

IKE Copper-Molybdenum-Silver Porphyry Deposit, Southwestern British Columbia (NTS 092O): Early Halo-Type Veins as a Tool for Vectoring Toward Higher Grade Mineralization

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Introduction

The IKE deposit is a Cu-Mo-Ag porphyry deposit located in the southern portion of the Canadian Cordillera in southwestern British Columbia (BC). It follows a calcalkalic porphyry model, as it is hosted in plutonic rock and has a large alteration footprint. Amarc Resources Ltd. drilled 21 discovery holes from 2014 to 2016 that cover an area of 1.2 km by 1.0 km to a depth of 875 m; all of these holes intersected long intervals of Cu and Mo mineralization. Significant amounts of early halo-type (EHT) veins are found throughout the deposit; such veins are typically associated with deep-seated porphyry deposits, such as Butte, Montana and Ann Mason, Nevada.

This project is an investigation of the geochemical properties of these early halo-type veins and how they relate to mineralization. Detailed petrographic studies were carried out on early halo-type veins in multiple parts of the system in order to identify the mineral assemblages that occur in the alteration haloes and how IKE compares to other deposits. Shortwave infrared (SWIR) spectroscopy was used on the hostrock at IKE to identify subtle geochemical changes in the alteration minerals. The main mineral picks, white mica absorption features and illite crystallinity values were examined to determine fluid composition and pathways in the deposit, and how they relate to grade and the formation of early halo-type veins.

The development of early halo-type veins is a key component of early high-temperature mineralization in the system and has the potential to aid in the exploration for high-grade zones at IKE and other deep-seated porphyry deposits.

Regional Geology

The IKE porphyry district is located on the eastern margin of the Coast Plutonic Complex (CPC) in southwestern BC, 33 km northwest of Gold Bridge (Figure 1). The CPC is Cretaceous to Eocene in age, and is thought to be linked to the subduction of the Pacific Plate beneath the western edge of the North American Plate, and partly a result of tectonic overlap and compressional thickening of crustal rocks during a collision between the North American Plate and two allochthonous terranes accreted to the western margin in the Mesozoic (Monger et al., 1982). Compared to the other morphogeological belts of the Canadian Cordillera, the Coast Belt is apparently lacking in mineral occurrences, and the exact mechanisms for this are not well understood (McMillan et al., 1996).

The IKE deposit is hosted in a late Cretaceous granodiorite intrusion that correlates with the Dickson-McClure batholith, which hosts several other calcalkaline porphyry occurrences. Rhenium-osmium dates from molybdenite at IKE yield ages of 46.4 ± 0.19 Ma and 47.55 ± 0.24 Ma, making it one of the few Eocene deposits in the region (Galicki and



Figure 1. Location of study area (modified from Galicki and Rebagliati, 2017).

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Rebagliati, 2017). The majority of porphyry deposits in the Canadian Cordillera are early Mesozoic in age, and the porphyry deposits that are late Mesozoic to Cenozoic were formed in intracontinental settings after the accretion of the Quesnel and Stikine terranes onto continental North America. The distribution of postaccretionary deposits is linked to crustal structure and subduction geometries (McMillan et al., 1996).

Mineralization at IKE may be related to dilation zones from the Tchaikazan fault, as there is no evidence on surface or in the drillcore of a major structure at the deposit (Galicki and Rebagliati, 2017). The Tchaikazan fault is a mid-Cretaceous strike-slip fault with a postulated dextral displacement of up to 30 km, and is truncated to the south by the Dickson-McClure batholith (Schiarizza et al., 1997). There is evidence that the Tchaikazan fault was reactivated in the late Cretaceous and the Eocene (Umhoeffer and Kleinspehn, 1995). Mineral occurrences in the IKE district line up geographically with the southeasterly trend of the Tchaikazan fault, as seen in Figure 2. These mineral occurrences range in age from late Cretaceous to Eocene, and may to correlate with movement on the Tchaikazan fault.

IKE Property Geology

The IKE deposit is hosted in felsic to intermediate intrusive rocks. The host granodiorite, the most intersected intrusion, is a medium-grained, biotite-bearing hornblende granodiorite and is associated with most of the mineralization in the system. It predates mineralization but was enriched in grade during the mineralizing event. Uranium-lead dating of the mineralized granodiorite yielded 85.7 ± 1.1 Ma, which is correlative with the Cretaceous Dickson-McClure batholith (Galicki and Rebagliati, 2017). There are several different syn-mineralization intrusions at IKE that range from quartz monzonite to diorite and can be distinguished from the pre-mineralization granodiorite by their porphyritic texture. There are minor amounts of late-mineralization and post-mineralization dikes, but they are not linked to significant Cu and Mo grades (Galicki and Rebagliati, 2017). An example of dike orientation and how it relates to the drillcore is shown in Figure 3.

There is a general trend of high- to low-temperature alteration with time, with the most significant episodes of mineralization associated with high-temperature alteration

