Airborne Hyperspectral Supported Porphyry Exploration in the Peruvian Andes

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ABSTRACT

A geological prospectivity map was created and combined with ASTER and LANDSAT multispectral datasets to produce >300 ranked areas of interest (AOIs) in central and southern Peru for porphyry copper exploration. Field validation of the AOIs was faced with challenges such as difficult access and dangerous topography, which resulted in increased field time per AOI validated and prohibited access to roughly 20% of AOIs. At the rate of field validation, it would have taken 8–10 years to properly assess all of the AOIs. A decision was taken to trial an airborne hyperspectral survey, which would overfly each of the AOIs in southern Peru including known deposits. This airborne hyperspectral survey resulted in the automatic downgrade of 25% of the existing AOIs based on spectral characteristics. As importantly, the hyperspectral survey has doubled the rate of the ground truthing process and allowed for better ranking of the existing AOIs, resulting in visiting the better AOIs sooner. It has also allowed the visualization of the surface mineralogy of AOIs that are impossible to field visit over land. To date, the hyperspectral supported generative effort has directly resulted in the identification and staking of four large porphyry systems and has supported the brownfields exploration of another two existing projects, it has also reduced the estimated time to complete the generative program by half, allowing First Quantum Minerals to take advantage of the current market conditions which are favorable for pegging free ground and deal making in Peru.

BACKGROUND

Central and southern Peru is home to numerous world-class porphyry copper deposits that occur within multiple metallogenic belts. Contained copper of the known deposits in these two regions exceeds 140 Mt, with the major copper bearers being Toquepala, Cerro Verde, Cuajone, Antamina, and Toromocho, each with more than 10 Mt of contained copper.

Prospectivity maps applying the mineral systems approach (e.g. Wyborn et al., 1994; McCuaig et al., 2010) were created using geologic, geophysical and geochemical based inputs and were combined with multispectral datasets such as ASTER and LANDSAT to create a fully integrated, ranked 'prospectivity map' for porphyry copper exploration in southern and central Peru (Figure 1). The geologic and geophysical datasets were used to create a favorable structural 'architecture' map, whilst the geochemistry and multispectral datasets were used to directly target potential hydrothermal systems and combined into one product.

Hotspots from the prospectivity map, referred to as 'Areas of Interest' (AOIs), occur where multiple favorable factors come together in one location, which thus is deemed a favorable location to explore for a porphyry copper deposit. Added confidence in the validity of the prospectivity map product is that all of the known major deposits (e.g. Cuajone, Toquepala, Quellaveco, and Cerro Verde) are associated with a high ranking AOI. In total there were roughly 330 AOIs deemed necessary for follow up fieldwork in the original products.

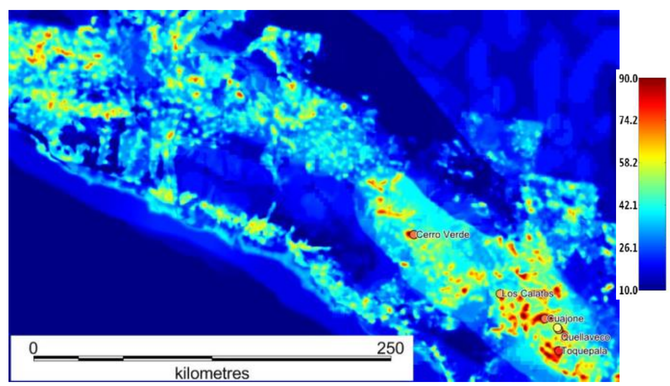

Figure 1: Original prospectivity map for southern Peru from 2014, based on geologic and geophysical inputs which model structural architecture and geochemical and multispectral (ASTER and LANDSAT) inputs used as direct detection tools for hydrothermal alteration systems. Score bar on right of image.

General Geology

Central Peru

Jurassic-Cretaceous marine and continental sedimentary rocks from back-arc rift and sag basinal facies act as host for most porphyry Cu deposits in central Peru. These basins were compressed and inverted in the late Cretaceous and throughout the Tertiary period, forming a fold and thrust belt. Miocene arc magmatism re-activated long-lived extensional structures and emplaced plutonic material in the crust utilizing these structures.

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Southern Peru

The 'Coastal Batholith' granodiorite intruded into an arc of dacitic-andesitic rocks as well as pre-existing Jurassic-Cretaceous marine and continental sedimentary rocks during the late Cretaceous and upper Paleocene (Clark et al., 1976, Clark et al., 1990). Known porphyry deposits are typically emplaced into or around the margins of this batholith. Post-mineral Miocene-Pliocene andesitic-dacitic pyroclastic flows (Tosdal et el., 1981) cover roughly 25% of the region of interest. Quaternary volcanic ash mantles much of the region and is typically less than 50 cm thick.

