Hydrothermal Alteration and Mineralization at the Kerr and Deep Kerr Cu-Au Porphyry Deposits, Northwestern British Columbia

MDRU Mineral Deposit Research Unit

a place of mind
THE UNIVERSITY OF BRITISH COLUMBIA

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Geoscience BC

KSM PROJECT
SEABRIDGE GOLD

I. Introduction

This research project focuses on the characterization and evolution of hydrothermal alteration assemblages and mineralization at the Kerr and Deep Kerr deposits. Kerr and Deep Kerr are part of the Kerr-Sulphurets-Mitchell (KSM) property, which represents one of the largest undeveloped porphyry systems globally. The objective is to provide a better understanding of the correlation between hydrothermal alteration and mineralization, in order to contribute to the improvement of exploration tools and geometallurgical decision-making, thereby increasing exploration and economic success within British Columbia and in other porphyry districts.

II. Tectonic and Geological Setting

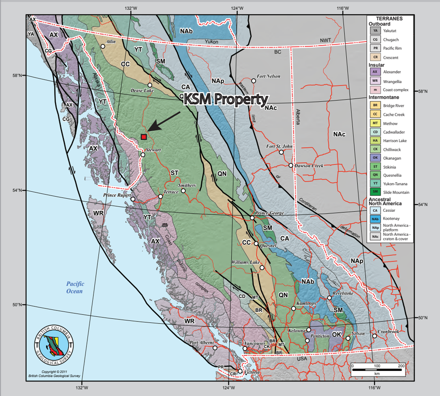


Fig. 1 Terranes of British Columbia (BCGS, 2011).

The KSM property is hosted within the western margin of northern Stikinia, in the Sulphurets district. Porphyry mineralization in this district has been dated between 197 – 190 Ma (Bridge, 1993; Margolis, 1993; Kirkham and Margolis, 1995; Febbo et al., 2015). The Stikine Terrane in northwestern British Columbia is composed of island arc volcanosedimentary successions that include the Stikine assemblage (Paleozoic), Stuhini Group (Late Triassic), and the Hazelton Group (Early Jurassic). The Mitchell intrusions of the Sulphurets district are considered a subset of the Texas Creek Plutonic Suite, an Early Jurassic suite that is comagmatic and coeval with the Lower Hazelton Group, and comprises I-type, calcalkaline intrusive rocks that are cospatial with Hazelton volcanic rocks (Kirkham, 1963; Alldrick and Britton, 1991; Logan et al., 2000).

III. KSM Property Overview and Geology

Measured Plus Indicated Resources (0.50g/t Gold Equivalent Cutoff-Grade)*

Zone	Tonnes (Mt)	Au (g/t)	Au (Moz)	Cu (%)	Cu (Mlbs)	Mo (ppm)	Mo (Mlbs)
Mitchell	1,776	0.61	34.8	0.17	6,585	58	226.3
Sulphurets	371	0.59	7.0	0.21	1,717	49	40.1
Kerr	**270**	**0.24**	**2.1**	**0.46**	**2,741**	**N/A**	**N/A**
Iron Cap	362	0.44	5.1	0.21	1,674	47	37.5
KSM Total	**2,780**	**0.55**	**49.0**	**0.21**	**12,717**	**55**	**303.8**

**2012 NI 43-101 Compliant Resource Estimate (http://seabridgegold.net/ksm_resources.php) The KSM project has total proven and probable reserves of 38.2 million ounces of gold and 9.9 billion pounds of copper.*

Deep Kerr Inferred Resource*

Zone	Tonnes (Mt)	Au (g/t)	Au (Moz)	Cu (%)	Cu (Mlbs)	Mo (ppm)	Mo (Mlbs)
Deep Kerr	**782**	**0.33**	**8.2**	**0.54**	**9,300**	**N/A**	**N/A**