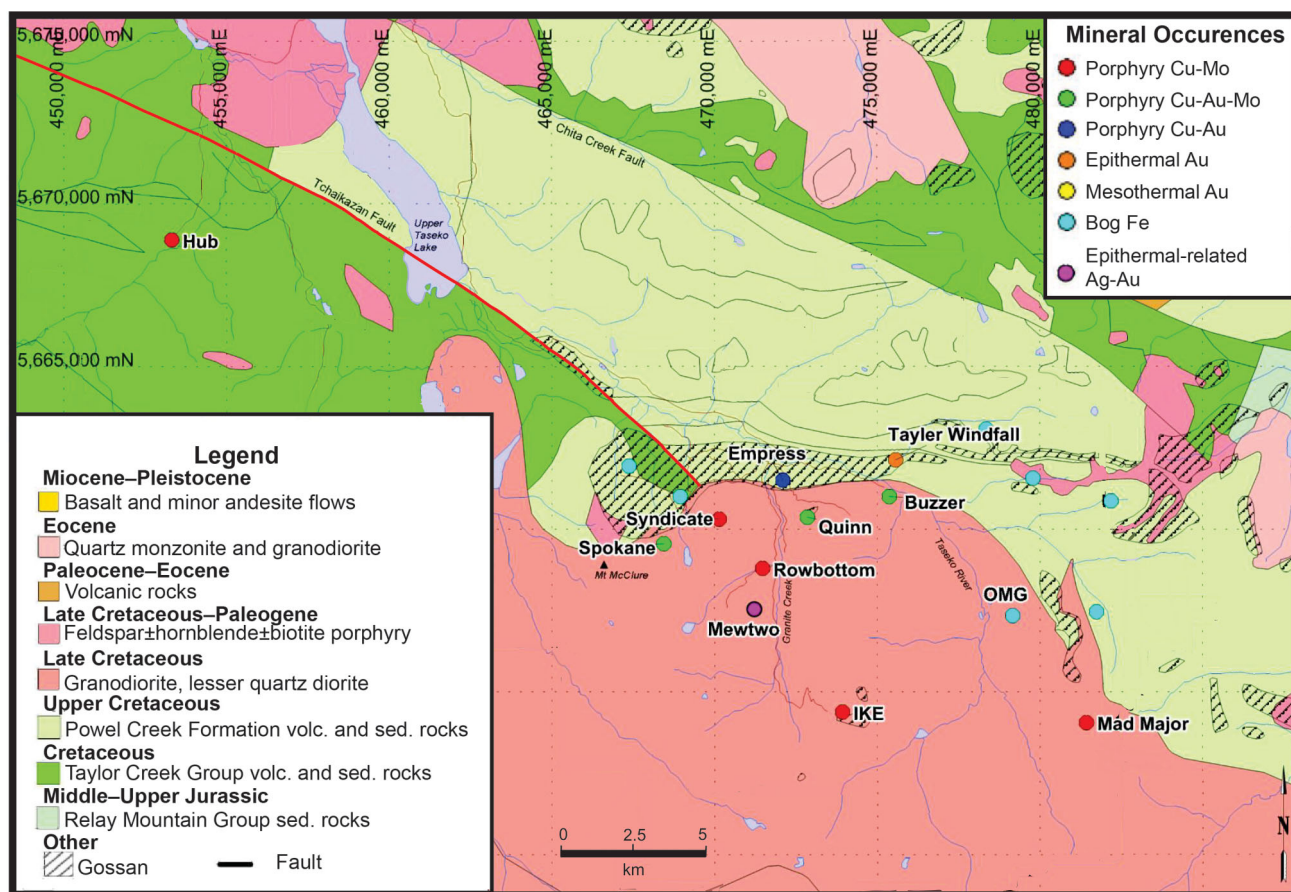


Figure 2. Regional geology of IKE and surrounding mineral occurrences. The Tchaikazan fault is outlined in red (modified from Galicki and Rebagliati, 2017). Abbreviations: sed., sedimentary; volc., volcanic.

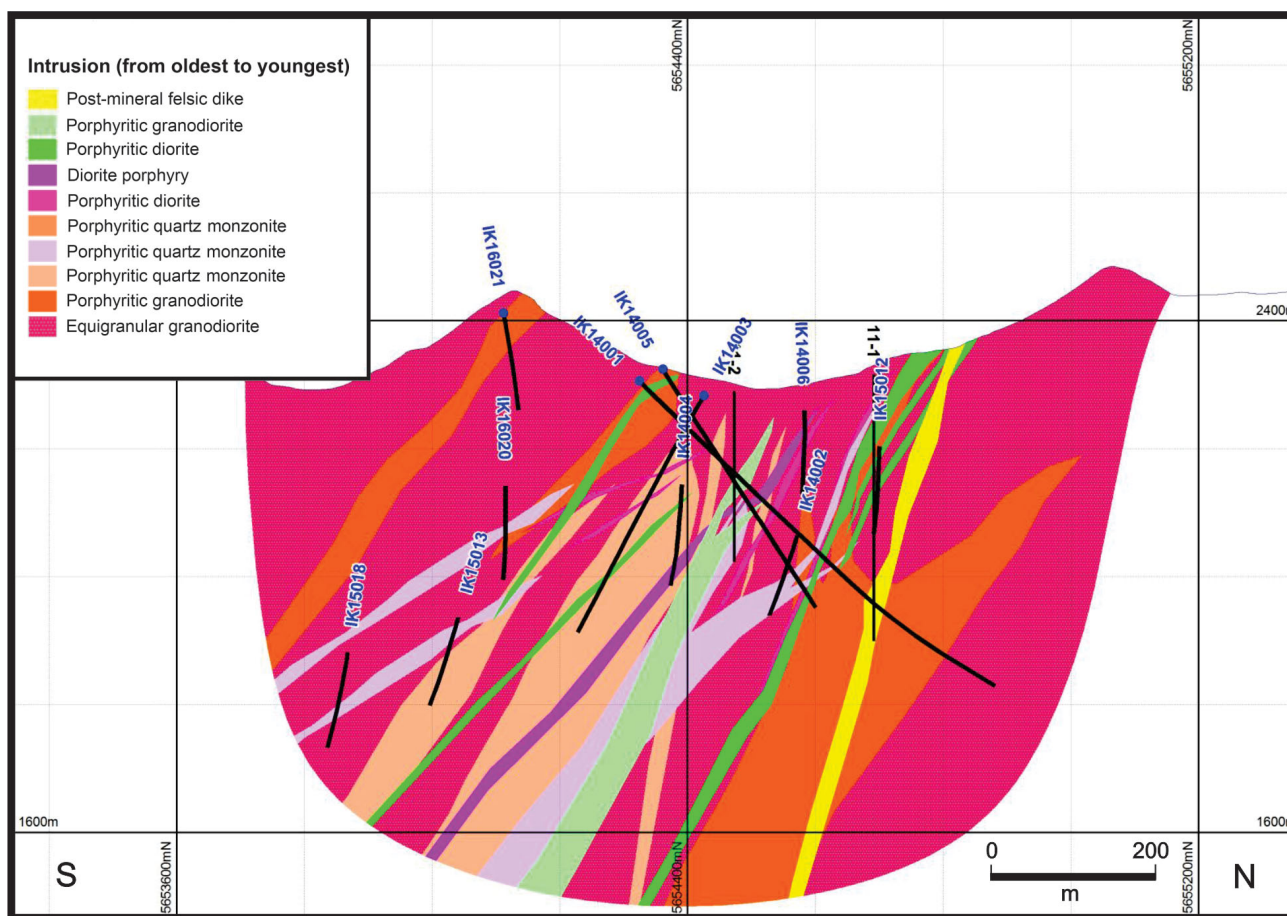


Figure 3. Geological cross-section of the IKE deposit, with location of some of the drillholes (modified from Galicki and Rebagliati, 2017).

(Galicki and Rebagliati, 2017). Potassium-silicate (biotite)±magnetite alteration is the earliest stage of hydrothermal alteration and involves the replacement of igneous biotite and hornblende with ‘shreddy’ hydrothermal biotite. Potassium-feldspar-quartz alteration consists of minor amounts of K-feldspar, generally found in alteration selvages of veins, most frequently in zones of high vein density. Propylitic alteration is relatively minor and is represented by a low-temperature assemblage of chlorite±carbonate±epidote. Rare quartz-chlorite-epidote-sulphide veins are associated with this alteration, suggesting sulphides were also introduced and/or remobilized at this stage of alteration. Phyllic alteration is the latest stage and consists of pyritic quartz veins with large sericite-pyrite-chlorite alteration haloes. It is minor in this deposit and is often seen in reopened, early halo-type veins and overprinting early-stage K-silicate alteration (Galicki and Rebagliati, 2017).

