Preliminary Study of the Magmatic Evolution, Mineralization and Alteration of the Red Chris Copper-Gold Porphyry Deposit, Northwestern British Columbia (NTS 104H/12W)

J.R. Norris, Mineral Deposit Research Unit, University of British Columbia, Vancouver, BC, jnorris@eos.ubc.ca

C.J.R. Hart, Mineral Deposit Research Unit, University of British Columbia, Vancouver, BC

R.M. Tosdal, Mineral Deposit Research Unit, University of British Columbia, Vancouver, BC

C. Rees, Imperial Metals Corporation, Vancouver, BC

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Introduction

The Red Chris porphyry copper-gold deposit is a unique deposit in British Columbia because it has geological features that are typical of both alkalic and calcalkalic porphyry deposit types. Quartz-vein stockworks, typically absent in alkalic porphyries, characterize the mineralized zones at Red Chris. Likewise, intense late-stage sericitic alteration, also characteristic of calcalkalic porphyry deposits, is present at Red Chris. Perhaps the most curious feature is the widespread and intense late carbonate alteration (Baker et al., 1999), which is not a common feature of porphyry copper systems (Seedorf et al., 2005). Nonetheless, Red Chris is hosted in monzonitic rocks, has a relatively limited lateral extent of mineralization, is deficient in molybdenum, has characteristic hematite alteration and has the high gold grades typical of BC alkalic porphyry deposits (Newell and Peatfield, 1995; Baker et al., 1999; Holliday and Cooke, 2007).

The property has been explored intermittently by several companies since the mid-1950s, with a hiatus between 1981 and 1994 when more focused drill projects dominated (Newell and Peatfield, 1995). Exploration drilling campaigns continued until 2005 and resulted in a calculated open-pit reserve by bcMetals Corporation of 276 million tonnes grading 0.35% Cu and 0.27 g/t Au (Ferreira, 2009). Following a takeover by Imperial Metals Corporation in February 2007, drilling targeted deeper mineralization in the 'East zone'. A vertical diamond-drill hole, RC07-335, intersected 1024.1 m of 1.01% Cu, 1.26 g/t Au and 3.92 g/t Ag over the length of the entire hole (Imperial Metals Corporation, 2007), which added new dimensions to the potential shape, depth, size and grade of the Red Chris deposit. More importantly, the deep drillhole demonstrates great vertical continuity at Red Chris and has significant implications for further exploration and mine planning. On a broader scale, results from the deep drillhole indicate significant potential for elevated gold and copper grades in BC's alkalic porphyry systems.

In light of this significant development, a research project has been jointly initiated by the Mineral Deposit Research Unit at the University of British Columbia, Imperial Metals Corporation and Geoscience BC. Observations and results presented herein are from investigations at the Red Chris deposit during a seven-week period in July and August of 2009, and provide the foundation for an M.Sc. research project. This project focuses on increasing the understanding of the magmatic evolution, mineralization styles and alteration of the deposit, with particular emphasis on the deeper parts of the system. Whereas significant mineralization is located in both the Main and East zones, this study focuses on the East zone along section line 452700E, where the nature of the intrusive rocks, mineralization, veins and alteration were investigated in four diamond-drill holes, RC94-079, RC94-106, RC95-225 and RC07-335. Previous descriptions of the rock units, mineralization, associated veins and alteration at Red Chris by Schink (1977), Ash et al. (1995), Blanchflower (1995) and Baker et al. (1999) provide additional information on the deposit.

The Red Chris deposit is in northwestern BC (Figure 1), approximately 80 km south of the town of Dease Lake and 12 km east of the Stewart-Cassiar Highway (Highway 37), and is accessed by a 23 km gravel road. Located in NTS area 104H/12W, the deposit is situated at latitude 57°42'N and longitude 129°47'W.

Keywords: *Stikine Terrane, copper, porphyry deposits, alteration*

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Tectonic Setting

Much of BC is underlain by several tectonic blocks that were accreted to the growing margin of western North America during the Mesozoic. Three of these accreted terranes, the Quesnel (or Quesnellia), the Stikine (or Stikinia) and the Cache Creek, form most of the Intermontane Belt that underlies much of central BC (Monger and Price, 2002). Stikinia and Quesnellia are Late Triassic to Early Jurassic island-arc terranes that host most of BC's porphyry deposits and are separated from each other by the intervening Cache Creek Terrane (McMillan et al., 1995; Figure 1). These dominantly Late Triassic volcanic island-arc terranes, which have surprisingly similar compositions and stratigraphy, formed outboard from the western North American continental margin and were subsequently accreted onto the margin during the Early Jurassic (Monger and Price, 2002). Porphyry copper deposits within Quesnellia and Stikinia formed largely prior to accretion, but some deposits continued to form into the Middle Jurassic (i.e., Mount Milligan; McMillan et al., 1995). The Red Chris porphyry deposit is hosted in the Late Triassic to Early Jurassic arc and arc-marginal sedimentary rocks in the northern portion of Stikinia.