**Updated (http://seabridgegold.net/News/Article/516/seabridge-gold-reports-52%25-resource-expansion-for-ksm-s-deep-kerr-deposit-estimated-782-million-tonne-inferred-resource-averages-0.54%25-copper-and-0.33-g-t-gold.-deposit-now-contains-estimated-8.2-million-ounces-gold).*

The KSM property comprises the Kerr, Deep Kerr, Sulphurets, Mitchell, Iron Cap, and Lower Iron Cap deposits, and has total proven and probable reserves of 38.2 million oz.'s Au and 9.9 billion lb.'s Cu. The KSM deposits are hosted in volcanic arc related Triassic to Jurassic volcanic and sedimentary assemblages that were intruded by Early Jurassic diorite, monzonite, and quartz syenite intrusions.

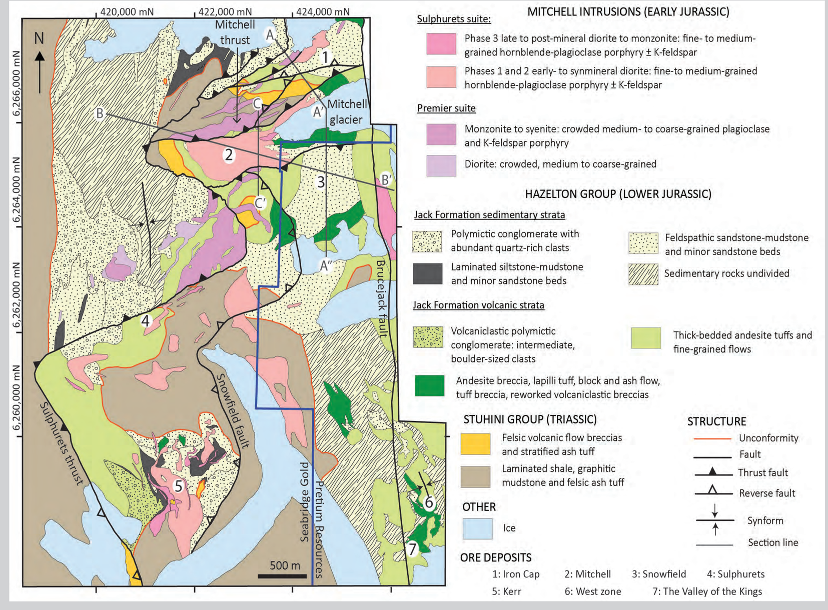


Fig. 2 KSM Property Geology (Febbo, in press)

IV. Structure

The Kerr and Deep Kerr deposits strike north and dip steeply to the west, with the shallower portion of the deposit (upper ~500m) defined as the Kerr deposit, and the newly discovered Deep Kerr deposit underlying the Kerr deposit and open at depth.

The Kerr deposit is strongly deformed, as pre-existing structures and intense alteration led to the development of a low competency zone where Cretaceous compression was focused (Ditson et al., 1995).

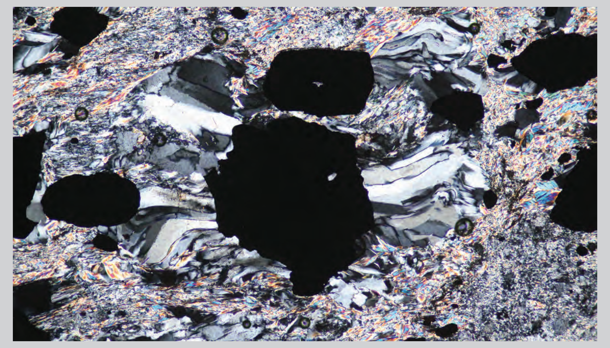
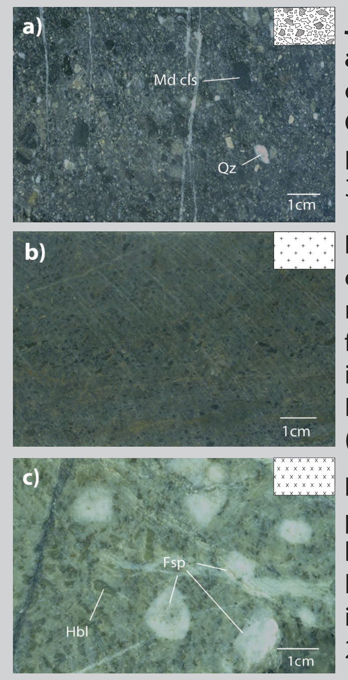


Fig. 3 Strain shadow of fibrous quartz developed around a pyrite grain (2015-094, K-13-34, 447.7m).

