration at the margins of the deposit. Chlorite±epidote±pyrite alteration overprints the K-feldspar+biotite+magnetite alteration and is locally intense at the margins of the deposit, but is weak to absent in the core. Illite alteration commonly occurs at the margins and upper levels with fracture-controlled hematite alteration overprinting chlorite+epidote+pyrite alteration. Mineralization is zoned from chalcopyrite-bornite mineralization anomalous in Au (~0.2 ppm) to pyrite-dominated mineralization at the margins. However, the low abundance of quartz veining is not a typical feature of calcalkalic deposits.

The Deerhorn deposit is hosted in a series of narrow (<100 m) monzonite intrusions that have ‘pencil’ geometries. No modal quartz is observed in the volcanic hostrocks or the monzonite intrusions. The lack of modal quartz is a common characteristic of alkalic porphyry systems in BC (Lang et al., 1995). Alteration is characterized by intense K-feldspar+biotite+magnetite in monzonite A and adjacent volcaniclastic rocks and is moderate to weak in monzonite D. Potassium feldspar+biotite+magnetite alteration is overprinted by chlorite+epidote+hematite+pyrite alteration and a later white illite alteration that occurs as a halo to tourmaline veins. The latest observed alteration stage comprises calcite+ankerite+pyrite. Mineralization is hosted in two vein stages: 1) a very dense laminated and sheeted network of quartz-magnetite-hematite-chalcopyrite veins that are strongly developed in monzonite A and the adjacent volcanic hostrocks and 2) later quartz-chalcopyrite-pyrite veins that crosscut all the hostrocks at the Deerhorn deposit, including monzonite D. The K-feldspar±biotite±magnetite alteration assemblage and the vein stages observed at the Deerhorn deposit are consistent with characteristics of Cu-Au calcalkalic porphyry systems (Sillitoe, 2000, 2010); however, the pencil-shaped intrusive hostrock lacking modal quartz is consistent with characteristics of Cu-Au alkalic porphyry systems (Holliday et al., 2002). These observations indicate that the Deerhorn deposit has characteristics of both alkalic and calcalkalic systems, similar to those at the Red Chris deposit in northwestern BC, where the hostrock is a quartz-poor monzonite and mineralization is hosted in banded quartz veins (Norris, 2011).

The close proximity as well as the similar alteration and vein stages of the SEZ and Deerhorn deposits suggest that they could be related and may represent a transition from the alkalic to calcalkalic environment. The next stage of this project will focus on the geochemistry and magmatic-hydrothermal evolution of these deposits in the Woodjam property, using detailed petrography and geochemical analyses.

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