Mineralization in the system is both vein hosted and disseminated. The majority of Cu mineralization is attributed to early-stage potassic alteration and is mainly in the form of chalcopyrite; however, there is minor malachite in the shallow intervals of some drillholes, which could be a re-

sult of surface alteration. Chalcopyrite occurs in the veins and their alteration haloes as well as disseminated throughout the hostrock, where it replaces biotite and hornblende. Molybdenum is mainly vein hosted in the form of molybdenite and is often associated with later stage K-feldspar alteration.

Early Halo-Type Veins

Early halo-type (EHT) veins often occur in areas of high Cu grade in many deep-seated porphyry deposits. They are defined as veins with significant alteration haloes that are texture destructive, contain sericite island and sericite bowtie textures, and are one of the first veining events of the system (Proffett, 2009). Examples of deposits with significant amounts of EHT veins include Butte, Montana and Ann Mason, Nevada. Another interpretation of veins with significant alteration haloes in deep portions of porphyry deposits is that they are formed from degassing of overpressurized hydrothermal fluids during late crystallization and have compositions and textures similar to veins found in greisen-type Sn-W-Mo districts (Runyon et al., 2017). Although the vein haloes in IKE also have sericite and quartz as some of the main alteration minerals, they differ from veins in the Runyon study because they do not have open-

space-filling textures and are associated with the first stage of mineralization in the system.

The IKE deposit has an abundance of EHT veins, which are linked to early Cu mineralization in the system. They are found most frequently in the pre-mineralization granodiorite but occur in all of the syn-mineralization intrusions. It is important to note that they are absent from post-mineralization intrusions. Their crosscutting relationships with other vein types and occurrence in intrusion types suggest that they occur in the first stage of mineralization at IKE. The centrelines are thin (1 mm) and generally consist of quartz, chalcopyrite, pyrite and sometimes magnetite. Composition is variable, but the most common minerals in the alteration halo are sericite and biotite, along with chlorite, quartz and K-feldspar. The average sericite-rich alteration halo has a true width of about 1 cm, and haloes containing significant amounts of biotite are slightly thinner. The EHT veins can host a significant amount of mineralization, most commonly in the form of pyrite and chalcopyrite. Figure 4 shows some of the most commonly seen EHT veins in the IKE deposit.

Preliminary studies indicate that EHT veins at the IKE deposit seem to be linked to early mineralizing events in the IKE system, as they are concentrated in areas of higher Cu grade. Percentages of EHT veins were estimated visually in each sample interval (~3 m) of drillholes IK15013 and IK15018, where the EHT veins are prevalent. Both the vein and the alteration halo are included in the estimation. They occur through the entirety of both holes but are of higher intensity in areas of medium to strong K-silicate-biotite±magnetite alteration. Figure 5 shows a positive correlation between EHT veins and Cu grades, whereas Ag and Mo grades do not show strong correlations.

Petrography

Sixty-six polished thin sections and ten fluid-inclusion sections were prepared from the IKE deposit, many of them containing EHT veins. The most common minerals in the alteration haloes are sericite, biotite and quartz, and minor minerals include chlorite, feldspar, clinopyroxene and apatite. Sulphides are hosted in the alteration haloes: mainly chalcopyrite and pyrite, and some sphalerite. The composi-

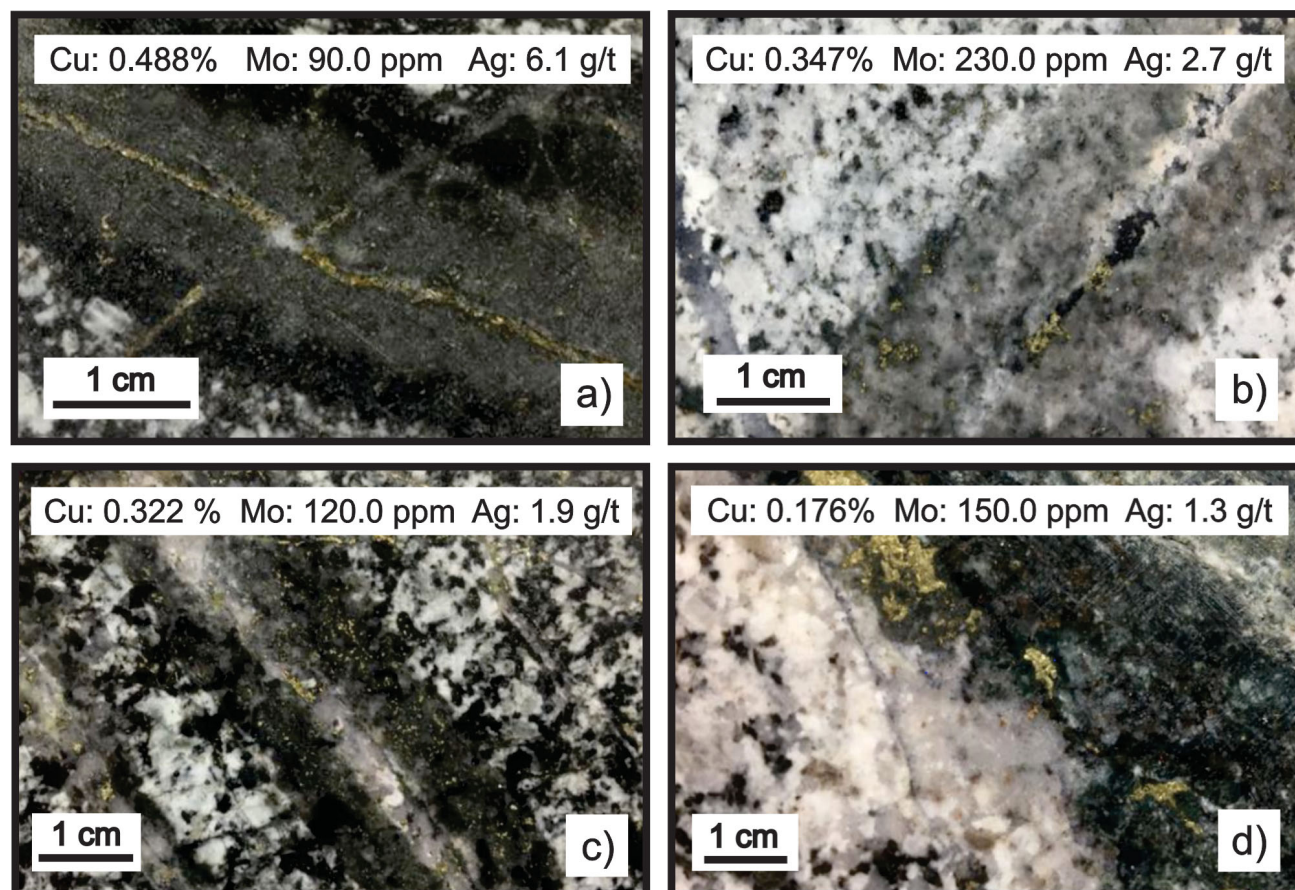


Figure 4. Examples of vein alteration haloes at IKE: **a)** zoned sericite-biotite alteration halo at 258 m in drillhole IK14001; **b)** sericite alteration halo at 630 m in drillhole IK15013; **c)** sericite-biotite alteration halo at 96 m in drillhole IK15013; and **d)** zoned sericite-biotite-chlorite alteration halo at 727 m in drillhole IK15018.

