

# Airborne hyperspectral surveying as a tool for mineral exploration at high latitudes: a pilot study over porphyry Cu deposits, eastern Alaska Range, Alaska

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**Abstract.** The U.S. Geological Survey collected airborne imaging spectrometer data over unmined porphyry Cu deposits in the eastern Alaska Range using the HyMap2™ sensor in 2014. The objective was to test whether this technology could aid regional mineral exploration efforts in rugged remote parts of the State. Maps of the distributions of predominant minerals, made by matching reflectance signatures in HyMap2™ data to reference spectra in the shortwave infrared region, do not uniquely discriminate individual rock units but do identify hydrothermal alteration associated with porphyry deposits and prospects hosted mostly within the Nabesna pluton. In the footprints of porphyry Cu deposits at Orange Hill and Bond Creek, unique spectral signatures are related to variations in chlorite and muscovite abundance and their chemical composition. This is best revealed by variations in 2.2  $\mu\text{m}$  Al-OH absorption feature positions in pixels spectrally dominated by muscovite. Electron microprobe analyses confirm that these longer wavelength 2.2  $\mu\text{m}$  absorption features are the result of chemical differences in micas spatially associated with the porphyry deposits. The same chlorite classifications and absorption feature positions also delineated new mineral occurrences. Our study suggests that airborne imaging spectroscopy has application for regional mineral exploration in mountainous terrain in Alaska.

## 1 Introduction

Alaska is a region with high potential for world-class mineral resources, but geologic mapping and exploration are hampered by Alaska's immense size, remoteness, and rugged terrain. Airborne imaging spectroscopy (often referred to as hyperspectral remote sensing) can rapidly provide information on rock and alteration mineral compositions over broad areas that can help guide mineral exploration. However, the technology has historically not been used in Alaska because of low sun angle, unpredictable weather, and abundant vegetation. The U.S. Geological Survey (USGS) completed an airborne survey using the HyMap2™ sensor (Cocks et al. 1998) flown over a portion of the eastern Alaska Range (Fig. 1) to test whether, despite these factors, shortwave infrared spectroscopy would identify unmined porphyry Cu deposits and occurrences (including Orange Hill and Bond Creek). The airborne data were calibrated using targeted ground-based field spectra and combined with historic and new geochemical and mineralogical data to improve and validate results.

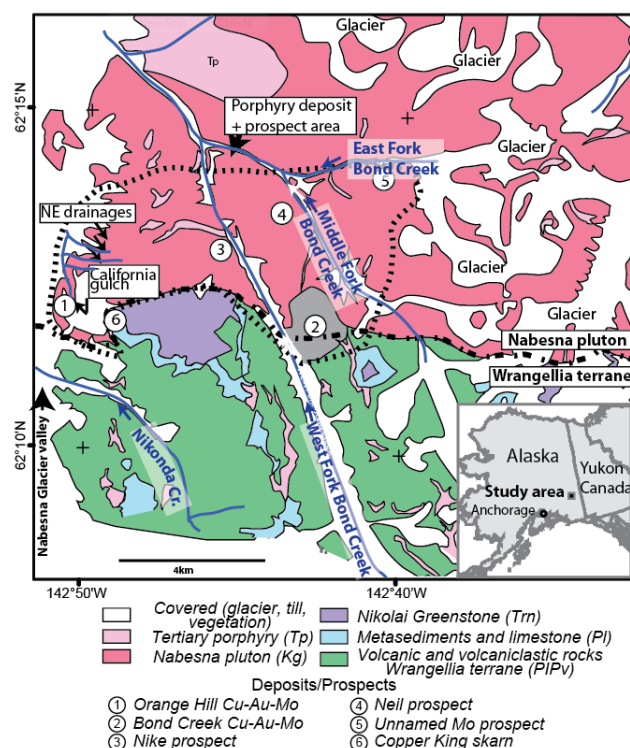


**Figure 1.** Location map (inset) and geologic map showing the distribution of porphyry prospects. Modified from Richter (1973). Grey zone is highly altered rock at Bond Creek.

