An African Copperbelt-Style District in Colombia: Insights from Longwave Infrared Satellite Imaging

Dave Forest* and Neil Pendock

N-Side Mining Technology Pte. Limited, Singapore

**Corresponding author: dforest@piercepoints.com*

Reports of sediment-hosted copper mineralisation have been noted in the Eastern Cordillera of Colombia for over half a century, with local geologists citing similarities to both the African Copperbelt and the Kupferschiefer. Despite high-grade sampling ranging up to 14% copper reported over a strike length of at least 250 km, little systematic modern exploration has been conducted on these targets. One of the major challenges for exploration is significant vegetation in this sub-tropical climate. Longwave infrared (LWIR) ASTER satellite imaging provides a valuable tool for regional exploration and discrete targeting. Inferred copper LWIR anomalies were found to occur along a contact between Devonian-Permian redbeds and Cretaceous shales, supporting the geologic model for sediment-hosted Africa Copperbelt-style mineralisation.

INTRODUCTION

In 1993, geologists C. Rodriguez and A.J. Warden wrote one of the only summary papers ever compiled on observations of sediment-hosted copper showings in the Eastern Cordillera of Colombia. These authors noted that "stratiform mineralisation has been traced intermittently along strike for 250 km within a sequence up to 100 m thick." They concluded, "In the authors' opinion there are definite similarities to the stratiform Cu-U mineralisation of the Zambian Copperbelt and also the base-precious metal mineralisation of the Polish Kupferschiefer" (Rodriguez and Warden, 1993).

Observations of such mineralisation largely coincided with a particular section of the thick sedimentary sequence within the Eastern Colombia sedimentary basin. Specifically, the contact between a sequence of Devonian to Permian reddish-grey grits typical of oxidizing redbed conditions (Thery, 1982), known as the Farallones Group, and a section of Cretaceous black shales ranging up to 4000 m in thickness (Gomez *et al.*, 2013), forming part of the Caqueza Group. Rodriguez and Warden reported sampling from near this contact horizon, returning grades ranging from 0 to 14% copper, with associated Au, Ag, Cr, Mn, Ni, Pb and U_3O_8.

Despite these known showings, little follow-up exploration has been conducted on these targets since the publication of this overview paper in 1993. Part of the challenge was political instability in the area during the 1990s and early 2000s, but even after the security situation improved markedly in the mid-2000s, exploration activity largely failed to return.

One of the key challenges in exploring for sediment-hosted copper in this region is moderate to dense vegetation, contrasting with the relatively sparse grasslands of the African Copperbelt. The relatively restricted width of typical sediment-hosted copper mineralisation, on the order of tens of metres (Hitzman *et al.*, 2005), makes exploration in well-vegetated terrains here a particular challenge, notably different than the exploration for large (kilometer-scale) porphyry targets that has typically dominated the exploration industry in South America.

METHODS

The Japanese ASTER satellite has been remotely sensing the Earth since 2000. Visible near-infrared and shortwave infrared (VNIR/SWIR) imagery samples the electromagnetic spectrum from 0.5 to 2.4 μm and senses the top millimetre of the Earth's surface at 30-metre spatial resolution. Longwave infrared (LWIR) imagery at 90-metre resolution samples from 8.3 to 11.3 μm and has some penetration below the surface thanks to the emissivity properties of minerals. All three spectral ranges produce images useful in mineral exploration.

LWIR was chosen as the focus for this study, to investigate whether the ground-penetrative properties of the longwave segment of the spectrum are effective in imaging copper sulphide minerals underneath vegetation. Cloud-free ASTER images were downloaded covering 8000 square kilometres of the Eastern Colombian Cordillera, corresponding to a segment of the area identified as prospective for copper mineralisation by Rodriguez and Warden (1993).

The first step in processing of the LWIR ASTER data was a separation of reflectance from emission effects in the imagery because these data were collected during daytime. Sixteen spectral endmembers were then derived for the image as it was assumed that each 90 m × 90 m parcel of ground is a non-negative linear combination of sixteen pure endmembers. Sixteen is an ad hoc number, chosen on the assumption that it is sufficient to explain the geological variability of the scene.