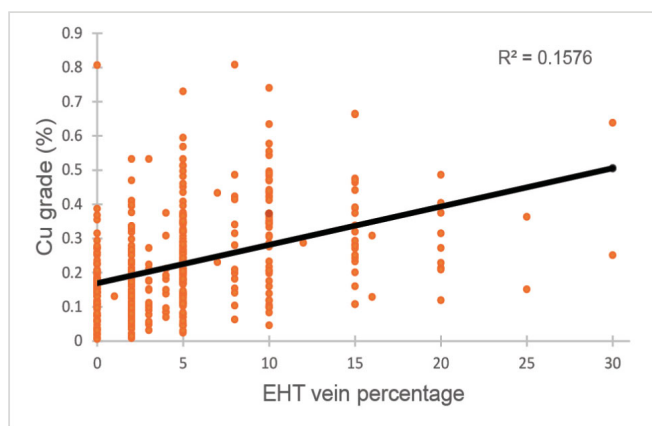


Figure 5. Copper grade versus percentage of early halo-type veins in drillholes IK15013 and IK15018, IKE deposit.

tion of alteration haloes does not appear to be affected by the hostrock because EHT veins that cross rock boundaries have the same alteration minerals in similar quantities, but the size of the alteration mineral grains reflects the grain size of the hostrock (Figure 6). The bowtie and sericite-island textures seen in the alteration haloes are diagnostic of EHT veins (Proffett, 2009).

Detailed petrographic studies were carried out on selected EHT veins at the IKE deposit in order to better understand the composition of the hydrothermal fluids and hostrock alteration. The veins highlighted in Figures 7–9 were chosen based on their variability of composition, sulphide content and position within the system. The veins studied were from drillholes IK14001, IK15013 and IK15018; their positions are shown in Figure 3. Sam-

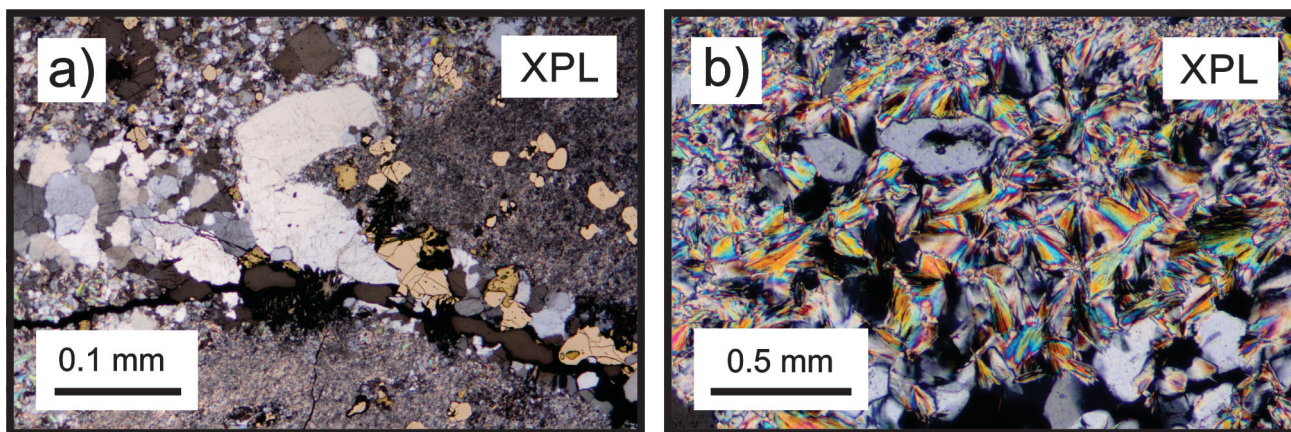


Figure 6. Thin-section photomicrographs from the IKE deposit: **a)** sericite alteration halo at the contact between equigranular granodiorite and porphyritic diorite at 434 m in drillhole IK15018; **b)** bowtie texture in sericite in the alteration halo at 249 m in drillhole IK14001. Abbreviation: XPL, cross-polarized light.

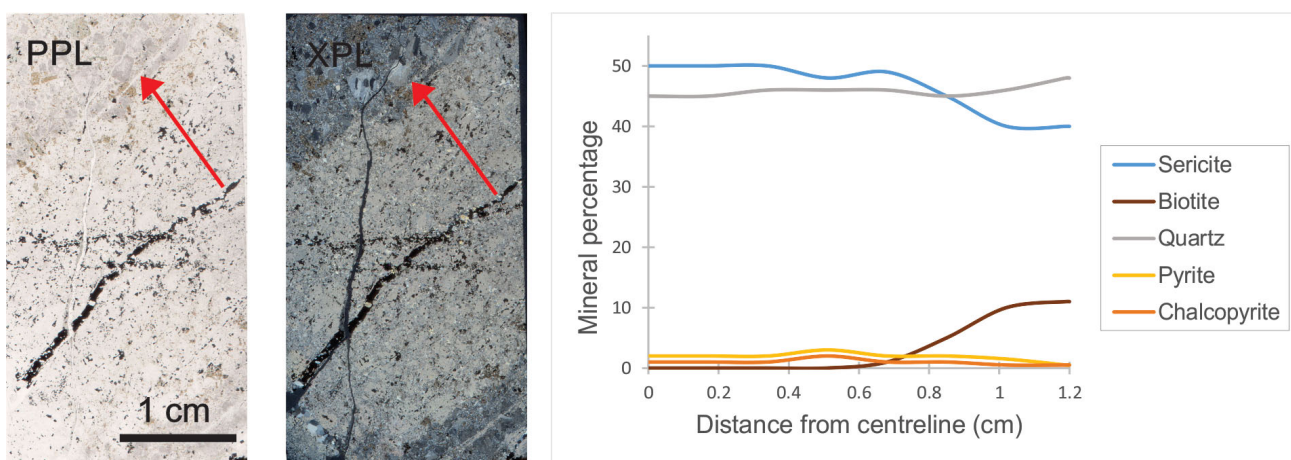


Figure 7. Mineral percentages in a zoned sericite-biotite alteration halo at 258 m in drillhole IK14001, with corresponding thin-section photomicrographs; cross-section indicated by red arrow, with tip of arrow denoting outer edge of alteration halo. Abbreviations: PPL, plane-polarized light; XPL, cross-polarized light.

