# Using mineral chemistry to detect the location of concealed porphyry deposits – an example from Resolution, Arizona

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## Introduction

Porphyry-related mineral districts can host many major ore deposits of diverse styles and metal associations, including porphyry, epithermal and skarn deposits. In these deposits, hydrothermal alteration is typically zoned, and alteration zoning has long been an important tool used in their exploration (Fig. 1). However, the various mineral assemblages and textures that characterize each alteration zone are also present within barren hydrothermal systems, and in some cases may also be produced by non-mineralizing processes such as regional metamorphism. Discriminating mineralized and barren systems, being able to locate well-mineralized hydrothermal centers, and recognizing the distal footprints of mineralization continue to be great challenges to explorers. In this abstract, we demonstrate how the combination of epidote and chlorite chemistry can be used to successfully detect the location of a porphyry deposit, using the Resolution porphyry Cu-Mo deposit as a case study. The results presented in this paper are derived from a blind site test submitted to AMIRA International project P765A by Rio Tinto Exploration (RTX).

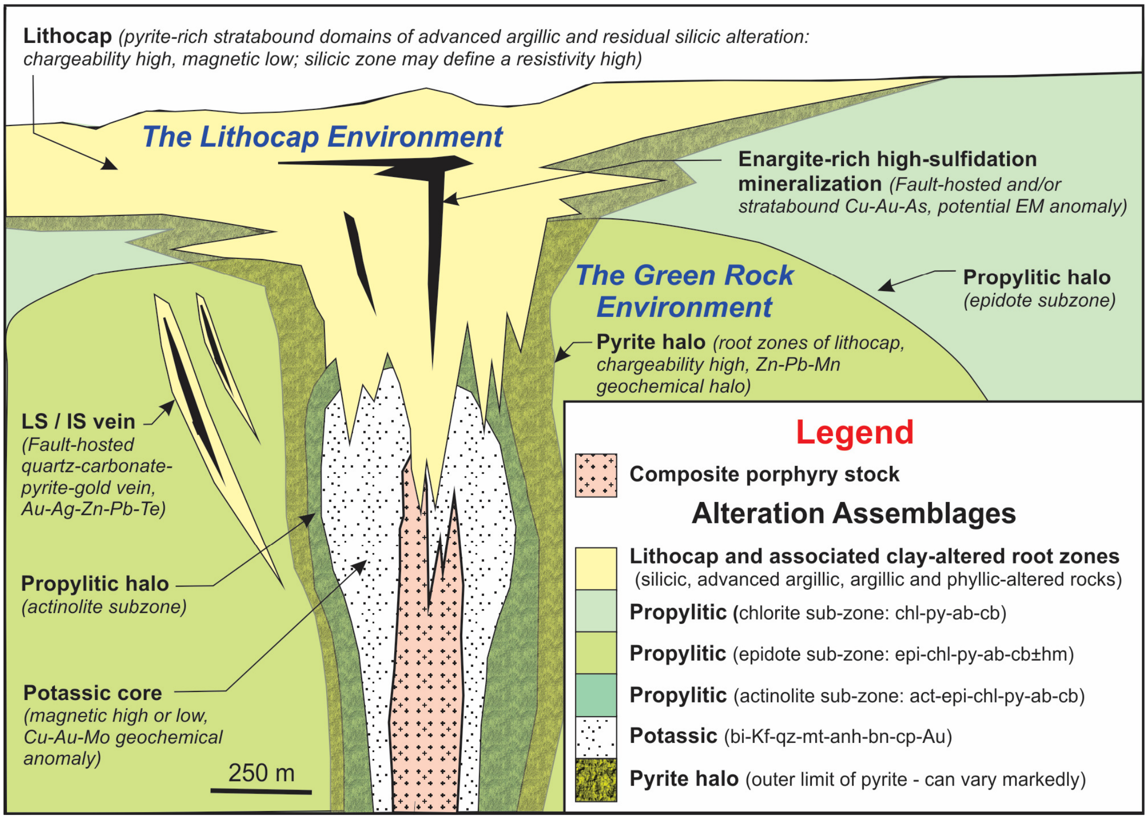

**Fig. 1.** Schematic illustration of alteration zoning and overprinting relationships in a porphyry system (modified after Holliday and Cooke, 2007; Cooke et al., 2014a and b). Mineralization occurs in intrusions and adjacent wall rocks that have undergone potassic alteration. Three propylitic alteration subfacies (actinolite, epidote, and chlorite zones) can occur around these altered rocks. In this example, the porphyry has been partially overprinted by a lithocap (silicic and advanced argillic alteration assemblages) that contains a domain of high sulfidation epithermal mineralization. The roots of the lithocap lie within the pyrite halo to the porphyry system. The degree of superposition of the lithocap into the porphyry system is contingent on uplift and erosion rates at the time of mineralization. Abbreviations: ab = albite, act = actinolite, anh = anhydrite, Au = gold, bi = biotite, bn = bornite, cb = carbonate, chl = chlorite, cp = chalcopyrite, epi = epidote, hm = hematite, Kf = K-feldspar, mt = magnetite, py = pyrite, qz = quartz.

Exploration in porphyry districts can be complicated by large areas of shallow-level alteration (e.g., lithocaps; Chang et al., 2011; Fig. 1). Beneath lithocaps, the background alteration assemblage is typically propylitic in volcanic successions, and we refer to this as the “green rock” environment due to the green colour of the altered volcanic rocks imparted by minerals such as chlorite, epidote and actinolite (Cooke et al., 2014a and b; Fig. 1). Because propylitic alteration is typically widespread, albeit weakly developed, explorers working in partially exhumed porphyry districts are likely to spend much of their time exploring in green rocks, where it can be difficult to identify the locations of productive ore zones that can occur between barren gaps of weakly developed hydrothermal alteration. It can also be difficult to evaluate and appreciate the significance of unmineralized veins that occur in these environments.