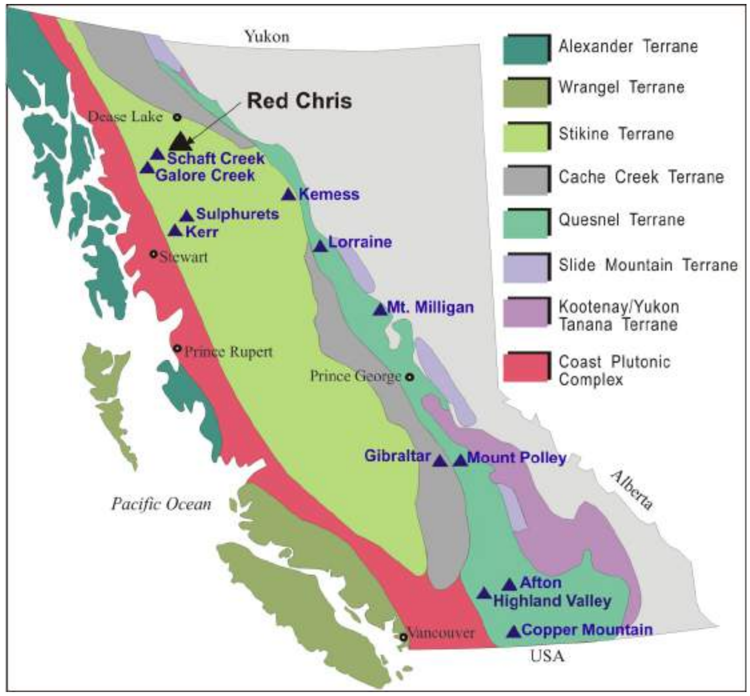


Figure 1. Major tectonic terranes and associated Mesozoic porphyry deposits of the Canadian Cordillera in British Columbia.

Regional Geology

In the Red Chris area, there are three main geological packages (Figure 2):

The Stuhini Group (**LTrS**) is a package of Late Triassic volcanic and volcanically derived sedimentary rocks that form part of Stikinia. These arc volcanic rocks are dominated by augite-phyric basaltic pillowed flows and flow breccias (Ash et al., 1995). The volcanic rocks are intercalated with fine-grained volcaniclastic siltstone, siliceous siltstone and feldspathic sandstone, on the order of metres to tens of metres.

Plutonic rocks of the Red stock (**LTrRmd**) intruded the Stuhini Group in the Late Triassic. The Red stock is elongated in an east to northeast direction, and is at least 4.5 km long and up to 1.5 km wide (Ash et al., 1995; Ferreira, 2009). The stock consists of medium- to coarse-grained hornblende-plagioclase–porphyritic quartz monzodiorite (Ash et al., 1995). A U-Pb zircon age from a sample taken at ~105 m depth in drillhole RC95-224 gave a crystallization age for the Red stock of 203.8 ±1.3 Ma (Freidman and Ash, 1997). The South Boundary fault truncates the Red stock at its southern margin and juxtaposes the plutonic rocks against the Bowser Lake Group.

Sedimentary rocks of the Middle Jurassic Bowser Lake Group (**MJB**) outcrop south of the South Boundary fault. These marine clastic sedimentary rocks, belonging to the Ashman Formation, were deposited unconformably on top of the Late Triassic volcanic and plutonic rocks. The sedimentary rocks represent the basal unit of the Bowser Lake Group and are composed of siltstone, chert-pebble conglomerate and sandstone (Evenchick and Thorkelson, 1993).

Deformation of the various rock units has complicated the deposit-scale geology. In particular, pre–Middle Jurassic deformation resulted in uplift and erosion of the Red stock and Stuhini volcanic rocks, and eventual depression to form the basement to the Bowser Basin.

Deposit Geology

The Red Chris deposit comprises several mineralized zones, the Main, East, Far West and Gully zones, but only the Main and East zones currently host economic resources (Figure 2). The Main zone has a larger areal extent than the East zone, with their centres ~600 m apart. Both the Main zone and East zone orebodies are vertical to subvertical, apparent pipe-like structures that are elongated along the general east-northeasterly-trending fault structures in the region (Collins et al., 2004).

The ore zones are hosted entirely within the Red stock, a plagioclase-hornblende–porphyritic monzodiorite that may consist of several different intrusive phases. However, the mineralized portion of the stock, particularly the East zone, is dominated by sericitic and K-silicate alteration, and fresh monzodiorite was not observed in the holes logged in this study. The stock is cut by several late-stage felsic dikes. Several different styles of veins are present in the Red stock. Copper mineralization occurs as disseminated and fracture-controlled chalcopyrite and bornite, whereas gold occurs as microscopic inclusions within these copper-sulphide minerals. Copper and gold occur within banded stockwork veins and sulphide-only veins.

Main Phase

The composite Red stock in the East zone along section line 452700E (Figure 3) consists of two phases (see also Schink, 1977), a main phase and a late phase, both of which are cut by post-mineral dikes.

The main phase of the Red stock is medium grey with phenocrysts of plagioclase and hornblende in a very fine grained groundmass (Figure 4a). The groundmass typically accounts for 40% of the rock and consists of anhedral microcrystalline alkali feldspar and minor quartz (Schink, 1977). The feldspar phenocrysts are generally buff white, 2–4 mm euhedral to subhedral crystals (Figure 4b–d). Hornblende phenocrysts are altered to secondary biotite and sericite, making the primary texture difficult to ascertain, but are typically euhedral, 2–10 mm crystals with distinct crystal boundaries (Figure 4b–d). The phenocrysts are randomly oriented within the grey aphanitic groundmass (Schink, 1977). Estimated visually, phenocryst abundance typically varies between 15 and 30% but can be as low as 5% and as high as 45% (Figure 4a–d).

Previous studies have demonstrated that the Red stock intrusive suite is monzonite to monzodiorite in composition (Ash et al., 1995). However, it is uncertain if the K-feldspar in the groundmass is primary or of secondary origin due to extensive alteration. Throughout this paper, the Red stock will also be referred to as a monzodiorite.

