Making the exploration process more efficient: A Case study from a porphyry exploration programme in the Peruvian Andes

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1. Background

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

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 (Fig. 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.

'Areas of Interest' (AOIs), occur where multiple favorable factors come together in one location and is thus 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 are associated with a high ranking AOI. In total there were roughly 330 AOIs deemed necessary for follow up fieldwork in the original products.

2. Methods

2.1. 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 bets of the *Cordillera Occidental* where altitudes range from 2000-5000m asl (e.g. Fig. 2). The majority of the high ranking AOIs occur within the *Cordillera Occidental* - most of which don't have direct road access. As a result a lot of field time is devoted to 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.

2.2. Multispectral Shortfalls

Due to the multispectral nature of ASTER, it is only possible to confidently map mineral groups, not species, within the 1900-2500nm 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 to 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 due to surficial weathering of existing geology.

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

3. Results

3.1. Examples of False Positives From Multi-Spectral Datasets

It was found that Jurassic-Cretaceous marine and continental sediments which occur throughout the region were providing ‘argillic’ and ‘advanced argillic’ false positive anomalies owing to the surficial weathering of shale to produce kaolin (Fig. 3). Additionally, weathering of the sediments liberates detrital white micas which can yield ‘sericite’ anomalies though are non-hydrothermal in origin and therefore also produce false positive anomalies.

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

Weathering of units with an andesitic composition liberates iron from the mafic minerals within the rock. 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 which are not associated to a hydrothermal alteration cell.

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.

3.2. Airborne Hyperspectral Acquistion

In order to speed up field validations of the AOIs, and in an attempt to reduce the number of false positive anomalies being visited, FQM decided to trial an airborne hyperspectral survey in southern Peru. 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.

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 were deemed to have formed from solely from surficial weathering processes.

The ability to accurately map the wavelength differences of the sericite 2200nm 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 sediment 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.

The specific hydrothermal mineral mapping of the AlOH group as well as the sericite 2200nm 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. Fig. 4.

The 6X smaller pixel size of the airborne hyperspectral survey relative to the ASTER pixel 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.

Additionally FQM 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.

Field validations have been made more efficient because the team can go directly to the anomalous outcrops to verify the size and intensity of hydrothermal alteration, on average visiting 1 AOI per day, twice as fast as pre-hyperspectral.

4. 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.

References

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Wyborn, L.A.I. & Heinrich, C.A. & Jaques, A. (1994). Australian Proterozoic mineral systems: essential ingredients and mappable criteria. Publication Series of the Australasian Institute of Mining and Metallurgy. 5. 109-115.

Attachments

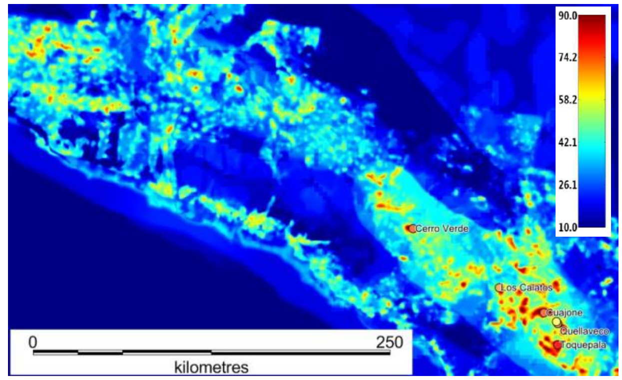

Figure 1. Original prospectivity map for southern Peru from 2014, based on geologic and geophysical inputs which model structural architecture and geochemical and multispectral (ASTER and LANDSAT) inputs used as direct detection tools for hydrothermal alteration systems. Score bar on right of image.

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 2500m 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.

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

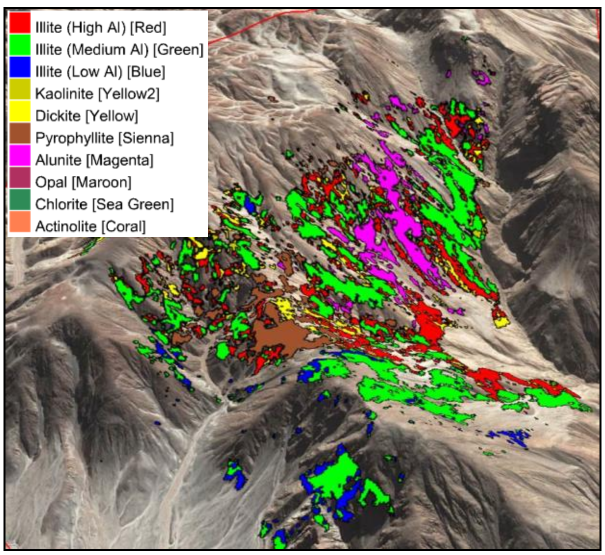

Figure 4. An example of an unmistakable porphyry style alteration cell in the hyperspectral dataset. Alunite-dickite-pyrophyllite-sericite representing the transition from roots of a lithocap to outer phyllic porphyry environment, which has subsequently been confirmed in the field and been staked by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

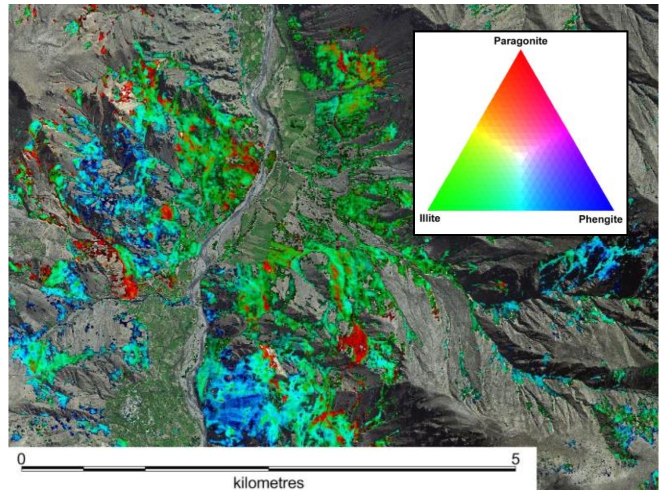

Figure 5. Illite index at the Huanarpo project showing the extents of hydrothermal sericite alteration. Note that much of the illite appears confined to creeks, this is because the surface is covered in a thin mantle of aspectral ash, and the hydrothermal alteration is exposed in creeks that cut through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

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