AMIRA International projects P765 (2004 – 2006), 765A (2007 – 2010), and 1060 (2011 – 2014) conducted research into the footprints of porphyry and epithermal deposits, and demonstrated that low-level hypogene geochemical dispersion halos are encapsulated in alteration minerals around porphyry deposits. These geochemical anomalies can be detected using laser ablation - inductively coupled plasma - mass spectrometry (LA-ICP-MS), and extend the geochemical footprint several kilometers beyond the footprint detectable by conventional geological and whole rock geochemical techniques. The techniques for detecting geochemical anomalies using epidote geochemistry were outlined recently in Cooke et al. (2014a). The capability of chlorite trace element geochemistry to detect and vector towards porphyry deposits has been outlined in Wilkinson et al. (2015).

## Resolution Porphyry Cu-Mo deposit

The Resolution Project is located three miles east of Superior, Arizona, USA. It was discovered by Magma Copper Co. and BHP Billiton via underground and surface drilling in an exploration campaign that ran from 1994 to 1998. Exploration conducted by Kennecott Exploration Co. from 2001 to 2003 confirmed a large body of copper mineralization at a depth of more than 1300m below surface. Resolution Copper Mining LLC (RCML) now holds 100 per cent of the assets and liabilities of the project, and is owned 55 per cent by Resolution Copper Company (RCC) and 45 per cent by BHP Copper Inc.

Resolution is a world-class porphyry Cu-Mo system located beneath a minimum of 1000m of post-mineral cover (Hehnke et al., 2012). The deposit is hosted in a sequence of sedimentary and intrusive rocks varying in age from Precambrian to early-Tertiary (Manske and Paul, 2002). It is strongly host-rock controlled with the best grades typically found in strongly altered and mineralized Precambrian diabase and limestone. Several faults with >200m displacement are present within the area of the deposit, but the bulk of movement pre-dates mineralization.

Although its ultimate size has not been fully defined, the deposit is characterized by consistent grades of >1% Cu mineralization in suitable host rocks above an elevation of 750m below sea level, and extends over an area of at least 2km in an east-northeast direction and 1.5km in a north-northwest direction (http://www.riotinto.com/). Its thickness is locally greater than 500 m. Significant but lower-grade mineralization extends beyond this defined body of strong mineralization. The total inferred resource is 1.624 billion tonnes at a grade of 1.47% Cu and 0.037% Mo (Hehnke et al., 2012), making Resolution, together with Hugo Dummett (Mongolia), Los Sulfatos (Chile) and Pebble (Alaska), one of the four exceptionally high-grade giant porphyry copper deposits discovered in the past two decades.