Variations in phenocryst size and abundance were observed in the drillholes across the section line. These changes may

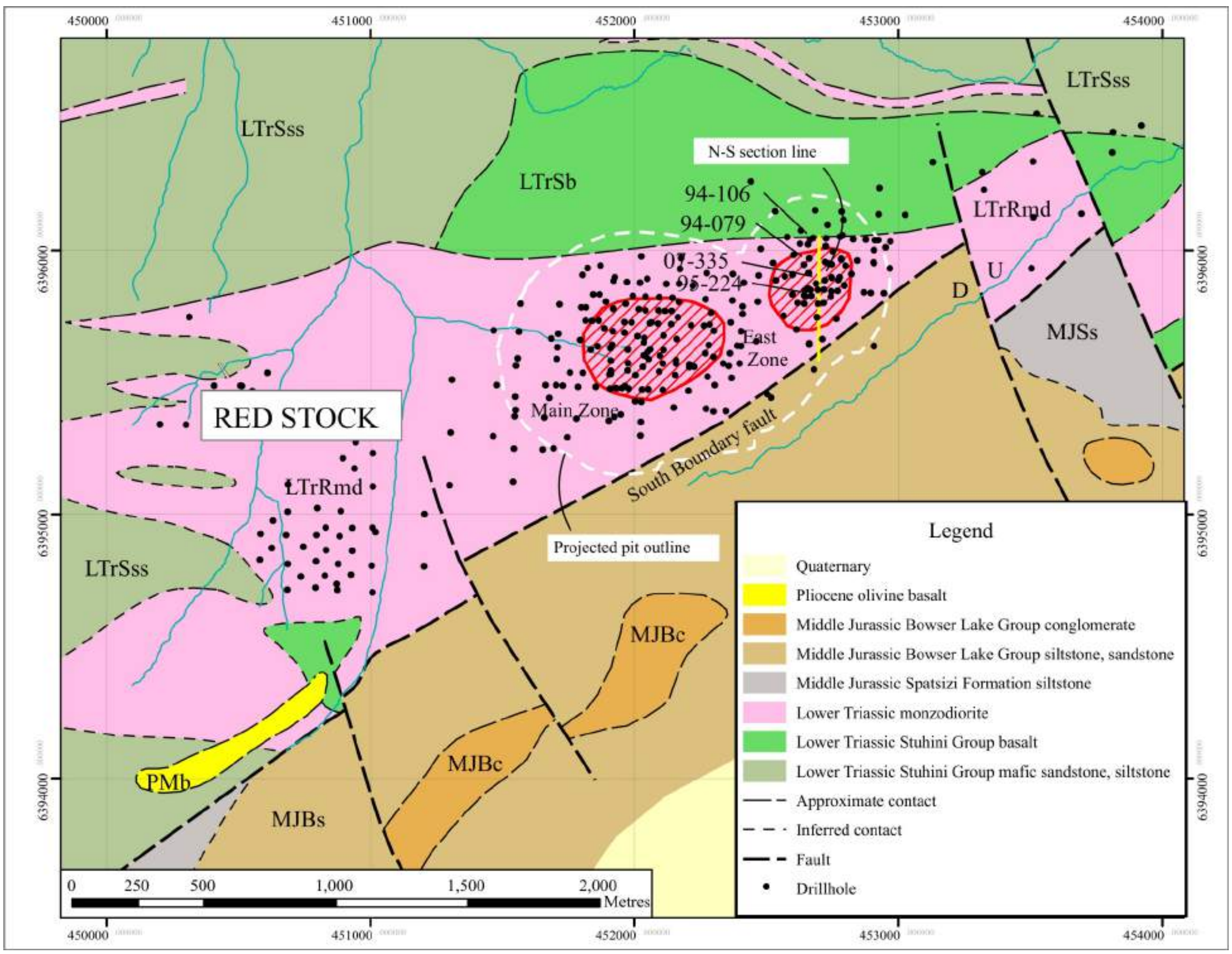


Figure 2. Deposit-scale geology of the Red Chris deposit, northwestern British Columbia, as interpreted by Imperial Metals Corporation. The Main and East zone orebodies are the red striped areas. The planned open-pit outline is indicated by a dashed white line, and the north-south cross-section investigated in this study, with the relevant diamond-drill holes, is a solid yellow line.

indicate that there are different porphyritic phases or intrusions that form the Red stock. Unfortunately, definitive intrusive relationships are uncommon due to late-mineral hydrothermal alteration and post-mineral breccia and faults occupying the contact zones.

Late Phase

A late phase of the Red stock was not observed during this study but is described by Schink (1977) as being very similar in composition to the main phase. It is a grey, medium-grained, plagioclase-hornblende–porphyritic monzonite. The main difference is that the late phase is less altered and barren of copper-Fe sulphides, making it hard to differentiate between a weakly altered main phase and the relatively unaltered late phase. The typical fresh look of the late phase has been used to distinguish it from the main phase. The late phase lacks quartz veins, which is a diagnostic feature in a comparison with the main phase of the intrusion (Blanchflower, 1995).