V. Lithology

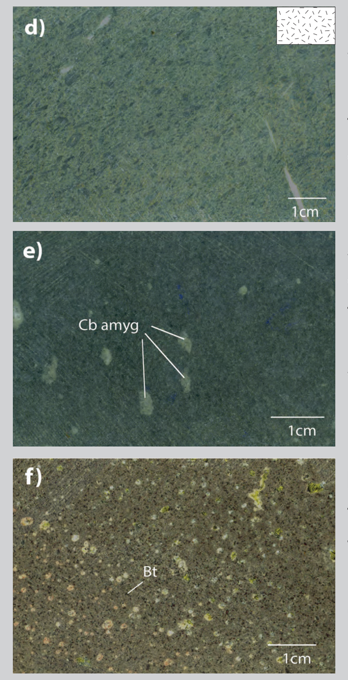
The Kerr deposit is largely hosted by assemblages of Stuhini and Hazelton groups, while the Deep Kerr deposit is largely intrusion-hosted. Late Triassic Stuhini Group host rocks are predominantly siltstone, graphitic shale, and mudstone, while Early Jurassic Hazelton Group volcanic and sedimentary host rocks are represented by sandstone, conglomerate (ex. Jack Formation, Fig. 4a), and lesser volcanic rocks. Syn-mineral composite intrusions of hornblende-plagioclase+/-k-feldspar-biotite porphyry are the most abundant intrusions at the Kerr and Deep Kerr deposits, and comprise the bulk of Deep Kerr (porphyritic andesite, Fig. 4b). These intrusions cross-cut each other, with multiple overprinting intrusive phases, and are also highly altered within the deposit, making recognition of individual phases difficult.



a) **Jack Formation conglomerate** featuring mudstone intraclasts and quartz pebbles. Common host of the Kerr deposit (2015-062, K-14-37, 388.95m).

b) **Porphyritic andesite** with chlorite-sericite pseudomorphs after hornblende and feldspar. Syn-mineral composite intrusions host the bulk of Deep Kerr mineralization (2014-014, K-13-34, 532.6m).

c) **K-feldspar megacrystic porphyry** is Early Jurassic, late-mineral, and overprinted by epithermal Au-Ag mineralization (Bridge, 1993; 2015-003, K-12-20, 149.4m).



d) **Porphyritic diorite dyke** with chlorite-sericite pseudomorphs after hornblende and feldspar. Dykes are post-mineralization and weakly altered (2015-091, K-13-31, 517.8m).

e) **Aphanitic diorite dyke** with carbonate amygdules. These finegrained dykes are post-mineralization and very weakly altered (2014-016, K-13-34, 568.13m).

f) **Biotite porphyry dyke** with feldspar. These Eocene kersantitic lamprophyres are post-mineralization dykes (2015-039, K-13-30, 617.3m).

Fig. 4 Key lithologies of the Kerr and Deep Kerr Deposits (sample number, drillhole number, depth (m)). Abbreviations: Bt – biotite, Cb amyg – carbonate amygdules, Fsp – feldspar, Hbl – hornblende, Md cls – mudstone clasts, Qz – quartz.