## Methodology

Rio Tinto Exploration submitted 12 drillcore samples of propylitic-altered Cretaceous volcaniclastic rocks and Proterozoic diabase to AMIRA project P765A as a blind site test of the mineral chemistry technique. These samples were provided to the research team with internally consistent sample coordinates, but the actual coordinates were changed by RTX systematically in order to obscure the location of the ore deposit.

Seven samples came from one deep drillhole (RT006), whereas the remaining five samples came from a cluster of drillholes 2 km north of RT006.

Each drillcore sample was subjected to detailed analysis by petrography, SWIR, whole rock geochemistry and K-feldspar staining in order to establish whether conventional techniques could detect the presence of nearby mineralization. LA-ICP-MS analyses of epidote, chlorite and pyrite grains were then conducted to test the proximity, fertility and likely location of any nearby mineralization. We obtained 168 valid LA-ICP-MS epidote analyses from 12 samples, 95 valid LA-ICP-MS analyses of chlorite on 11 samples, and 58 valid LA-ICP-MS analyses of pyrite on 7 samples, together with 2 chemical maps each of epidote and chlorite and 4 chemical maps of pyrite. LA-ICP-MS methodologies are outlined in detail for epidote in Cooke et al. (2014a), for chlorite in Wilkinson et al. (2015) and for pyrite in Large et al. (2009).

## Results

All 12 samples contained strong propylitic alteration, with epidote replacement of plagioclase and hornblende the most visually distinctive alteration style in each sample. Epidote occurs as an alteration mineral in all 12 samples and in a vein in one sample. Whole rock geochemical analyses and K-feldspar staining revealed that many samples had also undergone strong orthoclase (± biotite) alteration, which was not recognized from initial hand-specimen observations. The widespread distribution of potassic alteration implied either that this was a huge system (potassic alteration over 2 km) or there was more than one magmatic-hydrothermal center in the vicinity of the analyzed samples.

Nine of the samples had undergone pyrite alteration, and four had pyrite-bearing veins. Five samples contained traces of chalcopyrite as an alteration mineral, and four contained chalcopyrite-bearing veins, mostly from the bottom of RT006, where anomalous Cu (up to 0.35%) and S (up to 2.6%) were detected. SWIR analyses revealed that the chalcopyrite-pyrite veins in RT006 were associated with clay alteration, including illite and halloysite, implying that a moderately acidic fluid source was probably located nearby.

The trace element geochemistry of epidote yielded relatively subdued As and Sb responses in epidote compared to epidote from other porphyry deposits studied by the research team (e.g., Cooke et al., 2014) implying that the samples either came from close to a giant porphyry deposit, or were distal to a small deposit. Pyrite geochemistry indicated that As and Sb were being sequestered preferentially into pyrite, implying that the samples contained epidote from within the pyrite halo of a large porphyry deposit (e.g., Cooke et al., 2014). The Pb concentrations in epidote implied that a porphyry deposit was located at depth beneath the two clusters of samples, possibly at a distance of about 1.0 to 1.4 km from the deepest drillhole. Using the chlorite proximitor of Wilkinson et al. (2015), the chlorite geochemistry from all 11 samples gave a coherent result, more precisely locating Resolution at depth between the two sample clusters, with a coherent target defined in an area of approximately 400 m.

## Discussion & Conclusions

Conventional analytical techniques (e.g., whole rock geochemistry, alteration petrography, SWIR) applied to the 12 samples from Resolution gave indications of proximity to mineralization but did not give any indications as to which direction to explore. The combination of epidote and chlorite mineral geochemistry gave a coherent drill target located between the two clusters of drillholes and at elevations several hundred meters below the deepest analyzed sample, with a robust drill target defined. This combination of techniques successfully predicted the location of the Resolution orebody, providing encouragement for the application of mineral chemistry analyses to routine exploration in green rock environments elsewhere.

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