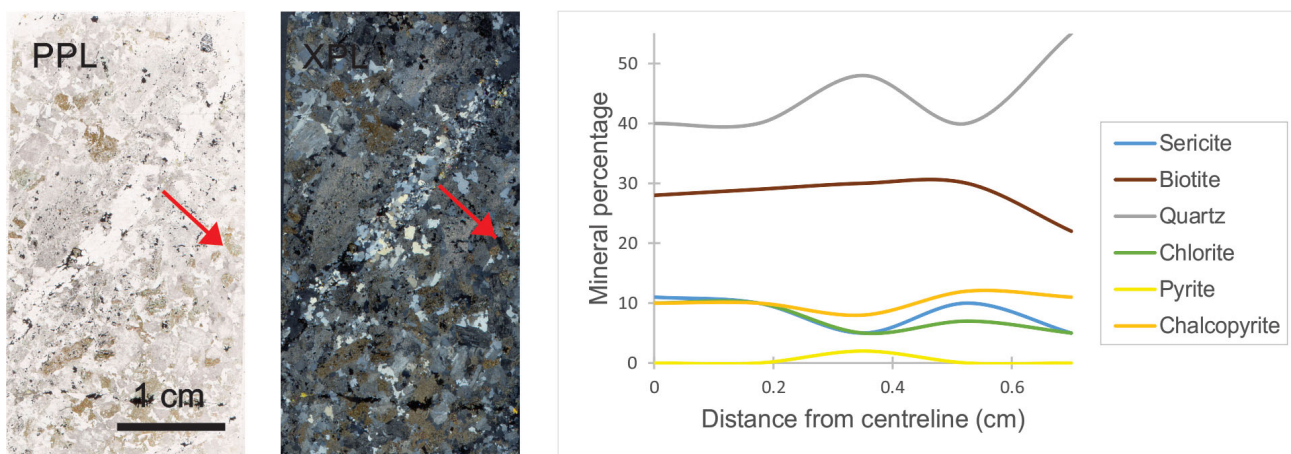


Figure 8. Mineral percentages in a sericite-biotite alteration halo at 96 m in drillhole IK15013, with corresponding thin-section photomicrographs; cross-section indicated by red arrow, with tip of arrow denoting outer edge of alteration halo. Abbreviations: PPL, plane-polarized light; XPL, cross-polarized light.

ple photos and interval grades of the EHT veins are shown in Figure 4. Mineral percentages were taken in portions of the alteration haloes that represented the general composition of the halo and did not include relict phenocrysts or crosscutting veinlets.

The sericite-biotite halo shown in Figure 7 demonstrates a common composition of zoned EHT veins found throughout the IKE deposit. The centreline consists of pyrite, chalcopyrite and quartz. The main alteration minerals are sericite and quartz, with biotite occurring at the outer edge of the alteration halo. Pyrite and chalcopyrite are disseminated throughout the halo, with chalcopyrite concentrated more closely to the centreline. Drillhole IK14001 is in the uppermost portion of the deposit, so the composition of the EHT vein may reflect cooling of the hydrothermal fluid as it moved to higher elevations in the system.

The vein highlighted in Figure 8 is an example of an unzoned EHT vein with biotite as the dominant vein mineral.

The centreline is composed of quartz, chalcopyrite, pyrite and molybdenite. This type of vein typically does not have an alteration halo in this system and, if a halo occurs, it is thin and composed of K-feldspar. The path of the centreline also does not perfectly follow the path of the alteration halo, which suggests that the original vein was reopened in a later mineralizing event. The alteration mineralization is relatively uniform throughout the halo. Biotite and quartz are the main alteration minerals, with less abundant sericite and chlorite. There are minor amounts of clinopyroxene in the alteration halo, but it was omitted from the graph for clarity. Chalcopyrite is the predominant sulphide in the alteration halo, with rare pyrite and trace molybdenite. Chalcopyrite often occurs with chlorite within the halo. Drillhole IK15013 is one of the deeper holes in the system and has the longest intervals of higher Cu grade (>0.3%), along with some of the highest percentages of EHT veins.

The EHT vein outlined in Figure 9 has a composition typical of higher grade Cu zones in deep porphyry deposits.

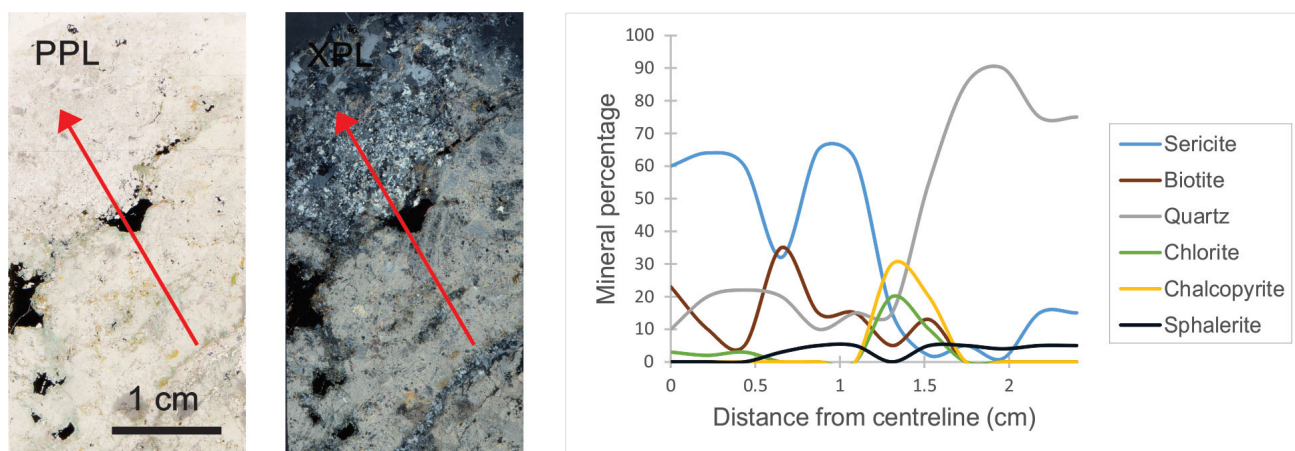


Figure 9. Mineral percentages in a zoned sericite-biotite-chlorite alteration halo at 727 m in drillhole IK15018, with corresponding thin-section photomicrographs; cross-section indicated by red arrow, with tip of arrow denoting outer edge of alteration halo. Abbreviations: PPL, plane-polarized light; XPL, cross-polarized light.