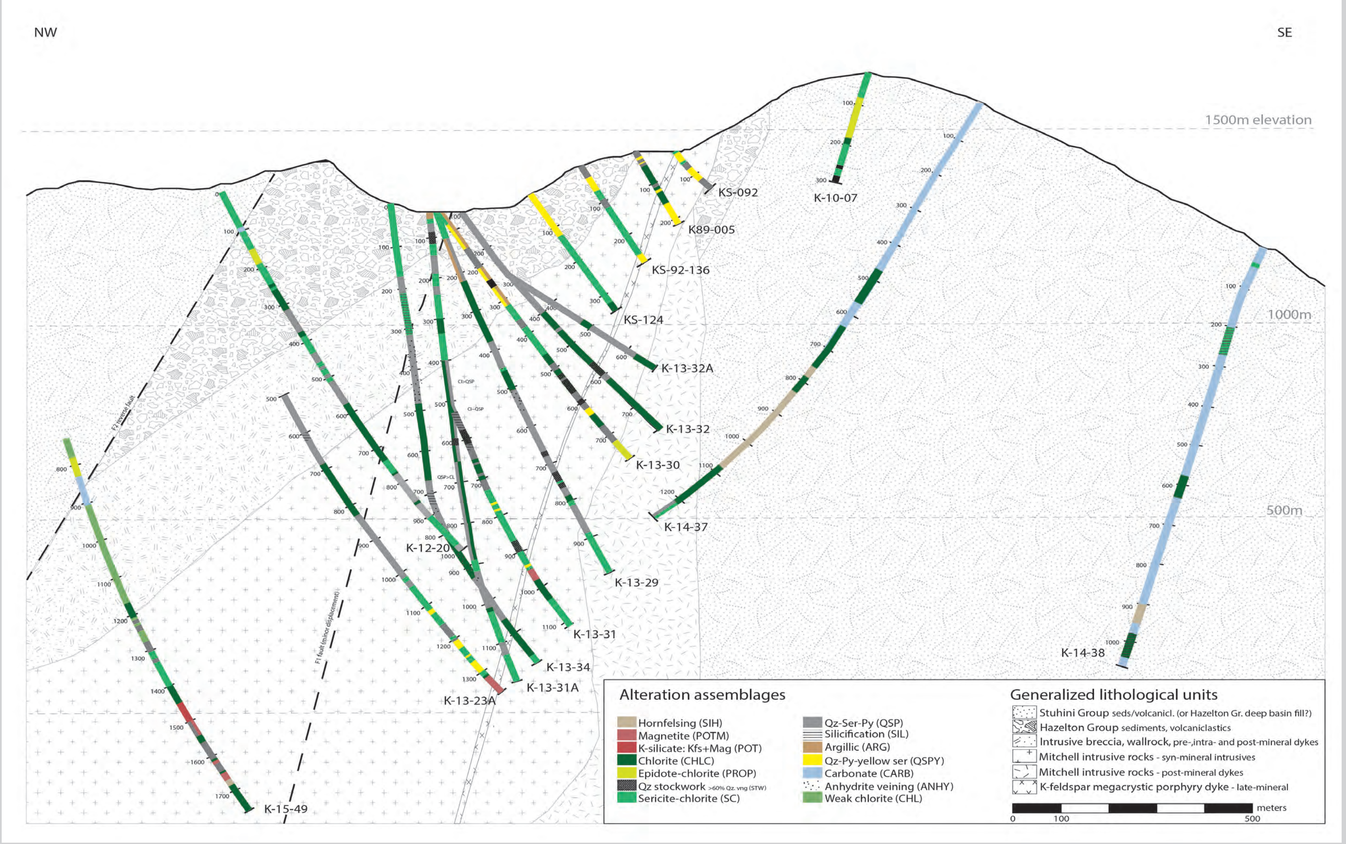
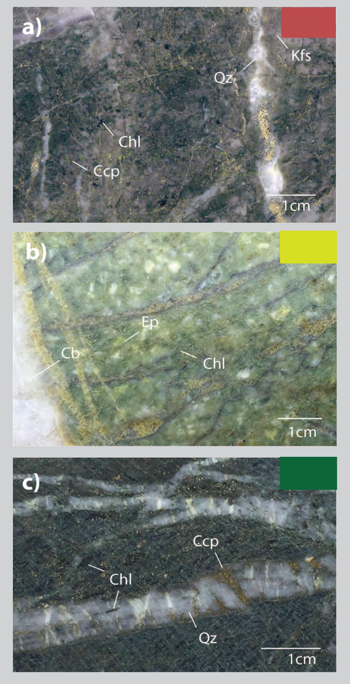


