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Spectral Analysis of Rock Samples from Molyhil, Northern Territory, Australia and the Application of Rock Spectra to Exploration Targeting Using Hyperspectral Imagery.

For

Thor Mining Plc.

By

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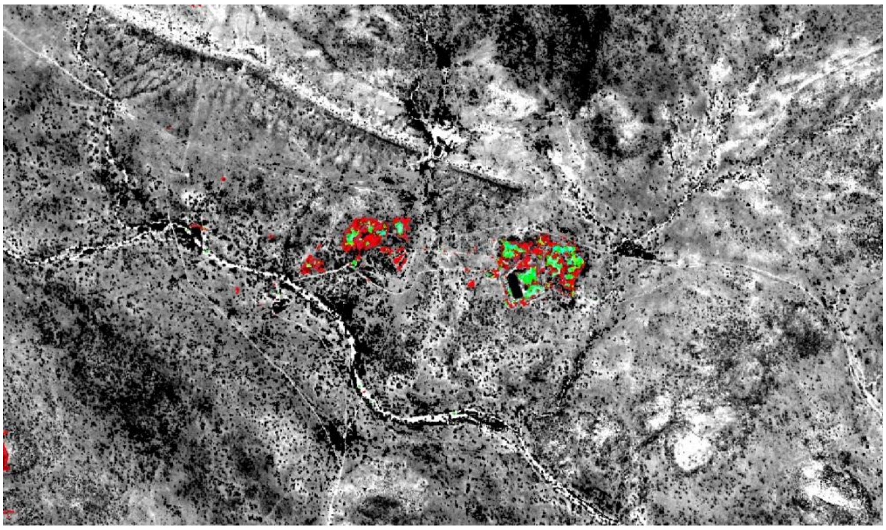

Regions of close spectral match with TK series rocks (red) and MHSS series rock (green) at Molyhil.

Spectral Analysis of Rock Samples from Molyhil, NT, Australia and the Application of Rock Spectra to Exploration Targeting Using Hyperspectral Imagery.

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Executive Summary

Thor Mining Plc. is in the process of developing a tungsten deposit at Molyhil and is exploring the surrounding area for further similar mineralisation. The company acquired Hy-Map hyperspectral image data over the Molyhil project and surroundings and the data were processed to produce standard alteration mineral map products presented in a GIS format showing the distribution and intensities across the survey area for a large suite of minerals. However, of these minerals, only epidote, chlorite, carbonate, muscovite and tourmaline showed any positive spatial relationship to the known mineralisation.

The minerals associated with the Molyhil deposit rarely occur together in any of the potential target areas they individually define but all constitute valid targeting criteria and an approach to identifying and ranking new targets would be to define target zones for each mineral and subsequently rank those zones on the number of constituent, key minerals that occur together within them. The disadvantage of this method however is that identifying areas of interest based upon apparent intensity of a spectrum can identify large targets but will always struggle to identify smaller, subtle zones where the intensity may be lost within noise. Furthermore, the process is subjective rather than objective.

Another approach using hyperspectral data to target mineralisation is to take surface samples of mineralised rock from known deposits and rather than trying to map individual minerals, map the distribution and intensity of rock or mineral assemblage spectra. The advantage of this method is that an assemblage should present uniform spectrum over a wider area than would any of the individual minerals that constitute the assemblage.

CoreScan hyperspectral data were acquired and processed to determine the end member minerals present in 12 rock samples collected from the Molyhil area. From the resultant data, the individual end member mineralogy for each sample was determined.

The TK series of samples are dominated by epidote and chlorite with traces of silica, illite/smectite, kaolinite, tourmaline, biotite and saponite whereas the MHSS series of samples contains more illite/smectite with subordinate chlorite, carbonate, epidote, saponite and nontronite. The main minerals identified in the airborne hyperspectral data are represented in each sample series.

The spectral mean or average spectrum was derived for each of the individual rock samples and was used as a reference spectrum to map the distribution of that particular rock throughout the study area. Initial inspection of the results for this procedure showed all samples to have high intensities or spectral similarities in and around the Molyhil area. Furthermore, when the

different levels of matching were compared to the reference spectra, consistent threshold levels above which the image spectrum showed characteristics of and an increasing similarity to the reference spectrum were observed and the distribution of the thresholded indices mapped coherently with very little noise.