Post-Mineral Dikes

Two types of 1–5 m wide, diorite to monzodiorite dikes crosscut the Red stock at steep angles. These two types, amygdaloidal monzodiorite and biotite diorite, make up <2% of the stock, do not contain mineralization and are both cut by minor, buff-white carbonate veins. The amygdaloidal monzodiorite dikes are beige to locally light green and very fine grained with carbonate>quartz amygdules 2–10 mm in size. Euhedral hornblende phenocrysts (<3%), up to 4 mm long, are altered to carbonate, ankerite and/or chlorite. The biotite diorite dikes are light to medium green and very fine grained, with up to 10% hornblende and/or biotite phenocrysts, up to 5 mm long, that are locally altered to carbonate, ankerite and/or chlorite.

Alteration

Alteration in the East zone along section line 452700E is dominantly potassic (herein called K-silicate alteration) and is overprinted by sericitic alteration. The main zone of K-silicate alteration is in the deeper parts (>350 m) of the cross-section. The main extent of the K-silicate alteration forms a narrow vertical zone centred near drillhole RC07-335. Potassium-silicate alteration was also noted in a few locations within drillholes RC94-106 and RC94-079, which are within 30 m of drillhole RC07-335. Potassium-silicate alteration in the shallower portion of the section has been overprinted by sericitic alteration, making it difficult to determine the original extent of the K-silicate zone. Primary igneous mafic minerals within the K-silicate–altered zone have been replaced by secondary biotite and have diffuse grain boundaries. These diffuse mafic crystal sites can be used as a general proxy to identify and recognize zones of monzodiorite that experienced K-silicate alteration prior to the sericitic overprint.

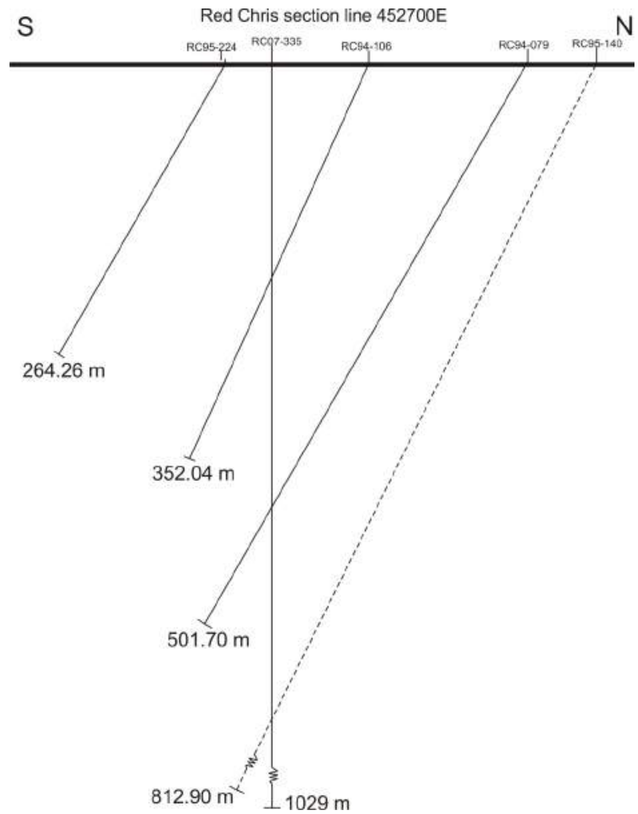


Figure 3.: North-south cross-section along section line 452700E (±30 m) across the East zone of the Red Chris deposit, northwestern British Columbia. Diamond-drill hole RC95-140 has yet to be investigated in this study.

The K-silicate alteration zone is characterized by secondary biotite and magnetite replacing igneous amphibole, and by texturally destructive K-feldspar that has replaced the groundmass and primary plagioclase feldspar phenocrysts (Figure 5a, b). Baker et al. (1999) noted that the porphyritic igneous texture may be completely destroyed by fine-grained orthoclase and albitic feldspar ($Ab_{80–94}$; Schink, 1977). Primary mafic minerals are replaced by secondary biotite and magnetite, and locally by later chlorite (Figure 5c). Hematite, also in the mafic sites, is the dominant oxide above 400 m (vertical depth), whereas magnetite is in much greater abundance below 400 m, an observation also made by Baker et al. (1999). Specular hematite is also observed as 1–2 mm blebs replacing magnetite in secondary biotite within the K-silicate alteration zone. In deeper portions of the zone (below 400 m), magnetite-only veins are directly associated with the K-silicate alteration.

Sericitic alteration is widespread, dominantly in the upper ~300 m of the section (Figure 5d, e) and outboard from the margins of the K-silicate zone. It has a gradational overprint on the K-silicate–altered monzodiorite. Also noted by Baker et al. (1999) are minor lenses of K-silicate–altered monzodiorite with a very weak sericitic overprint, as observed in drillholes RC94-079 and RC94-106. Sericite pervasively alters both plagioclase and alkali feldspars and hornblende phenocrysts of the primary monzodiorite to buff white, pale orange and locally pale green colours (Figure 5d, e). Throughout the sericitic zone, pervasive but minor hematite occupies the mafic sites and has both sharp and diffuse crystal boundaries. The hematite is very fine grained and maroon coloured. Pyrite alteration within the sericitic zone tends to increase in the upper portion of the section, occurring as very fine to fine-grained anhedral crystals occurring preferentially within the mafic crystal sites. Pervasive carbonate alteration is spatially associated with the sericitic alteration in the upper portions of the section. Baker et al. (1999) reported a ferroan-dolomite composition for this carbonate alteration (Figure 5e, f).

Veins

Five main vein types are recognized cutting the Red stock. They are described below in order of abundance (by volume).