The centreline is composed of quartz, with small amounts of chlorite and calcite. The alteration halo is zoned, with green sericite, biotite and minor chlorite as the dominant alteration minerals closer to the centreline, and quartz and minor sericite on the outer edge of the halo. Minor amounts of K-feldspar, clinopyroxene and apatite are found throughout the alteration halo as well. Most of the chlorite occurs at the transition between the two portions of the alteration halo, along with larger grains of chalcopyrite. Smaller grains of sphalerite (<1 mm) are found in both zones of the alteration halo. This vein was in the last sample intervals of drillhole IK15018, which is the deepest hole of the system.

Preliminary fluid-inclusion studies have shown a variety of different fluid inclusions within the quartz veins at the IKE deposit. There are fluid inclusions that are liquid dominant or vapour dominant, and some that contain daughter minerals that appear to be halite and anhydrite. Two-phase fluid inclusions in the system are mostly liquid dominant; however, vapour-dominant two-phase inclusions are quite common as well. The porphyry boiling assemblage can be seen in a quartz-chalcopyrite-molybdenite vein, which involves a two-phase liquid-dominant fluid inclusion, a two-phase vapour-dominant fluid inclusion and a three-phase fluid inclusion, all occurring in the same quartz crystal (Figure 10). This is significant, as boiling of hydrothermal fluids in a porphyry system is thought to lead to mineralization (Nash, 1976). Detailed fluid-inclusion studies may not be suitable for this deposit, as fluid inclusions are very small and often appear to be secondary.

Shortwave Infrared Spectroscopy

Shortwave infrared (SWIR) spectroscopy has been used to identify alteration minerals and estimate crystallinity and mineral abundance. There is no sample preparation, it is nondestructive and measurements can be made directly on dry rock or pulp samples. Spectra are generated by measuring the electromagnetic radiation absorbed by submolecular vibrations related to covalent bonds, most notably Al-

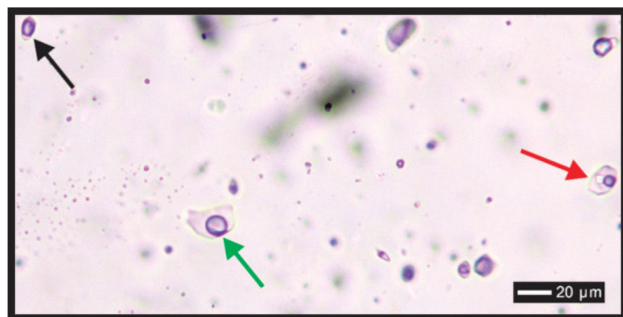


Figure 10. Fluid inclusions hosted within quartz of a quartz-chalcopyrite-molybdenite vein in sample 06-253.47, showing a typical porphyry 'boiling' assemblage of fluid inclusions ranging in composition from a three-phase (halite + liquid + vapour) fluid inclusion (red arrow) to a two-phase liquid-dominant (liquid + vapour) fluid inclusion (green arrow) to a two-phase vapour-dominant (vapour + liquid) fluid inclusion (black arrow).

OH, Fe-OH, Mg-OH and H₂O. (Simpson, 2015). Phyllosilicates, sorosilicates, carbonates and certain sulphates and ammonium-bearing minerals can be identified using this method. Some minerals, such as quartz, cannot be identified using this method as they do not yield a spectral response. Alteration minerals common in porphyry systems that can be measured using SWIR spectroscopy include muscovite, biotite, chlorite, epidote, calcite, kaolinite, illite and montmorillonite (Hauff, 2008). Minerals are identified based on patterns in the spectra. As an example, kaolinite is recognized by a doublet in the absorption features around 1400 and 2200 nm, and a relatively shallow water-absorption feature around 1900 nm (Figure 11). Multiple minerals can contribute the same absorption features in one spectrum, known as mixed spectra, which should be considered when performing calculations involving specific mineral groups (Halley, 2016).

There are many applications of SWIR spectroscopy, but this study focuses on mineral picks, illite crystallinity and wavelength positions around 2200 nm, and how they compare to grade and abundance of EHT veins. Pucks of core taken at every sample interval were analyzed for drillholes IK14001, IK15013 and IK15018, as they are from different parts of the system and contain significant amounts of EHT veins. The pucks often did not contain veins or alteration haloes, so the host rock was the focus of this alteration study. The analysis was done at The University of British Columbia using a TerraSpec 3 and the data were processed using The Spectral Geologist (TSG) 8 software. The spectral range for the instrument is 350–2500 nm, and the duration of the scans was 10 seconds. White references were taken hourly along with a Mylar™ standard to ensure consistent measurements. As a form of quality control, samples were rescanned if the absorption features were not pronounced.

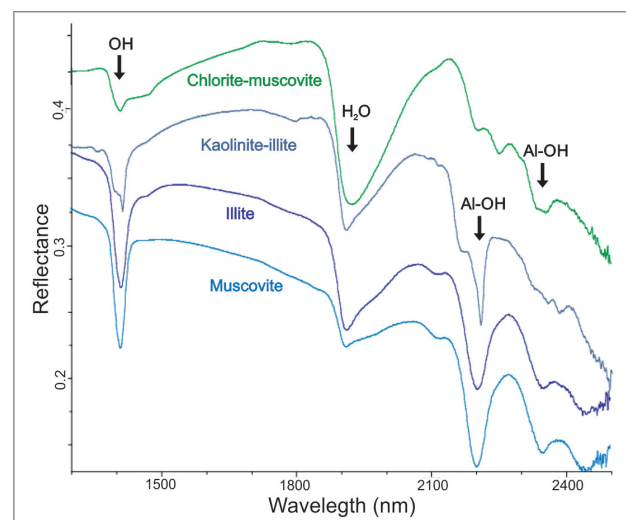


Figure 11. Example of spectra of common alteration minerals in the IKE deposit, with some absorption features labelled.

A vital function of SWIR spectroscopy is to quickly identify alteration minerals. The Spectral Geologist software generates mineral picks based on the spectral signatures, and can have up to three mineral picks for one spectrum. This study will focus on the main mineral pick, which is the most abundant mineral in a particular spectrum. The most common mineral picks in the IKE deposit are chlorite, muscovite, biotite, kaolinite, illite, montmorillonite, paragonite, phlogopite, siderite and tourmaline. Chlorite and muscovite are associated with the highest Ag, Cu and Mo grades (Figure 12). Some spectra yielded only one main mineral pick (e.g., epidote, hornblende and phengite), and