EARLY FIELDWORK

The terrain of the work area varies from relatively flat desert within the coastal Jurassic belt, to steep, rugged terrain in the Paleocene-Eocene and Miocene belts of the Cordillera Occidental where altitudes range from 2000–5000 m asl (e.g. Figure 2). The majority of the high ranking AOIs occur within the Cordillera Occidental, most of which do not have direct road access. This means a lot of field time is devoted trying to gain vehicle access as close as possible to each AOI, and then hiking to field truth each AOI. Approximately 20% of the time it was found impossible to reach the AOI on foot due to extreme terrain, with an average of two days to vet each AOI.

After the first year of fieldwork, based on the rate of AOI verification, it was anticipated that it would take 8–10 years to field check all of the AOIs with the personnel resources on hand.

Figure 2: Example of terrain from the Rosa Roja Norte project in southern Peru. From the bottom of the valley to top of the mountains in the background is 2500 m all of which needs to be mapped on foot and is much more time consuming when compared to mapping on flat terrain at lower altitudes.

Multispectral Shortfalls

Due to the multispectral nature of ASTER, which was a key dataset for the original generative program, it is only possible to confidently map mineral groups, not species, within the 1900–2500 nm range for clays and white micas. These mineral groups contain some of the key indicator minerals associated with porphyry hydrothermal systems, and can represent hydrothermal alteration associated with phyllic, argillic and advanced argillic alteration zones. However in the field it was found that the vast majority of the AOIs that were being visited (> 80%) were not actually hydrothermal in origin, rather simply being due to surficial weathering of existing geology.

It was also found that the 30 m ASTER pixel size was not sufficient to identify some true hydrothermal anomalies that were variably covered by Quaternary ash, but had hydrothermal alteration outcropping in creeks which incuse the thin ash layer.

Some Examples of False Positives from Multi-Spectral Datasets

It was found that Jurassic-Cretaceous marine and continental sedimentary rocks which occur throughout the region were providing 'argillic' and 'advanced argillic' false positive anomalies owing to the surficial weathering of shale to produce kaolin (Figure 3). Also, upon weathering of the sedimentary rocks, detrital white micas are liberated which also yield 'sericite' anomalies which are non-hydrothermal in origin and are therefore also produce false positive anomalies.

The voluminous dacitic-andesitic lavas throughout the region often have a porphyritic texture, with up to 2–10 mm phenocrysts of feldspar common. When these units are weathered, the feldspar converts to kaolin, which yields a false positive argillic/advanced argillic signal.

Weathering of units with an andesitic composition liberates iron from the mafic minerals within the rocks. The iron is often remobilized and forms secondary iron oxide coatings on the outside surfaces of the rock which causes broad hematite and goethite anomalies, though these are not associated to a hydrothermal alteration cell.

Figure 3: A shale unit which, when weathered, converts to kaolin and also liberates detrital micas which give a white mica anomaly.

It is a common phenomenon for mafic units that have undergone regional metamorphism to form epidote and chlorite veins which yield a false 'propylitic' signal.

AIRBORNE HYPERSPECTRAL ACQUISITION

In order to speed up field validations of the AOIs, and in an attempt to reduce the number of false positive anomalies being visited, First Quantum Minerals (FQM) decided to trial an airborne hyperspectral survey in southern Peru—a first for the company. A novel survey design allowed for all priority AOIs to be overflown as well as all eight of the known deposits within the survey area within budget constraints.

Filtering Out False Positives

The ability to be able to accurately distinguish the hydrothermal minerals of alunite, pyrophyllite and dickite from kaolinite was key to be able to downgrade the AOIs that exhibit just kaolinite which was deemed to have formed from solely surficial weathering processes.

The ability to accurately map the wavelength differences of the sericite 2200 nm absorption feature in the airborne hyperspectral data allowed the calculation of illite chemistry and crystallinity, which assisted with distinguishing true hydrothermal sericite vs detrital micas liberated from weathered sedimentary rocks which further helped to filter spurious anomalies

In total roughly 25% of the AOIs were able to be filtered out in this manner, saving 2–3 years of fieldwork, a further 50% more were ranked as low priority for field visits due to different alteration intensities or non-favorable erosional levels.

Additional Benefits of Hyperspectral Data

The specific hydrothermal mineral mapping of the AlOH group as well as the sericite 2200 nm absorption feature and crystallinity, both of which are particularly useful in quartzite packages, allowed FQM to immediately re-rank the existing AOIs based on their favorable mineralogy. This meant that the truly high priority AOIs could be flagged for immediate field validation e.g. Figure 4.

The 6X smaller pixel size of the airborne hyperspectral survey relative to the ASTER pixels, allowed for previously subtle multispectral anomalies (i.e. concealed by ash cover) to properly reveal themselves in creeks and gullies. It also enabled the desktop vetting of the inaccessible AOIs, which previously would have had to be visited via helicopter, both costly and a safety risk in the Andes.