While the different samples and sample series do not map to exactly the same locations or with the same intensities, they are all very closely spatially associated and so constitute genuine exploration targets wherever they occur together. Zones in the study area that contain thresholded matches with either of the TK or MHSS series of samples have been selected as potential exploration targets.

The mineral mapping carried out from the airborne hyperspectral image data identified epidote, chlorite, carbonate, muscovite and tourmaline as the main alteration indicators and the rock samples analysed spectrally from the CoreScan image data confirmed this.

While the alteration mineral mapping showed increases in intensity for the matches of the key minerals, separating out potential target zones from the individual intensities alone would be a subjective exercise and likely to miss small, relatively subtle targets.

Furthermore, targeting using a method that relied upon the co-location of a number of minerals from the airborne output data would be limited by the level of confidence in un-mixing complex spectral signatures that would vary across a zone where the mineral assemblage was essentially the same.

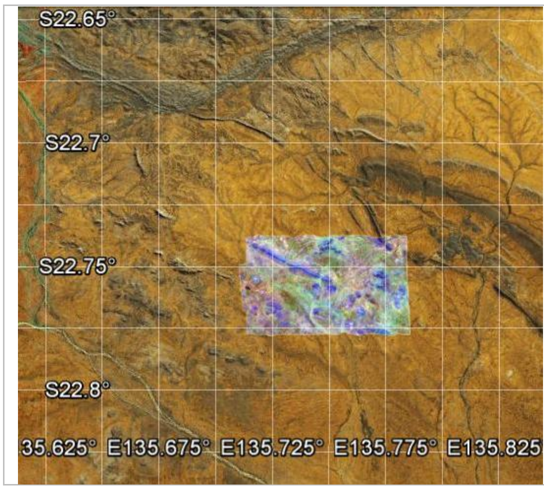
The CoreScan data enabled the generation of spectral means or average spectra for each of the individual rock samples submitted and, rather than un-mixing individual minerals from complex spectra, a simple spectral matching technique was able to identify tightly constrained areas or zones where above a certain threshold value for the spectral match, each of the rock type spectra were identifiable.

These zones were found to all be closely spatially associated at Molyhil itself and indeed elsewhere in the image suggesting that they truly represent the rock types analysed and thus, wherever they were seen to occur in the survey area, realistic exploration targets.

A total of 26 target zones comprising close spatially associated indications of one or both of the rock sample series assemblages were identified as possible exploration targets. These targets should be reviewed in terms of the number and intensities of spectral matches within them as well as with the original individual mineral map data provided by Hy-Vista in order to assess their relative strengths and provide a means of ranking and prioritising field follow up.

Introduction

Thor Mining Plc. is in the process of developing a tungsten deposit at Molyhil in Australiaôs Northern Territory (figure 1) and is actively exploring the surrounding area for further similar mineralisation. To that end, the company acquired Hy-Map hyperspectral image data over the Molyhil project and surroundings and the data were processed to produce standard alteration mineral map products by Hy-Vista Corporation. These products were presented in a GIS format showing the distribution and intensities across the survey area for a large suite of minerals. However, of these minerals, only those listed in table 1 showed any positive spatial relationship to the known mineralisation at Molyhil itself.



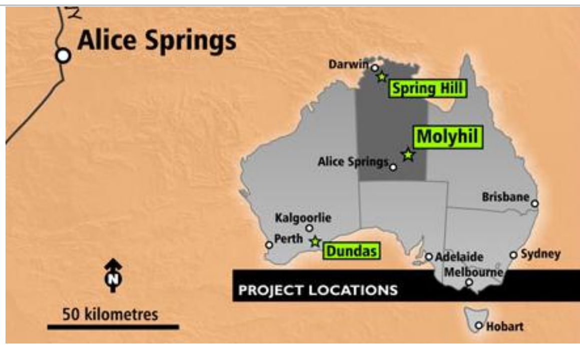


Figure 1; The location of the Molyhil deposit (above) and the Hy-Map survey area (left).