## 2 Geologic background

The study area lies near the leading edge of the Wrangellia terrane, which was accreted to the North American margin in the Jurassic to Cretaceous (Plafker and Berg 1994). Mid-Cretaceous plutons, including the Nabesna pluton intruded the Wrangellia terrane volcanic rocks and landward flysch basins (Richter 1973). A number of porphyry Cu deposits formed during this magmatic event; the largest of these in the current study area are Orange Hill and Bond Creek (Fig. 1). The Orange Hill deposit is partially exposed on the eastern edge of the Nabesna Glacier valley in intermediate igneous rocks of the Nabesna pluton. The Bond Creek deposit is well exposed between the west and middle forks of Bond Creek. Alteration associated with Bond Creek (gray zone, Fig. 1) extends from within the Nabesna pluton into the adjacent Wrangellia terrane volcanic rocks. Several smaller

prospects, including the Copper King skarn are localized in the southwestern portion of the pluton margin. Widely distributed small Cu and Au occurrences are reported in the Wrangellia terrane rocks (not shown).

### 3 Methods

#### 3.1 Spectral analyses

In July 2014, approximately 2,000 line kilometers were collected using the HyMap2™ sensor over several areas including the focus area of this paper. The imaging spectrometer measured reflected sunlight in 126 narrow channels spanning the 0.4 to 2.5 micron ( $\mu\text{m}$ ) wavelength region of the electromagnetic spectrum. The nominal pixel size was  $\sim 6$  meters. Additional ground calibration and field spectral measurements were taken using an Analytical Spectral Devices (ASD) FieldSpec4™ spectrometer.

The HyMap2™ data were converted from radiance to reflectance using a multi-step calibration process (Kokaly et al. 2013). Reflectance images were processed using the Material Identification and Characterization Algorithm (MICA), a module of the USGS PRISM (Processing Routines in IDL for Spectroscopic Measurements) software (Kokaly 2011). The MICA analysis identifies the spectrally dominant mineral(s) in each pixel of imaging spectrometer data by comparing its reflectance spectrum to a reference spectral library of minerals, vegetation, water, and other materials. Since the spectral library contains multiple chlorite samples of different compositions, we were able to map qualitative differences in chlorite-dominated pixels across the study area. Shifts in the 2.2  $\mu\text{m}$  Al-OH absorption feature (due to vibrational effects of the aluminium-oxygen-hydrogen bond) in pixels containing dominant muscovite signatures, related to chemical differences in micas (e.g., Duke 1994), were also mapped across the area.

Spectral analysis of hand specimens was completed using the Corescan Hyperspectral Core Imager Mark III™. These analyses identified spectral shifts in muscovite across specimens for follow-up microprobe analyses to confirm a relationship between spectral shifts and mineral chemistry. Corescan reflectance data were processed with MICA as above.

#### 3.2 Geologic/geochemical investigations

Stream sediment, soil, and rock sampling was conducted to characterize the deposit geochemical signatures. Targeted sampling was also completed in areas away from known deposits in order to 1) establish background concentrations, and 2) test whether spectral anomalies similar to those in the known deposit areas reflect previously unrecognized porphyry Cu occurrences.

Electron microprobe analyses of muscovite/illite with different 2.2  $\mu\text{m}$  absorption feature positions were completed on four thin sections to establish if there is a

correlation between observed spectral shift and chemical signature.

## 4 Results

#### 4.1 Spectral results

The spectrally predominant mineral(s) mapping at the regional scale indicates that the Nabesna pluton away from porphyry deposits is dominated by muscovite signatures, but that near the porphyry deposits shows much more complex mineralogy, with lesser muscovite and more chlorite, epidote, clay, and sulphate pixel classifications. Similar complexity (excluding sulphates) is observed in the Wrangellia terrane rocks, which display a patchwork of different predominant minerals. Comparison with regional mapping by Richter (1973) indicates that mineral predominance mapping alone does not distinguish specific geologic units.

Spectra from chlorite-dominated pixels demonstrated best spectral matches (based on the  $R^2$  value from the linear regression of the spectral feature of the reference spectrum and the same wavelength region of the pixel spectrum) to one of three chlorite-bearing reference standards. Two of these classifications are nearly ubiquitously mapped within the volcanic arc rocks of the Wrangellia terrane. The third is mapped almost exclusively in and around the porphyry cluster defined in figure 1. Notably, this class extends into the volcanic arc rocks where altered by the Bond Creek porphyry system and into two additional zones on the north side of the east fork of Bond Creek, just outside of the defined porphyry deposit/prospect cluster.