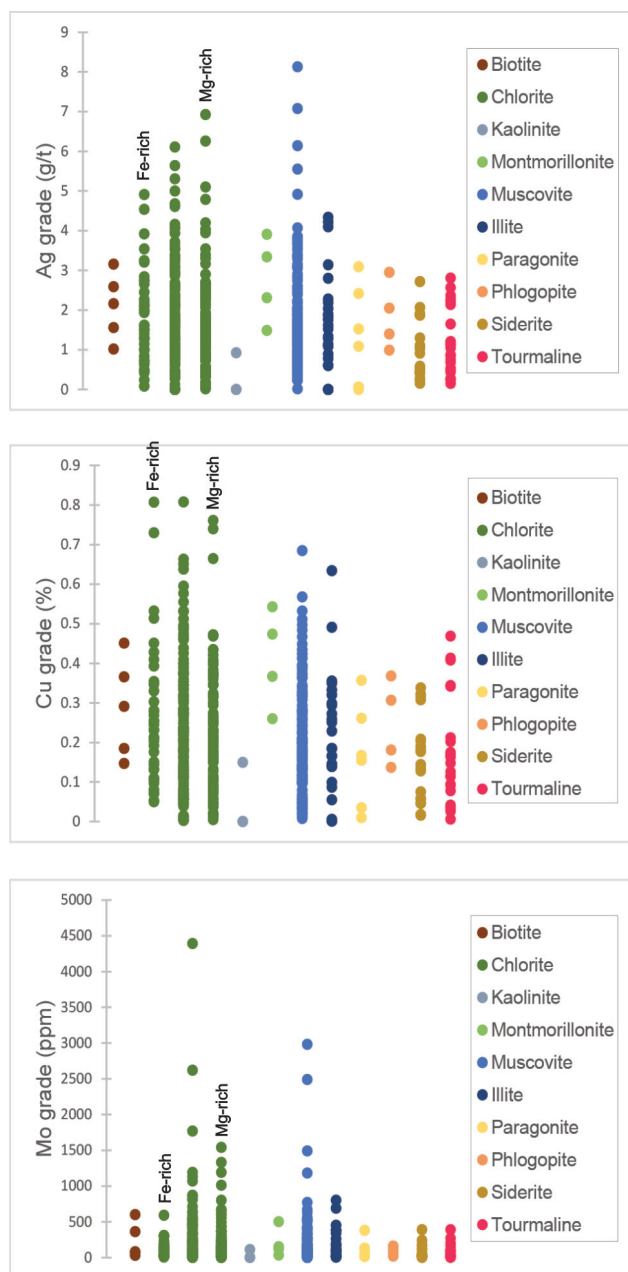


Figure 12. Grades of Ag, Cu and Mo related to the main mineral picks from SWIR spectroscopy data.

they were left out of the figure for simplicity. Muscovite, chlorite, biotite, tourmaline and siderite occur consistently in all of the drillholes. Biotite only occurred as the main mineral in drillholes IK15013 and IK15018, which are the deepest holes, elevation wise, in the deposit. It is interesting to note that all occurrences of kaolinite as the main mineral pick and the only occurrence of epidote as the main mineral pick occur in drillhole IK14001, which is the shallowest of the three drillholes studied.

Similar patterns are seen when comparing EHT vein percentage to the main mineral picks. As seen in Figure 13, the sample intervals with the highest amounts of EHT veins have mineral picks of chlorite, muscovite and illite. The EHT veins are more frequent in areas of Mg-rich chlorite than those of Fe-chlorite.

Illite crystallinity can be used as an estimation of the conditions of formation of alteration minerals. A broad measurement of illite crystallinity can be made using the ratio between the water and white mica absorption features at 1900 nm and 2200 nm, respectively (Halley, 2016). Once the spectra were obtained, the minimum values of the 1875–1925 nm and 2175–2225 nm ranges were plugged into equation 1. Higher values are associated with more crystalline phases, which tend to form at higher temperatures. Only data points with white micas and montmorillonite were used, to avoid the overestimation of water absorption from minerals like chlorite and biotite (Halley, 2016).

$$\text{Illite crystallinity} = \left(\frac{\text{minimum at 2200 nm}}{\text{minimum at 1900 nm}} \right) \quad (1)$$

Comparing illite crystallinity to ore grade in this system did not yield any clear relationships. As seen in Figure 14, Ag and Cu do not show a significant correlation with illite crystallinity, whereas Mo has a slightly positive correlation with higher crystallinity. Illite crystallinity plotted against EHT percentage shows no correlation as well, although removing points with minerals such as chlorite resulted in a small dataset. Further studies may be needed to establish

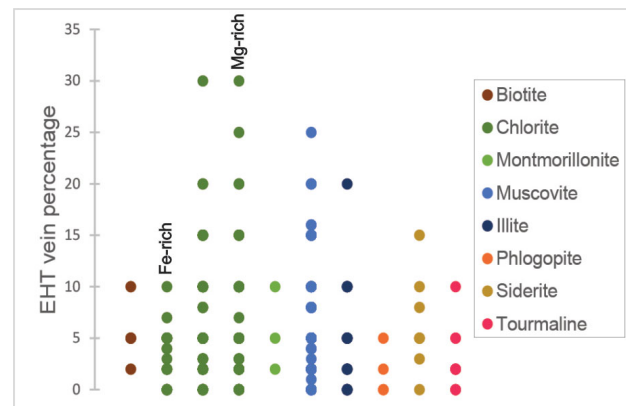


Figure 13. Percentage of early halo-type veins related to the main mineral picks from SWIR spectroscopy data.

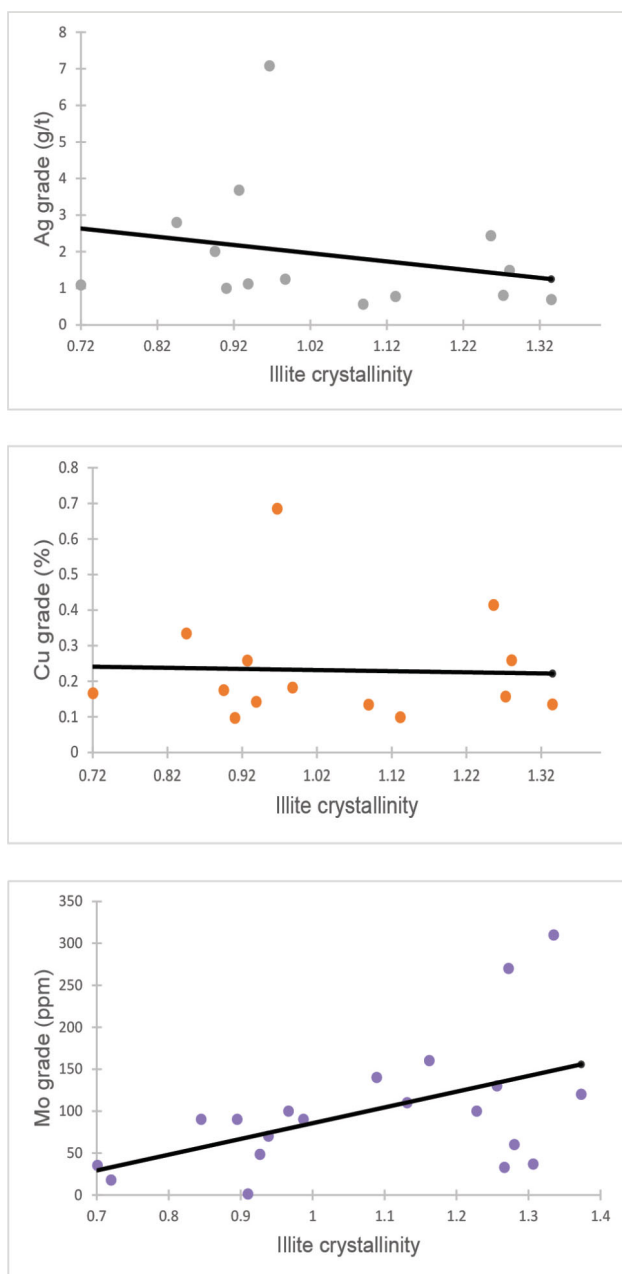


Figure 14. Grades of Ag, Cu and Mo compared to illite crystallinity.