Fig. 5 2.5km cross-section across the northern Kerr and Deep Kerr deposits, centered on ~421261mE, 6259537mN, at a strike of ~295 degrees, with envelope of 100m. Data obtained from geochemical analysis, petrography, sulfur isotope analyses, SEM, EPMA, XRD, and SWIR analysis will be integrated with macroscopic observations obtained during fieldwork to complete the alteration cross-section. Geology is highly generalized (lithology: Seabridge Gold Inc., pers. comm., 2015).

VI. Alteration

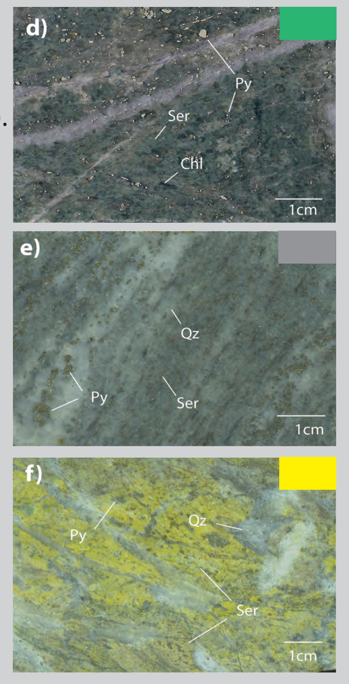
Alteration at Kerr is the result of a long-lived, relatively shallow hydrothermal system produced by intrusion of monzonite (Ditson et al., 1995). Alteration affects sedimentary and volcanic host rocks, as well as pre- to syn-mineral intrusions, with weaker alteration of post-mineralization intrusive rocks. Supergene alteration is noted in the shallower Kerr deposit to consist of leached hematite/jarosite, minor native copper, and chalcocite/covellite, with extensive hydration of anhydrite to gypsum (Bridge, 1993). This hydration has caused an extensive 'rubble' zone in the near-surface environment at Kerr.



a) **K-feldspar-chlorite-magnetite** alteration with finegrained chalcopyrite in hornblende porphyritic intrusion (K-15-49, 1476.6m). Assemblage is minor, with pressure-limited extent to depth.

b) **Epidote-chlorite-carbonate** alteration within a feldspar porphyritic intrusive (K-14-37, 978.4m). Assemblage is minor, and visible at the eastern and western margins of the deposit.

c) **Pervasive chlorite** alteration within a hornblende and feldspar porphyritic intrusion, and associated quartz-chalcopyrite-chlorite veining (K-13-31, 594.4m). Overprints K-silicate alteration.



d) **Pervasive sericite-chlorite** and disseminated pyrite alteration within a hornblende porphyritic intrusion (K-14-39, 952.2m). Abundant throughout the deposit.

e) **Pervasive intense quartz-sericite-pyrite** alteration of unknown protolith (2014-023, K-13-31, 1110.9m). Overprints sericite-chlorite and chlorite alteration.

f) **Intense yellow sericite** alteration of a sedimentary protolith (2015-094, K-13-34, 447.7m). Not associated with grade, and appears to be restricted to sedimentary units.

Fig. 6 Key alteration assemblages of the Kerr and Deep Kerr deposits (sample number, drillhole number, depth (m)). Abbreviations: Cb – carbonate, Chl – chlorite, Ccp – chalcopyrite, Ep – epidote, Ser – sericite, Py – pyrite, Qz – quartz.