Each pixel was then expressed as a sum of sixteen spectral abundances, most of which will be zero because they are estimated in such a way as to produce a sparse representation of the nine-dimensional data in sixteen-dimensional space. Each endmember was interpreted as corresponding to a geological meaningful unit and interpretation consisted of the process of interpreting these endmembers by comparing them with an appropriately resampled spectral library from Johns Hopkins University, National Aeronautics and Space Administration (NASA) and Jet Propulsion Laboratory (JPL) (Salisbury *et al.*, 1991). Best spectral matches for common sediment-hosted copper minerals chalcocite and chalcopyrite (Hitzman *et al.*, 2005) were selected and their relative abundances plotted across the study area.

RESULTS

The processed LWIR imagery revealed a strong linear trend in the spectral endmember representing a best match for chalcocite, as seen in Figure 1. The linear LWIR anomalies observed show a distinct northeast–southwest to north–northeast–south–southwest orientation. This corresponds to the strike of geologic units within the study area, including the redbeds of the Farallones Group and the overlying black shales of the Caqueza Group.

The most prominent linear LWIR anomaly extends from the far northeast corner of the study area to the far southwest corner, covering a length of approximately 100 km. The location of this linear trend matches well with the location of the contact between the oxidized Farallones Group redbeds and the reduced Caqueza Group shales, as reported in regional geologic mapping (Figure 2).

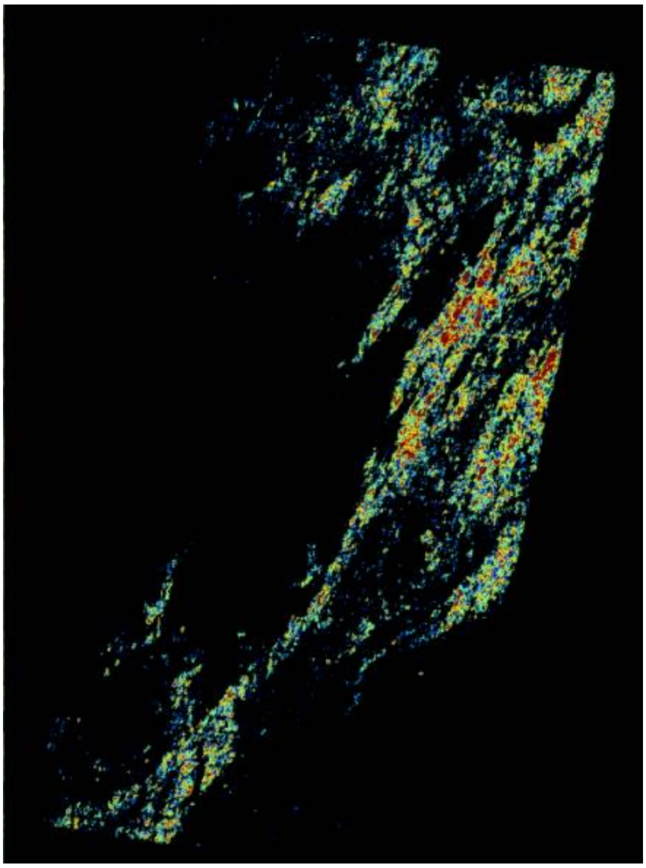

Figure 1: Plot of relative abundance for spectral endmember representing best match for chalcocite across the study area.