this relationship. X-ray diffraction can also be used in conjunction with SWIR spectroscopy as an indicator of relative temperature of formation of illite and sericite, which would be useful in understanding conditions of the formation of certain phyllosilicates in the IKE deposit.

The composition of white mica can also be determined by the wavelength positions of Al-OH absorption features in the spectra. The wavelength at the minimum reflectance was recorded for the range 2185–2225 nm as a proxy for white mica composition (Harraden et al., 2013). When these values were plotted against grade and EHT vein percentage, the highest values of grade and EHT vein percent-

age tended to be in intervals where the minimum reflectance value was close to 2200 nm; however, there was no overall correlation.

Conclusions

It is clear that the presence of EHT veins is related to higher Cu grades in the system. Areas with higher percentages of EHT veins (>10%) have Cu grades of at least 0.1%. It is important to understand the processes that resulted in the formation of early halo-type veins, as they could be a tool for finding higher grade areas within the system.

Mineral assemblages seen in the alteration haloes of EHT veins at the IKE deposit reflect those of a deep-seated porphyry system. The EHT veins in drillhole IK14001, which is in the upper portion of the deposit, tend to have sericite as the dominant mineral, with some veins having significant amounts of biotite as well. Alteration haloes with sericite as the main component are thought to be a result of fluid cooling in shallower portions of the system. Studies on these types of veins provide an estimated formation temperature of 370–450°C (Rusk and Reed, 2008). In drillholes IK15013 and IK15018, which are the deeper holes in the system, there are still many sericite-dominant EHT veins; however, there are more occurrences of biotite-rich EHT veins, as well as green sericite and chlorite, in the alteration haloes. In deposits containing EHT veins, the presence of biotite, chlorite and green sericite indicate the most Cu-rich zone, as seen at Ann Mason, Nevada, where most of the Cu grade within the potassic B alteration zone is hosted in veins with alteration haloes containing chlorite (Dilles et al., 1992). Veins with alteration haloes consisting of chlorite, biotite and green sericite form at temperatures of around 475°C (Rusk and Reed, 2008). The presence of sphalerite in alteration haloes at the IKE deposit is interesting because, in Butte, Montana, it indicates the peripheral main-stage veins, which were formed at temperatures of 230–340°C (Rusk and Reed, 2008). A study done on the Butte deposit suggests that one hydrothermal-fluid composition may be responsible for alteration in the entire system. Differing compositions of alteration haloes can be due to changing temperature, varying extent of the reaction between the hydrothermal fluid and the host rock, and changing pressure (Reed et al., 2013). Compositions of EHT veins at the IKE deposit are quite similar to those seen in the main-stage mineralizing event at Butte, which would suggest similar fluid composition and temperature.

The SWIR spectroscopy alteration studies carried out on the IKE deposit suggest a large potassic-alteration footprint, as drillholes in opposite portions of the system seem to have predominantly high-temperature alteration minerals. The main mineral picks in this study were used to define the alteration zones in the system. Individual readings, by themselves, should not be overanalyzed too much, as re-

peating the reading could yield different mineral picks; however, identifying patterns in the data is useful in understanding fluid pathways (Halley, 2016). Drillhole IK14001 is the only hole that contains epidote and kaolinite, which would put it closer to the propylitic alteration zone; however, potassic minerals still seem to dominate. Illite crystallinity can be a useful estimate of the temperature of the mineralizing fluids. The Mo grade was the only factor that seemed to correlate with illite crystallinity, and the correlation would suggest that it is linked to hydrothermal fluids of higher temperature. The Cu grade may not show a correlation with illite crystallinity, as it is linked to the earlier stages of alteration and overprinting by later pulses of hydrothermal fluid could affect the results obtained in this alteration study. The conversion of illite to muscovite is a low-temperature reaction, occurring at 210–230°C (Garcia, 2013), so this method may not be suited for deeper portions of porphyry deposits.

Properties of the IKE deposit do not fit perfectly into a previously proposed Cu porphyry deposit model. The deposit is dominated by K-silicate alteration, lacks a defined propylitic alteration zone, and phyllic alteration is only seen in vein-alteration haloes, so it does not fit into the ‘classic’ porphyry model (Lowell and Guilbert, 1970). The alteration at IKE has more similarities to batholithic ore deposits, where the alteration zones are ‘inside-out’ with respect to the classic porphyry model, but differs in that it is not cut by a major fault and has more porphyritic rocks and quartz veins than expected in a batholithic deposit (Cheney and Trammell, 1966).

Future Work

Cathodoluminescence (CL) studies on quartz veins may be of use in this project. Temperature of the formation of quartz can be found comparatively using CL, where high intensity of luminescence would indicate a high temperature of formation (Rusk et al., 2006). Different quartz generations can be further defined using this method, assuming the physical and chemical characteristics were consistent throughout each vein-formation event. It would also be useful in determining primary and secondary fluid inclusions within quartz grains. Titanium diffusion within the quartz can also be measured using this technique, and may be a way to further constrain the timing of mineralization (Mercer et al., 2015).

Apatite luminescence, texture and geochemistry can be used to estimate the chemical compositions of the magmas that formed the hydrothermal fluids in a porphyry deposit (Bouzari et al., 2016). As apatite is found in a vein-alteration halo at IKE, CL studies on these particular apatites could aid in the understanding of how EHT veins contribute to mineralization in the system.

Further research using SWIR spectroscopy, in conjunction with X-Ray diffraction and microprobe work, could be useful in further constraining alteration patterns in the deposit. These studies would be done on more drillholes in the system, as well as the alteration haloes, to see how the spectra change with depth and mineralization.

Using data gathered from the above methods, as well as data already collected by Amarc Resources Ltd., a conceptual model for the IKE deposit will be developed. A model of this type of porphyry deposit could be useful because it will characterize not only this deposit but other porphyry deposits emplaced at greater depth, and could provide a new model for exploration.

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