SEM analysis of K-silicate alteration shows K-feldspar, magnetite, Mg-Fe chlorite, apatite, biotite, and chalcopyrite.

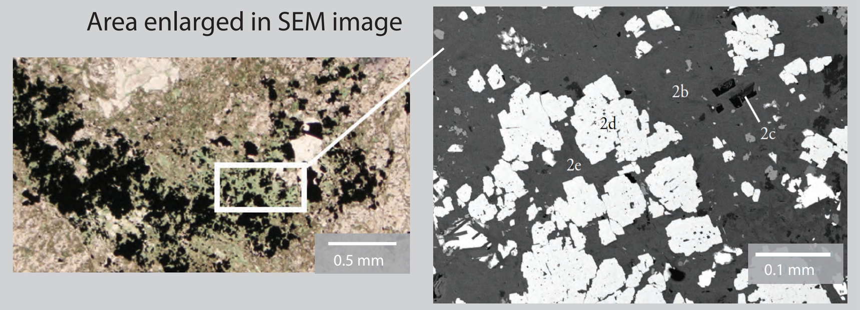


Fig. 7 right: Thin section of chlorite and magnetite under plane polarized light, 5x magnification.
Far right: Scanning electron microscope image of magnetite (2d), chlorite (2b, 2e), and biotite (2c).

The degree of alteration, overprinting, and subsequent deformation makes recognition of lithologies within the deposits difficult to impossible. Therefore understanding the temporal and spatial evolution of hydrothermal alteration and mineralization is requisite to the understanding of the ore system.

Alteration assemblage	Sulfide assemblage	Vein Types and Analogs (Sillitoe, 2010; modified from Gustafson & Hunt, 1975)	Distribution	Alteration assemblage analog
K-feldspar - chlorite - magnetite +/- biotite	Pyrite-chalcopyrite+/-bornite	Quartz-sulfides (A- and B-types), Magnetite	Limited distribution. Occurs at depth (DDH K-15-49), with only remnant rafts within deposit, where magnetite+/-K-feldspar alteration has been largely overprinted	K-silicate
Epidote - chlorite +/- carbonate	Pyrite	Quartz-pyrite-epidote	Limited peripheral distribution. Occurs at eastern and western margins of deposit.	Propylitic
Chlorite +/- magnetite	Chalcopyrite-pyrite	Quartz-sulfides (A- and B-types), Magnetite associated	Throughout the deposit, with the most intense chlorite alteration within the core of the deposit. Potential artifact of K-feldspar- magnetite +/- biotite alteration.	Chlorite
Chlorite - phengite +/- sericite	Pyrite	Quartz-pyrite (D-type)	Throughout the deposit, abundant peripheral to core, and overprinting earlier chlorite alteration.	Sericite-Chlorite
Quartz - sericite	Pyrite	Quartz-pyrite (D-type)	Abundant throughout the deposit. Commonly overprinting chlorite alteration in the core, and peripheral sericite-chlorite alteration.	Phyllic
Yellow sericite +/- quartz	Pyrite	Quartz-pyrite (D-type)	Limited distribution. Occurs extensively within sedimentary units peripheral to deposit, and within sedimentary rafts.	-

Table 1. Overview of alteration assemblages at the Kerr and Deep Kerr deposits (vein type analogs are derived from Sillitoe, 2010, modified after Gustafson and Hunt, 1975).

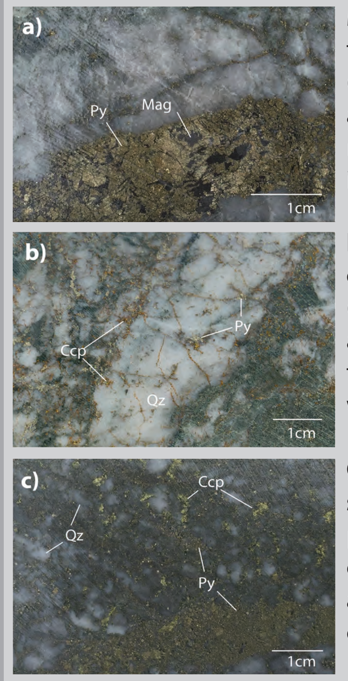
VII. Vein Paragenesis and Mineralization