The 2.2  $\mu\text{m}$  absorption feature position in muscovite/illite-bearing pixels ranges mostly from  $\sim 2.196$  to  $\sim 2.209$   $\mu\text{m}$  (Fig. 2). The majority of the muscovite pixels in the region have relatively short ( $< 2.203$   $\mu\text{m}$ ) absorption positions. However, the rock exposures in and around the porphyry deposits (Orange Hill and Bond Creek) display mostly  $> 2.204$   $\mu\text{m}$  wavelength absorption feature positions. Pixels displaying these longer absorption feature positions are spatially coincident with but more aerially extensive than the chlorite classifications.

Similar to that shown by the chlorite mapping, additional areas north of the east fork of Bond Creek also contain pixels with long wavelength absorption features (areas 7 and 8; Fig 2). Only small scattered areas with abundant long wavelength signatures are observed in Wrangellia terrane rocks, with the most extensive located along the southern edge of the survey (loc. 11, Fig. 2). Similar ranges of absorption feature positions are observed in Corescan data of individual hand specimens.

#### 4.2 Geochemical results

In the study area, sediments and soils with anomalous concentrations of Cu + Au and (or) Mo are mostly centered about the known porphyry deposits (Fig. 2). Samples in

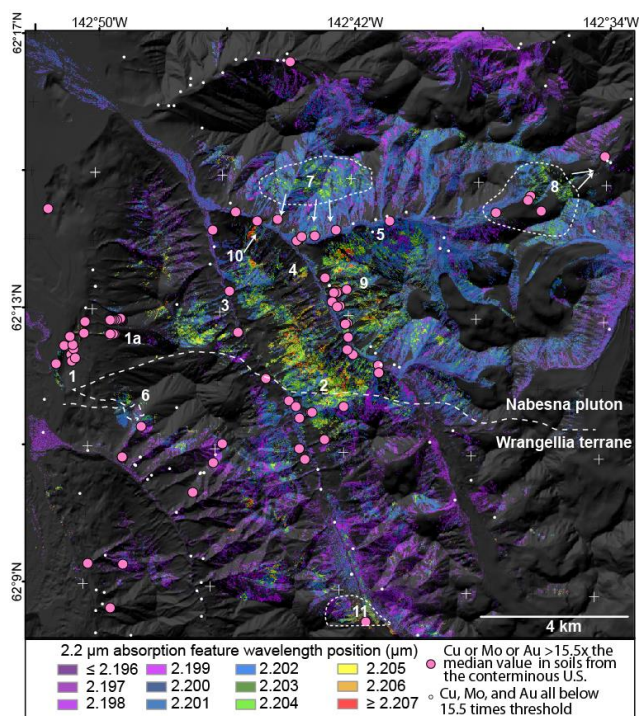


**Figure 2.** 2.2  $\mu\text{m}$  absorption feature map. Locations equivalent to figure 1. 1a – extension(?) of Orange Hill. Locations 7-11 are additional long wavelength zones identified in survey.

the Wrangellia terrane typically contain only anomalous Cu and lack Mo and Au. Two areas identified by the chlorite and long 2.2  $\mu\text{m}$  absorption feature positions that are outside of the known porphyry deposits are located along and at the headwaters of the east fork of Bond Creek (locs. 7 and 8; Fig. 2). Targeted sampling around the hyperspectral anomalies confirms that these rocks are also mineralized because rock, soil, and sediment samples in these areas contain anomalous Cu-Au and (or) Mo concentrations.

Electron microprobe analyses of micas characterized by shortward and longward wavelengths shift of the 2.2  $\mu\text{m}$  absorption features based on Corescan data of hand specimens indicate that the absorption feature positions are a consequence of mineral chemistry (Fig. 3). Micas with longest wavelength position have higher Si and Mg, and lower Al ( $\pm$ Na) than shorter wavelength micas.

## 5 Discussion

The spectral mineral predominance mapping as a proxy for geology is only interpretable to the level of detail of the existing reconnaissance geologic mapping (Richter 1973). Complexity in the distributions of mineral classifications in the predominance mapping arises from several factors, such as lithologic variations (and structural complexity?) which are most prominent in the volcanic arc rocks of the Wrangellia terrane, unit mixing from mass wasting, and weathering and hydrothermal overprinting. The evidence for hydrothermal overprint, most strongly suggested by the