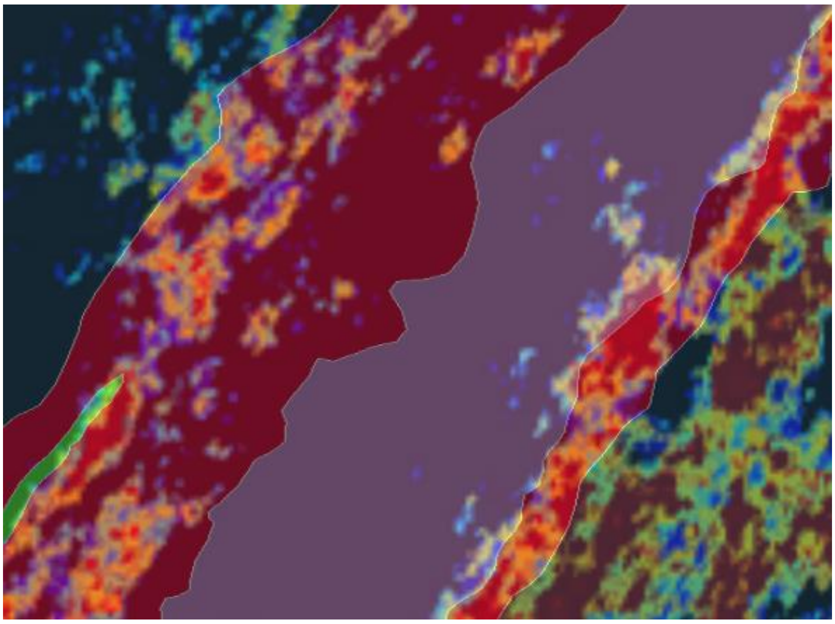

Figure 2: Detail location of chalcocite LWIR response plotted on regional geologic map for the Eastern Colombian Cordillera. Oxidized clastic sediments of the Farallones Group shown in pink, with shales and carbonates of the Caqueza Group shown in red and blue.

DISCUSSION

The location of a linear chalcocite LWIR anomaly occurring near the geologic contact between the Farallones Group and Caqueza Group units fits the general model for sediment-hosted copper deposits, where mineralisation is interpreted to form at or near the contact between oxidized sediments (representing the source of copper for mineralizing fluids) and reducing sediments, which alter fluid chemistry and cause precipitation of copper as chalcocite, bornite and chalcopyrite (Hitzman *et al.*, 2005).

To field-test the validity of the observed LWIR anomalies, field traverses were made through several segments of observed high LWIR response. In all cases, these areas were found to be heavily vegetated (Figure 3), with restricted outcrop generally limited to streambeds and cliffsides where rock is exposed by landslides.

Figure 3: Typical vegetation within the study area.

In areas where outcrop was available, the LWIR anomaly was confirmed as near to the geologic contact between redbeds and shales (Figure 4). The linear trend of the LWIR anomaly conformed well to the interpreted and regionally mapped continuation of this contact under vegetated and covered areas.

In several locations, chalcocite and chalcopyrite LWIR anomalies were found to correspond to occurrences of dark, highly-graphitic shales showing strong silicification, carbonatisation, and hematite alteration. Such altered shale was found to host sulphide and/or oxide mineralisation (Figure 6) over a strike length of approximately 10 km.

Figure 4: Redbed sediments (left) and black shales (right) observed within the field study area in zone of LWIR chalcocite response.

CONCLUSIONS

LWIR imaging for copper sulphides is an effective tool for exploration for sediment-hosted copper in the moderately to heavily vegetated terrains of Colombia. This technology is especially useful as a tool for exploring for Africa Copperbelt-style copper deposits, given that these types of deposits are much more restricted in scale than porphyries (Hitzman *et al.,* 2005), and may be easily missed by traditional exploration in areas where exposure is lacking.

LWIR response for chalcocite and chalcopyrite in the study area was found to correspond to the contact between older redbeds and younger black shales, as reported in regional geologic mapping. Intriguingly, some notable LWIR responses for copper sulphides were also observed in areas where redbed exposures have not been reported (Figure 7), raising the possibility that the LWIR imagery is detecting previously unidentified highs in the redbed formations where the potential mineralised zone is brought close to surface, or that the imagery is detecting mineralisation within a new and different position in the stratigraphic column.

The use of this technology in the study area has led to a number of discoveries of new copper mineralisation. Consideration should also be given as to whether LWIR signatures can be used to identify broader zones of alteration associated with sediment-hosted copper systems, with potential pathfinder minerals including hematite, albite and gypsum.