Mineralization at the Kerr and Deep Kerr deposits is present as disseminations and within veins, as finegrained hypogene chalcopyrite, bornite, molybdenite, and pyrite, with the occurrence of gold and silver intimately associated with sulfide mineralization (M. Savell, pers. comm., 2015). Mineralization is controlled by permeability, and therefore more homogeneous within deeper, intrusion-hosted portions of the system, and more erratic in shallower, mixed sedimentary, volcanic, and intrusion-hosted portions of the deposit.

Timing: Early- to syn-mineralization → Late- to post-mineralization. Alteration assemblage analog → K-silicate, Chlorite, Sericite-Chlorite, Quartz-Sericite, Pyrophyllite-Dickite.

Mineral-sulfide assemblage	Vein Selvage	Description	Distribution	PCD Vein Type Analog*
Magnetite +/- pyrite-quartz	None	3-30mm; sharp, sinuous margins; alter to pyrite	At depth, with minor remnant magnetite within chloritic alteration in the core of the deposit	M Type
Quartz-chalcopyrite+/-pyrite-bornite-molybdenite	Typically none; Ksp locally (B-veins)	Granular to translucent; white to gray/pink; 5-40mm; A-veins sinuous, B-veins more planar and may contain sulfide centerline	Common in deposit core, associated with grade and quartz stockwork veining	A & B Types
Quartz-pyrite +/-sphalerite-galena	Sericite+/-quartz +/-pyrite	2-10mm; parallel margins; wide selvages	Throughout, with Sph/Ga common on margins of deposit into wallrock	D Type
Anhydrite	None	Grey, white, or pink; 1mm to >1m; recessively weathered, alter to gypsum	Late stage, overprinting Qtz stockwork zones	-
Quartz-bornite-tennantite/enargite	Quartz-pyrophyllite/dickite	5-40mm; crackle sulfides within quartz veins; high sulfidation	Overprinting quartz stockwork zones in center of deposit	-

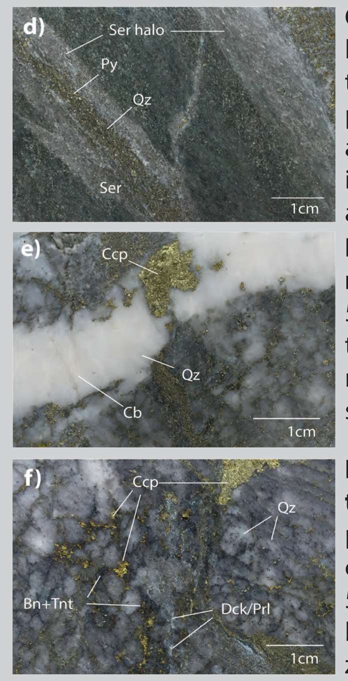
Table 2. Key vein types at the deposits (*analogs are derived from Sillitoe, 2010, modified after Gustafson and Hunt, 1975).



a) **Magnetite-pyrite** vein with alteration of magnetite to pyrite (K-13-32, 635m). Magnetite veins are early, and alteration of magnetite to pyrite obscures the original extent of these veins.

b) **Early granular, milky quartz-chalcopyrite-pyrite** A-type vein (K-13-34, 483.4m). These veins are associated with K-silicate alteration, and are commonly seen with sinuous margins.

c) **Quartz-chalcopyrite-pyrite stockwork** veining in core of deposit (K-13-31, 590m). Quartz-chalcopyrite-pyrite veining is extensive and intimately associated with copper and gold mineralization.