Quartz Stockwork Veins

Massive quartz stockwork veins cut the Red stock monzodiorite. These veins are banded with repeating zones of quartz±sulphides±oxides (Figure 6a). The quartz stockwork veins vary significantly in density and can form up to 90% of the rock, as observed in drillcore. A single banded vein is typically 1–5 cm in width but can be up to 10 cm wide in zones of intense veining. Quartz stockwork veins are cut by younger generations of the same vein style but at different orientations. Mineral assemblages within the veins include 1) quartz±magnetite±specular hematite±white carbonate (quartz-oxide-carbonate veins); 2) quartz±bornite±chalcopyrite±pyrite±white carbonate (quartz-sulphide-carbonate veins); or 3) a combination of the two previous types, containing quartz±magnetite±specular hematite±bornite±chalcopyrite±pyrite±white carbonate. The banded quartz veins are locally cut by sulphide-only veins that occur in the vein centres. Quartz veins containing magnetite and hematite occur proximal to the core of the K-silicate–altered zone, whereas quartz veins with hematite as the only oxide decrease in abundance outward from the K-silicate core. Alteration envelopes are not pervasive around the quartz stockwork veins. However, in deep portions of the section, envelopes of K-silicate alteration can occur around thin, wispy chlorite±pyrite±quartz veins (Figure 6b).

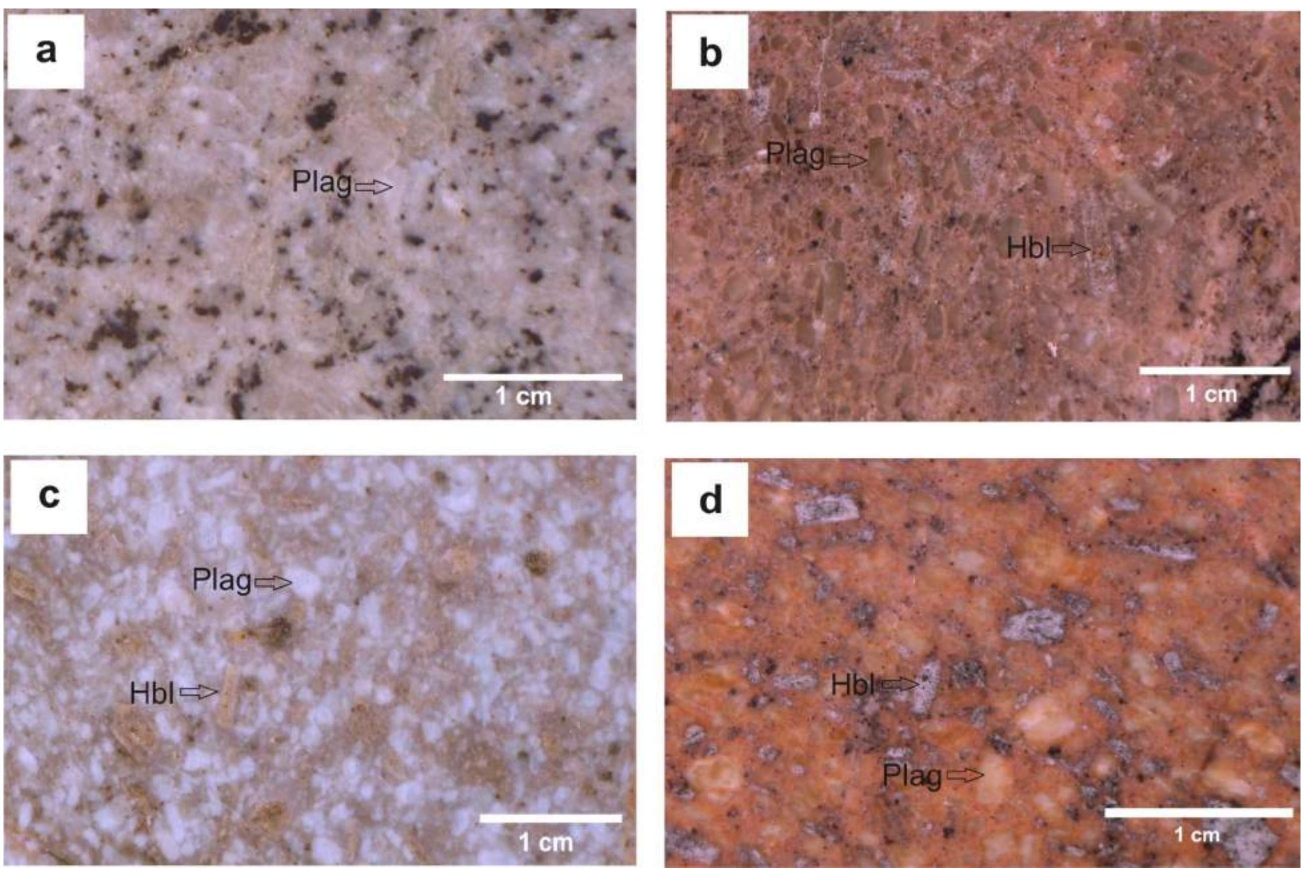


Figure 4. Examples of the Red stock taken from diamond-drill holes on the Red Chris deposit, northwestern British Columbia, illustrating the variability in phenocryst size and abundance. **a)** 10% plagioclase (Plag) up to 2 mm in length, drillhole RC79-003 (51.52 m); **b)** 15% plagioclase up to 4 mm in length and 10% hornblende (Hbl) up to 1 cm in length, drillhole RC106-038 (405.51 m); **c)** 25% plagioclase up to 4 mm in length and 5% hornblende up to 7 mm in length, drillhole RC335-036 (461.90 m). **d)** 10% plagioclase up to 3 mm in length and 15% hornblende up to 5 mm in length, drillhole RC224-006 (124.48 m).