Figure 5: Sulfide and oxide mineralisation in hematitzed black shales and argillites.

ACKNOWLEDGEMENTS

This work was carried out with the support of DTMW Private Limited (Singapore).

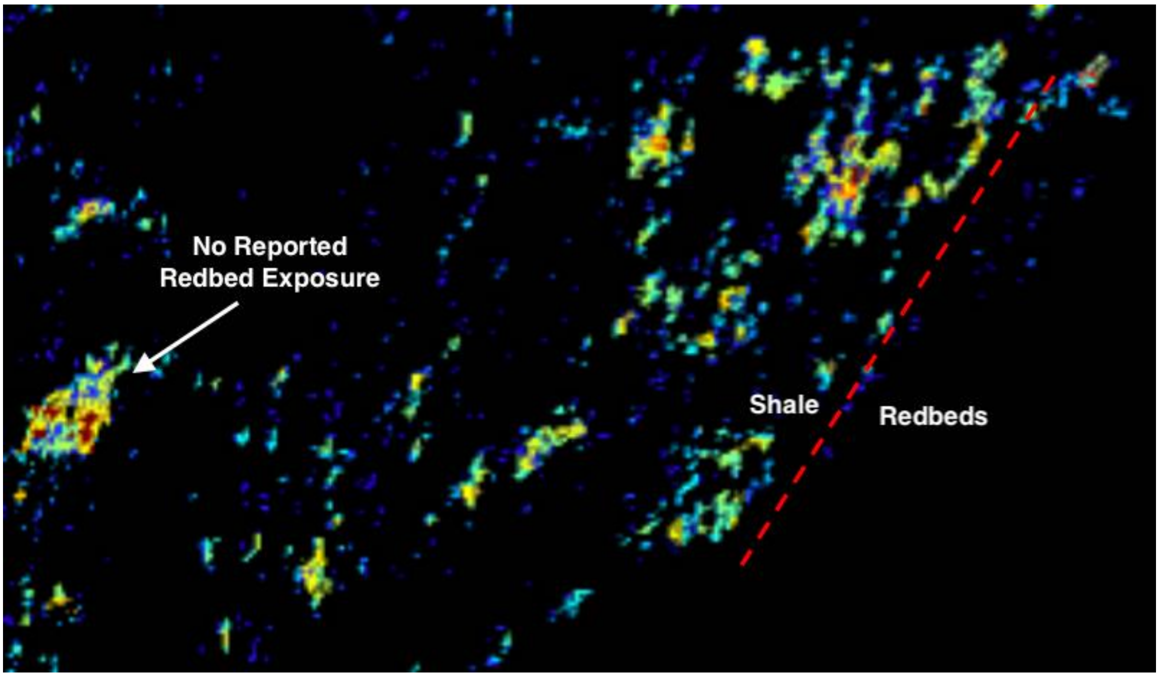

Figure 6: Strong LWIR response for chalcocite in the western section of the study area, more than 15 km away from the reported contact between redbeds and shales.

REFERENCES

Gomez, L.C., Peña, J.E., Andrade, J.C., Burgos, H.M. (2013). Exploracion y caracterizacion de azufre en el sector Gachala-Gacheta en el Departamento de Cundinamarca. Informe Final, Servicio Geologico Colombiano.

Hitzman, M., Kirkham, R., Broughton, D., Thorson, J., Selley, D. (2005). The sediment-hosted stratiform copper ore system. *Economic Geology,* One Hundredth Anniversary Volume, 609-642

Rodriquez, C., Warden, A.J. (1993). Overview of some Colombian gold deposits and their development potential. *Mineralium Deposita* 28, 47–57.

Salisbury, J.W., Walter, L.S., Vergo, N., D'Aria, D.M. (1991). *Infrared (2.1–25 micrometers) Spectra of Minerals*. Johns Hopkins University Press, 294 pp.

Thery, J.M. (1982). Constitution du Nord Quest du Continent Sud American avant les tectoniques andines. Tomes 1 and II. These 3 eme cycle Univ. Bordeaux.