Iron oxide species are better mapped and subtle jarosite anomalies (resulting from the oxidation of sulfides) were revealed at several AOIs.

First Quantum Minerals was able to take the mineralogical fingerprint of all the known deposits in the region and use it as a training dataset for favorable spectral characteristics to our AOIs.

During field validation, the team can go directly to the anomalous outcrops to verify the size and intensity of hydrothermal alteration in a highly efficient manner, on average visiting 1 AOI per day, twice as fast as pre-hyperspectral.

Following the successful hyperspectral trial in southern Peru, a second hyperspectral survey, following a very similar design was commissioned and carried out in 2016 in Central Peru.

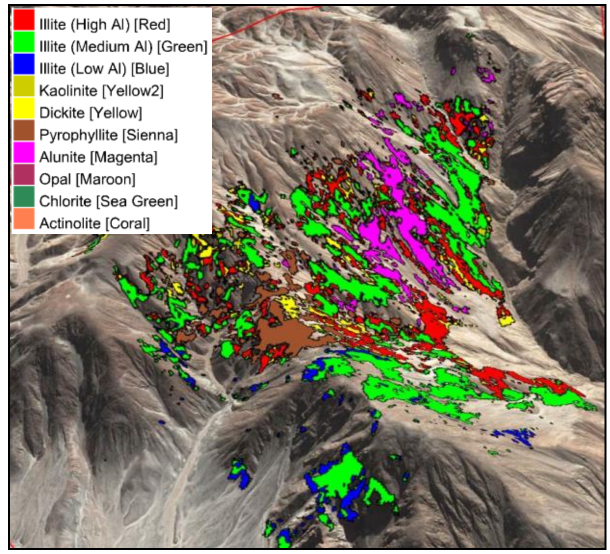

Figure 4: An example of an unmistakable porphyry style alteration cell in the hyperspectral dataset. Alunite-dickite-pyrophyllite-sericite representing the transition from roots of a lithocap to outer phyllic porphyry environment, which has subsequently been confirmed in the field and been staked by FQM. Hyperspectral processing by D. Coulter (2015).

Use of Airborne Hyperspectral Data in Existing Projects

Additionally, airborne hyperspectral data was acquired over two of FQM's existing projects, one each in the southern and central Peru surveys. In both instances the hyperspectral data has assisted with defining the extents of the alteration cell by mapping weak hydrothermal sericite that generally extends further outboard than mapped by field geologists (Figure 5) and also by defining the extents of propylitic alteration.

First Quantum Minerals provided the minerology of pre-existing ASD points with the consultant carrying out the hyperspectral interpretation and they also served as an internal cross check to the mineral interpretation. The hyperspectral mineralogy has also assisted the geologists working at the projects with mineral identification when mapping and also with where to prioritize further mapping at the projects.

CONCLUSIONS

Conducting hyperspectral surveys has reduced what would have been an 8–10 year generative program to a 4–5 year program. By being able to re-rank the existing AOIs based on their hyperspectral characteristics, FQM was able to prioritize field visits to the most exciting AOIs earlier than would have occurred if the survey was never acquired. This has been especially important in the current exploration climate where large tracts of free exploration ground are becoming available in Peru. This has resulted in the identification of four large porphyry alteration zones, three of which were able to be fully staked by FQM. Additionally, in two of FQM´s current projects, the survey has assisted by defining the limits of alteration as well as highlighting the areas of interest and assisting with mineral identification.

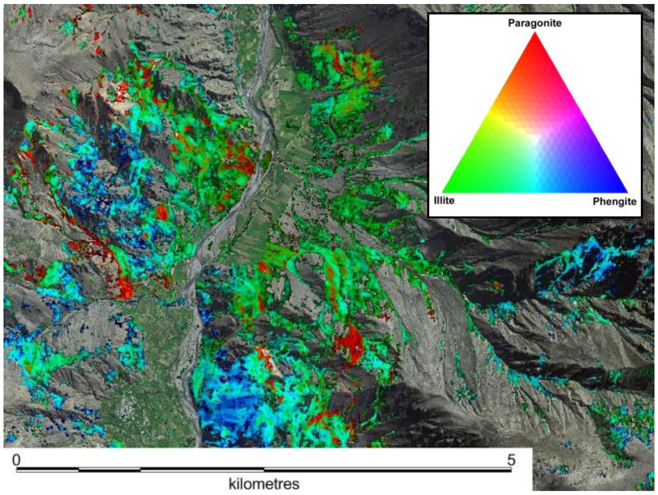

Figure 5: Illite index at the Huanarpo project showing the extents of hydrothermal sericite alteration. Note that much of the illite appears confined to creeks, this is because the surface is covered in a thin mantle of aspectral ash, and the hydrothermal alteration is exposed in creeks that cut through the ash layer. Hyperspectral processing by Coulter (2015).

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