Quartz-Pyrite Veins

Quartz-pyrite veins are common throughout the observed drillholes of the cross-section and are slightly more abundant in the upper sericitic zone. The quartz-pyrite veins are typically 2–5 mm in width but can be up to 1 cm. These veins are locally banded with three to five bands of quartz containing one or more millimetre-wide, central lines of pyrite. Rare, light green sericitic alteration envelopes are associated with these generally straight-edged quartz-pyrite veins.

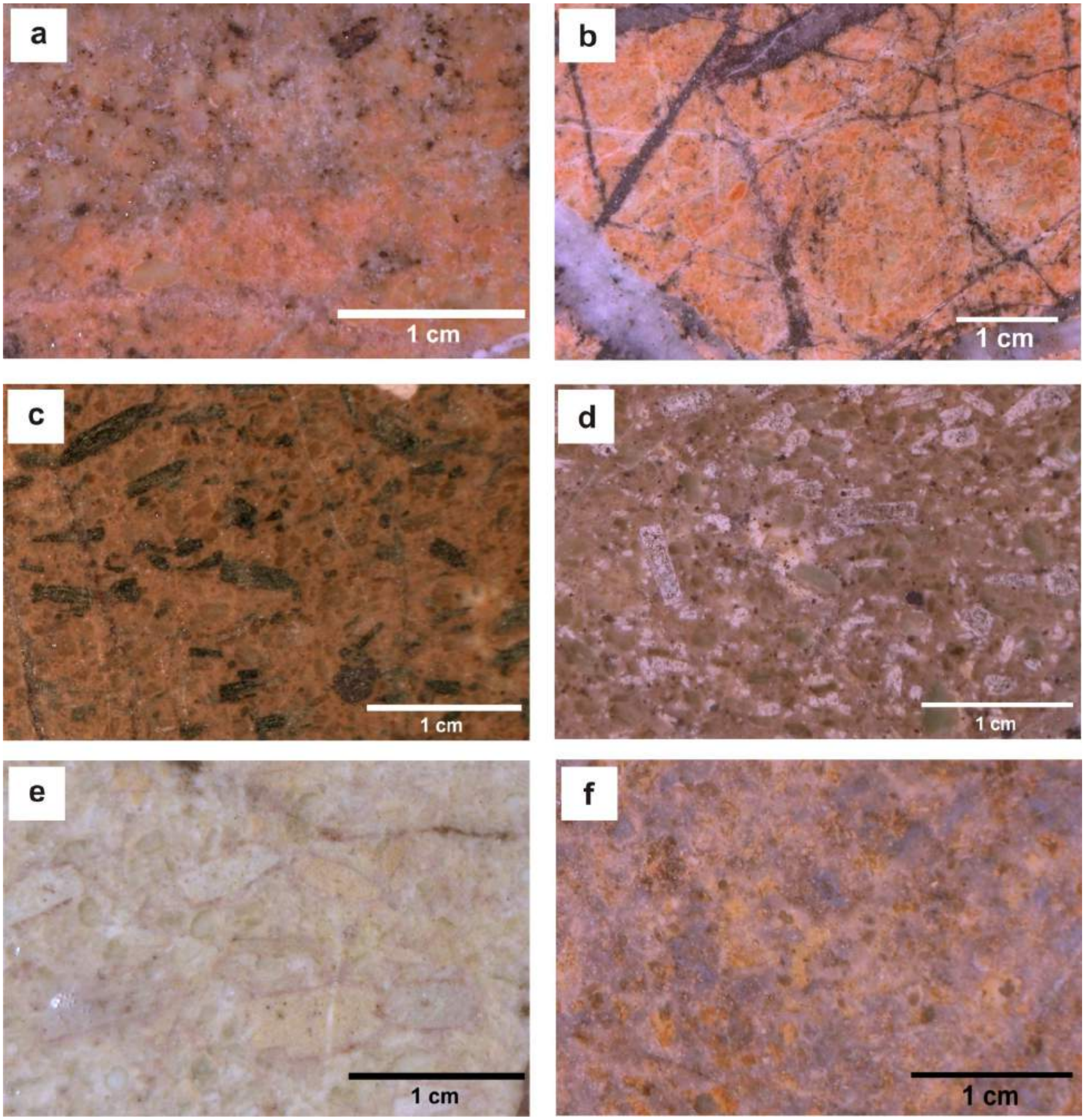


Figure 5. Typical examples of K-silicate and sericitic alteration in the Red stock from drillholes in the East zone of the Red Chris deposit, northwestern British Columbia: **a)** texturally destructive K-silicate alteration of monzodiorite, drillhole RC335-070 (985.37 m); **b)** intense K-silicate alteration of the groundmass, drillhole RC335-060 (863.54 m); **c)** K-silicate alteration of the groundmass with secondary biotite phenocrysts being altered to magnetite and chlorite, drillhole RC335-034 (409.48 m); **d)** illite (light green) alteration of plagioclase phenocrysts and kaolinite (blotchy white) alteration of hornblende phenocrysts (illite and kaolinite logged as sericite), drillhole RC335-041 (532.90 m); **e)** intense kaolinite and illite alteration of the plagioclase and hornblende phenocrysts and of the groundmass (illite and kaolinite logged as sericite), with the groundmass also being pervasively carbonate altered, drillhole RC335-035 (441.17 m); **f)** pervasive carbonate (ankerite?) alteration of plagioclase and hornblende phenocrysts (orange coloured), along with intense carbonate alteration of the groundmass, drillhole RC106-019 (151.31 m).