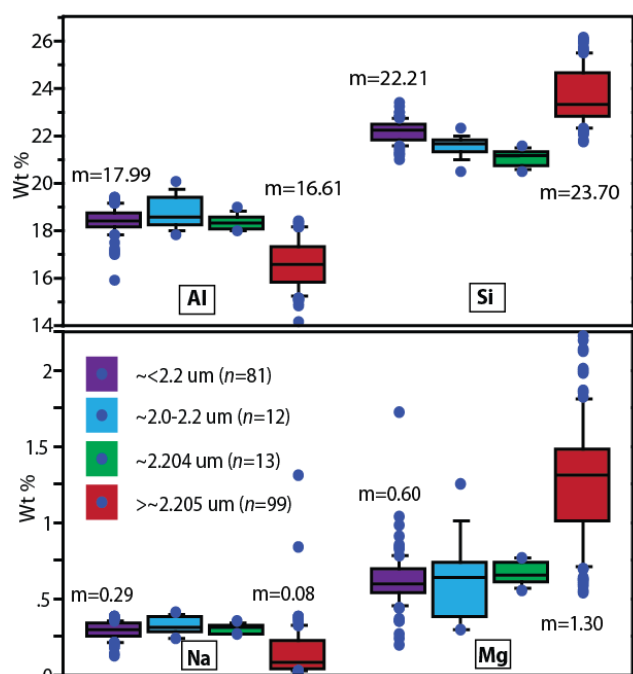


**Figure 3.** Boxplots of Al, Si, Na, and Mg concentrations of muscovite/illite with different 2.2  $\mu\text{m}$  absorption feature positions established by Corescan analyses. Data support mineral chemistry influencing spectral signatures, particularly for longest wavelength positions. m=median and n= number of analyses.

abundance of chlorite, epidote, sulphates and clays in the Nabesna pluton porphyry cluster area is of particular interest to mineral explorationists.

Empirically, the distinct chlorite classification and observed longward 2.2  $\mu\text{m}$  absorption feature position for muscovite-dominated pixels further record the hydrothermal activity. Associated fluids primarily altered parts of the Nabesna pluton but also adjacent Wrangellia terrane rocks at the Bond Creek deposit (Figs. 1, 2) and produced a chemically and spectrally distinct suite of minerals. The similar spectral signatures and follow-up geochemical sampling at locations 7 and 8 (Fig. 2) indicate that this hydrothermal activity and mineralization extended beyond the previously recognized porphyry cluster footprint.

Spectral feature wavelength shifts related to changes in mineral chemistry in hydrothermal mineral deposits have been recognized in a number of deposit types, including other porphyry Cu deposits (e.g., Halley et al. 2015; Harraden et al. 2013). The porphyry studies typically suggest that shorter wavelength positions associated with the mica chemistry are produced during main stage mineralization. However, porphyry systems are complex, and our longer wavelength signatures may result from mica formation during the waning stages of deposit formation. Regardless of the causes, the key observation is spectral contrast with surrounding rocks, particularly of supposed similar primary composition.

Although there have been spectral investigations of VMS systems in Canada (e.g., Laakso et al. 2014), to our knowledge there has been no concerted effort to apply

airborne hyperspectral surveying as a tool in regional mineral exploration in Alaska, likely due in part to the assumed significant limitations of its application (requires clear weather, collection within short data acquisition window near solar noon, exposed bedrock with limited lichen cover). However, our study demonstrates that rapid acquisition and subsequent processing of data can be successful in distinguishing alteration mineralogy of both known and new mineral occurrences in a remote rugged area. Therefore, extensive underexplored mountainous regions remaining in Alaska are prime targets for this technology. With additional research efforts, it is plausible to further expand the applications of airborne imaging spectrometry in mineral exploration to even more challenging vegetated areas at northern latitudes.

## 6 Conclusions

Imaging spectroscopy provided important geologic information even though data were collected at high latitudes in rugged terrain.

- 1) Although not uniformly effective for mapping different geologic units, spectrally predominant mineral mapping identified areas of complex alteration mineralogy related to hydrothermal activity in the porphyry Cu deposit cluster area.
- 2) Chlorite-dominant pixels within the porphyry Cu deposit cluster are spectrally distinct and interpreted to reflect the porphyry alteration/mineralization processes.
- 3) Muscovite-dominated pixels in the porphyry Cu cluster are generally characterized by longward 2.2  $\mu\text{m}$  wavelength positions because of different chemical compositions and genetic origins (ie., formed during magmatic hydrothermal activity.)
- 4) Follow-up sampling around areas with chlorite and muscovite wavelength signatures similar to those displayed in regions with known deposits demonstrated additional previously unrecognized Cu-Au-Mo occurrences.
- 5) Airborne imaging spectrometry can be a useful guide in reconnaissance regional exploration in exposed mountainous regions of Alaska.

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