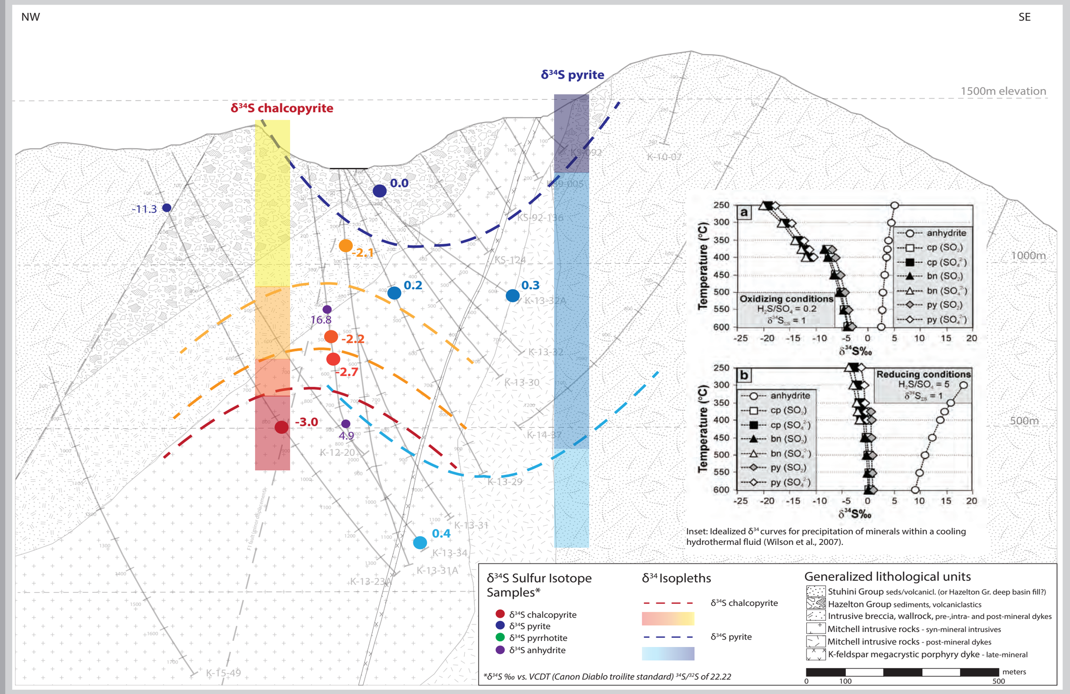


d) **Quartz-pyrite** vein with wide sericite halo overprinting chlorite-sericite alteration (K-13-30, 749.6m). Quartz-pyrite veining overprints earlier veins and is associated with chlorite-sericite and quartz-sericite-pyrite alteration.

e) **Late white quartz-chalcopyrite-carbonate** vein (K-13-30, 598.6m). These veins commonly contain chlorite, with higher chalcopyrite contents in higher grade areas suggesting local remobilization.

f) **High sulfidation bornite-tennantite +/-dickite-pyrophyllite** overprint of quartz stockwork with chalcopyrite in core of deposit (K-13-30, 567.2m). This high-sulfidation assemblage overprints quartz stockwork zones.

Fig. 8 Overview of vein types (drillhole number, depth (m)). Abbreviations: Bn – bornite, Cb – carbonate, Chl – chlorite, Ccp – chalcopyrite, Dck – dickite, Mag – magnetite, Py – pyrite, Prl – pyrophyllite, Ser – sericite, Tnt – tennantite, Qz – quartz.



Initial results from sulfur isotopic analysis show a small range in $\delta^{34}S$ of sulfides, and weakly negative values, indicating a more reducing (calc-alkalic) environment. Chalcopyrite is increasingly depleted in $\delta^{34}S$ with depth, consistent with a more oxidized fluid at depth, whereas $\delta^{34}S$ of pyrite increases with depth, reflecting a cooling fluid that is no longer experiencing a change in oxidation state (decreasing $\delta^{34}S$ with cooling).

Fig. 9 $\delta^{34}S$ sulfur isotope values for anhydrite, chalcopyrite and pyrite.

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