Barren Quartz Veins

Quartz veins contain minor oxide minerals±sulphide minerals±white carbonate but are barren of significant ore minerals (Figure 6c). These quartz veins can be banded and contain very fine crystals of chalcopyrite, pyrite or hematite. They are generally straight edged, are typically 2–10 mm thick and lack alteration envelopes.

Sulphide-Only Veins

Veins containing only sulphide minerals occur in the deeper K-silicate–altered portions of drillhole RC07-335. These sulphide-only veins are either 1) bornite only, 2) bornite+chalcopyrite, 3) chalcopyrite only, 4) chalcopyrite+pyrite, or 5) pyrite only (Figure 6d, e). Abundant pyrite-only veins occur in the upper portions of the cross-section, where sericitic alteration dominates. They are absent in the lower portion, where K-silicate alteration is dominant. These veins are typically only 1–2 mm in width and are generally straight edged to slightly anastomosing. No obvious alteration envelopes were noted.

Late-Stage Carbonate Veins

Buff-white carbonate veins cut all other types of veins. These veins are typically carbonate only (Figure 6f, g) but locally include pyrite±chalcopyrite (Figure 6h). The pyrite typically forms fine- to medium-grained subhedral crystals and is more abundant than chalcopyrite. Veins are typically 1–30 cm wide. Locally, carbonate veins are associated with breccia zones. Angular clasts of monzodiorite (5–20 mm) and quartz-vein fragments are cemented by carbonate and can form zones up to several metres wide. Carbonate veins are found at all depths of the cross-section.

Mineralization

Copper and gold grades in the East zone at Red Chris are concentrated in both disseminated and vein-hosted bornite and chalcopyrite that are mostly within the banded quartz stockwork veins. Bornite and chalcopyrite are dominantly fine anhedral grains within veins and wallrock. Locally, they form aggregates within quartz veins that host minor to moderate white carbonate. Sulphide-only veins of chalcopyrite and/or bornite, 1–2 mm thick and moderately wavy in character, are particularly common in deeper portions of drillhole RC07-335 where K-silicate alteration dominates. Trace amounts of very fine grained chalcopyrite are present within the K-silicate–altered mafic mineral sites.

Bornite, chalcopyrite and pyrite in quartz veins are observed along the length of drillholes RC94-079, RC94-106, RC95-224 and RC07-335. Sulphide mineral assemblages appear to form a lower chalcopyrite+bornite–only core that is surrounded by a zone of chalcopyrite+pyrite, then surrounded by an outer zone dominated by pyrite, For example, strong to intense pyrite in the uppermost 50 m of drillhole RC07-335 decreases to trace amounts at the end of the hole, whereas chalcopyrite is variably strong to intense down to depths of 770 m and bornite increases from trace amounts between 240 and 685 m to somewhat more than that by 760 m, with both bornite and chalcopyrite occurring in moderate amounts to the bottom of the hole at 1029 m.

Gold in the East zone at Red Chris has an average ratio of approximately 1:1 with copper (i.e., g/t Au : % Cu) and they are strongly correlated (r^2 = 0.89; Baker et al., 1999). No visible gold was observed. The highest gold grades are associated with the highest densities of banded quartz stockwork veins.

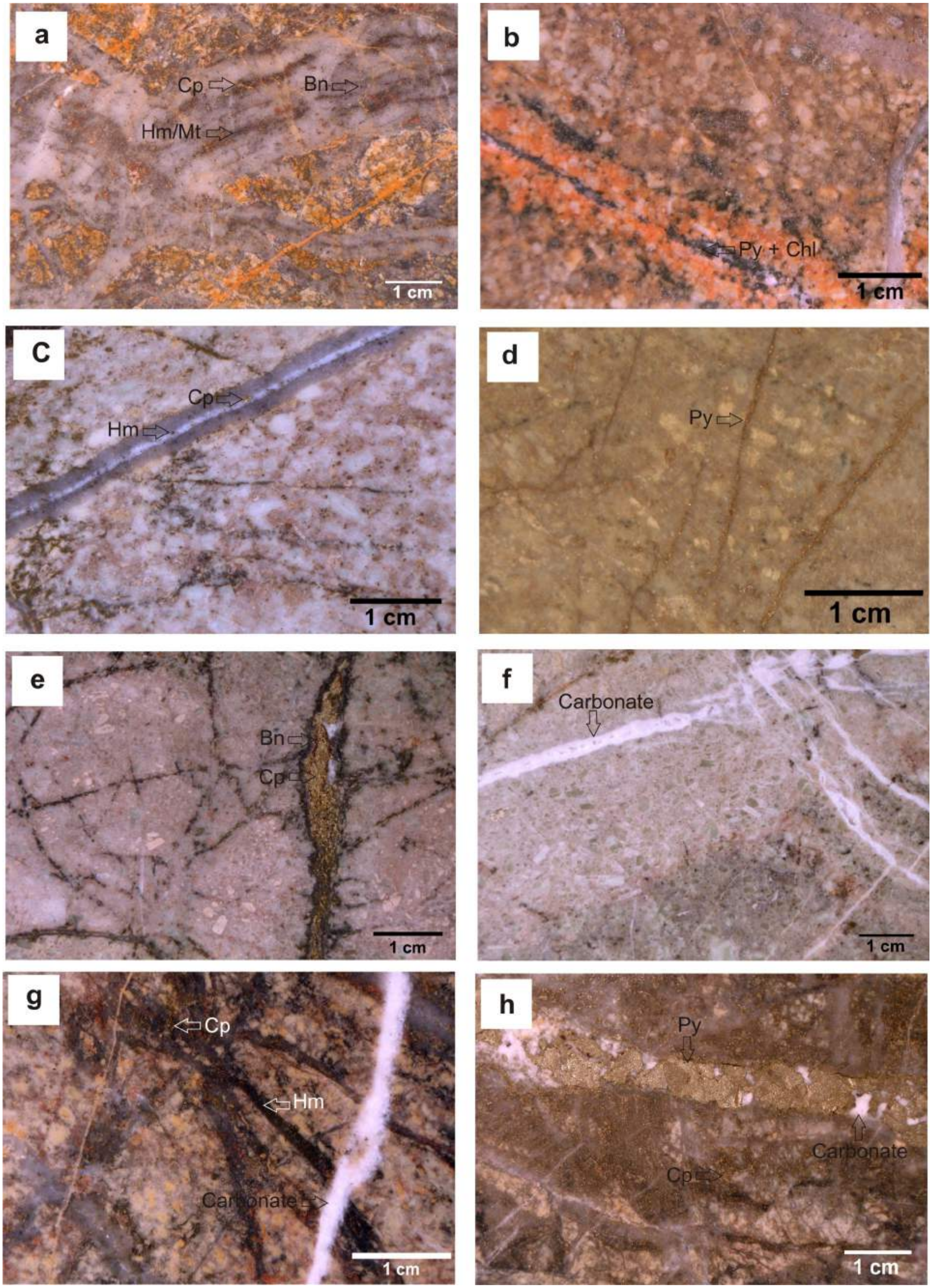
Discussion and Conclusions

Although only one main phase of the Red stock was recognized in this study, observed changes in phenocryst sizes and abundances indicate that several different porphyritic phases may collectively form the Red stock. The contacts between these different phases are typically marked by zones of brecciation, which make crosscutting relationships difficult to determine. It is likely that these brecciated zones represent the original intrusive contacts between different porphyry units that were later exploited by successive structural and fluid events, including deposition of the abundant late carbonate cement that is characteristic of these breccia zones. Some of these porphyry phases have much higher densities of veins and higher copper and gold grades, and are interpreted to be early phases of the intrusion. Simple use of copper and gold grades may therefore help to distinguish between different porphyritic phases in the absence of other paragenetic information.

The typically high-grade mineralization at Red Chris is closely associated with areas that have multiple generations of the banded quartz stockwork veins. In general, the copper and gold grades are much lower in areas where sericitic alteration is intense and dominant. This alteration may have reduced the grade by remobilizing copper sulphide minerals that were deposited in previous mineralizing events.

Controls on the distribution and occurrences of hematite and magnetite remain ambiguous. The presence of hematite and magnetite in veins is directly associated with the K-silicate core. However, the occurrence of hematite and magnetite within mafic sites is patchy and irregular. Magnetite replaces hornblende and secondary biotite locally within the K-silicate–altered zones, whereas hematite occurs in the mafic sites within zones of the widespread sericitic-alteration overprint. The fluids involved in the sericitic alteration of the monzodiorite may have altered the magnetite to hematite.

Numerous crosscutting relationships between the different vein types observed in the East zone make it difficult to confidently determine a relative paragenesis. Fluids associ-


a
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ated with individual porphyritic intrusions fractured earlier intrusions of the Red stock. The evolution of the magmatic compositions and their relationships to the veins, mineralization and alteration, and the characterization of paragenetic vein sequences, are the focus of the next stage of research on the Red Chris deposit.

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Figure 6.: Typical examples of vein types that cut the Red stock monzodiorite, from drillholes in the Red Chris deposit, northwestern British Columbia: **a)** banded quartz stockwork veins with disseminated and fracture-controlled hematite-magnetite (Hm/Mt), chalcopyrite (Cp) and bornite (Bn), drillhole RC106-032 (316.03 m); **b)** thin quartz-pyrite (Py)±chlorite (Chl) veinlets with K-silicate alteration envelope, drillhole RC335-075 (1020.78 m); **c)** barren quartz vein (banded quartz+carbonate vein with minor disseminated hematite [Hm]+chalcopyrite [Cp]), drillhole RC335-019 (229.88 m); **d)** sulphide-only veins (thin, wispy pyrite veins), drillhole RC106-011 (102.51 m); **e)** sulphide-only vein (chalcopyrite+bornite vein with minor quartz and carbonate and a thin, dark brown-green alteration selvage [secondary biotite? chlorite?]), drillhole RC335-046 (618.13 m); **f)** late-stage carbonate vein (multiple generations of thin carbonate [dolomite?] veins), drillhole RC106-037 (404.07 m); **g)** late-stage, thin white carbonate vein (dolomite?) cutting quartz veins and quartz+hematite±chalcopyrite±bornite veins, the monzodiorite hostrock being weakly K-silicate altered, drillhole RC335-008 (88.27 m); **h)** late-stage carbonate vein with abundant coarse-grained pyrite crosscutting quartz+pyrite+chalcopyrite stockwork veins, drillhole RC335-039 (505.42 m).

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