Mineral / Assemblage	Comments
Carbonate + chlorite	Strong intensity in Molyhil area, diffuse and weak elsewhere apart from one large additional target area.
Chlorite	Very strong intensity at Molyhil, weak and diffuse elsewhere apart from 5 small outlying targets.
Epidote	Very strong intensity at Molyhil, weak and diffuse elsewhere but with 7 outlying targets.
Mizzonite	Slightly stronger intensity over Molyhil but also in several other zones in the region and following stratigraphy
Muscovite	Strong intensity at Molyhil and in a number of discrete zones elsewhere. Also strong along drainages. Shows an increase in absorption wavelength at Molyhil.
Muscovite + carbonate	Very strong at Molyhil and in several discrete target areas.
Serpentinite	Slight increase in intensity over Molyhil and in a few targets but difficult to separate from background noise.
Talc	Strong at Molyhil and in several other target areas
Tourmaline	Very strong at Molyhil and in a few discrete target areas.

Table 1; Minerals associated with the Molyhil deposit as identified using Hy-Map and their intensity relative to background.

On a regional basis, the minerals associated with the Molyhil deposit rarely occur together in any of the potential target areas they individually define. Nevertheless, with the exception of serpentinite, where it is difficult to separate a slight increase in intensity from background noise, they all constitute valid targeting criteria and an approach to identifying and ranking new targets would be to define target zones for each mineral and subsequently rank those zones on the number of constituent, key minerals that occur together within them. The disadvantage of this method however is that identifying areas of interest based upon apparent intensity of a spectrum can identify large targets but will always struggle to identify smaller, subtle zones where the intensity may be lost within noise. Furthermore, the process is subjective and not objective.

Another approach using hyperspectral data to target mineralisation is to take surface samples of mineralised rock from known deposits and rather than trying to map individual minerals, map the distribution and intensity of rock or mineral assemblage spectra. The advantage over this method is that an assemblage should present a more or less uniform spectrum over a wider area than would any of the individual minerals that constitute the assemblage. Although spectral un-mixing allows the identification of the presence of an individual mineral within an assemblage, the degree of certainty is reduced and can result on a mineral appearing to be more widespread than it is in reality, albeit with low relative intensities.

Consequently, Thor Mining decided to try to map the characteristic Molyhil mineralised rocks using their overall average spectra. To this end, 12 rock samples were submitted to CoreScan to be spectrally scanned so that their mean spectrum could be determined and subsequently applied to the Hy-Map data.

CoreScan Analysis

The CoreScan hyperspectral imaging system scans the surface of drill core, drill cutting or rock samples at a pixel resolution of 0.5mm across a wavelength range extending from 450nm to 2500nm with a spectral resolution of between 4-5nm. The data so acquired are processed to determine from the pixel spectra, the end member minerals present in the core from which an assemblage map can be produced. In this study, the 12 rock samples were aligned in two rows for scanning (figure 2). From the resultant image and hyperspectral data, the individual end member mineralogy for each sample was determined and is listed in table 2.

Sample	End Member Mineral Components
TK001	Epidote-Silica-Kaolinite-Saponite-Smectite-
TK002	Epidote-Chlorite-Saponite---
TK003	Silica-Illite-Chlorite-Biotite-Epidote-Magnetite-Kaolinite
TK004	Chlorite-Clinozoisite-Magnetite-Saponite-Smectite--
TK005	Chlorite-Tourmaline-Illite-Smectite-Epidote--
MHSS001	Illite-Smectite-Calcite-Chlorite-Epidote-Saponite-
MHSS002	Calcite-Chlorite-Nontronite-Illite-Smectite-Prehnite-Saponite
MHSS003	Illite-Smectite-Chlorite-Kuthnahorite---
MHSS004	Nontronite-Siderite-Smectite-Saponite---
MHSS005	Illite-Smectite-Calcite-Chlorite-Siderite--
MHSS006	Illite-Smectite-Calcite-Clinozoisite-Kuthnahorite-Jarosite-
MHSS007	Smectite-Illite-Chlorite-Epidote---

Table 2; Interpreted end member mineral components for the Molyhil rock samples

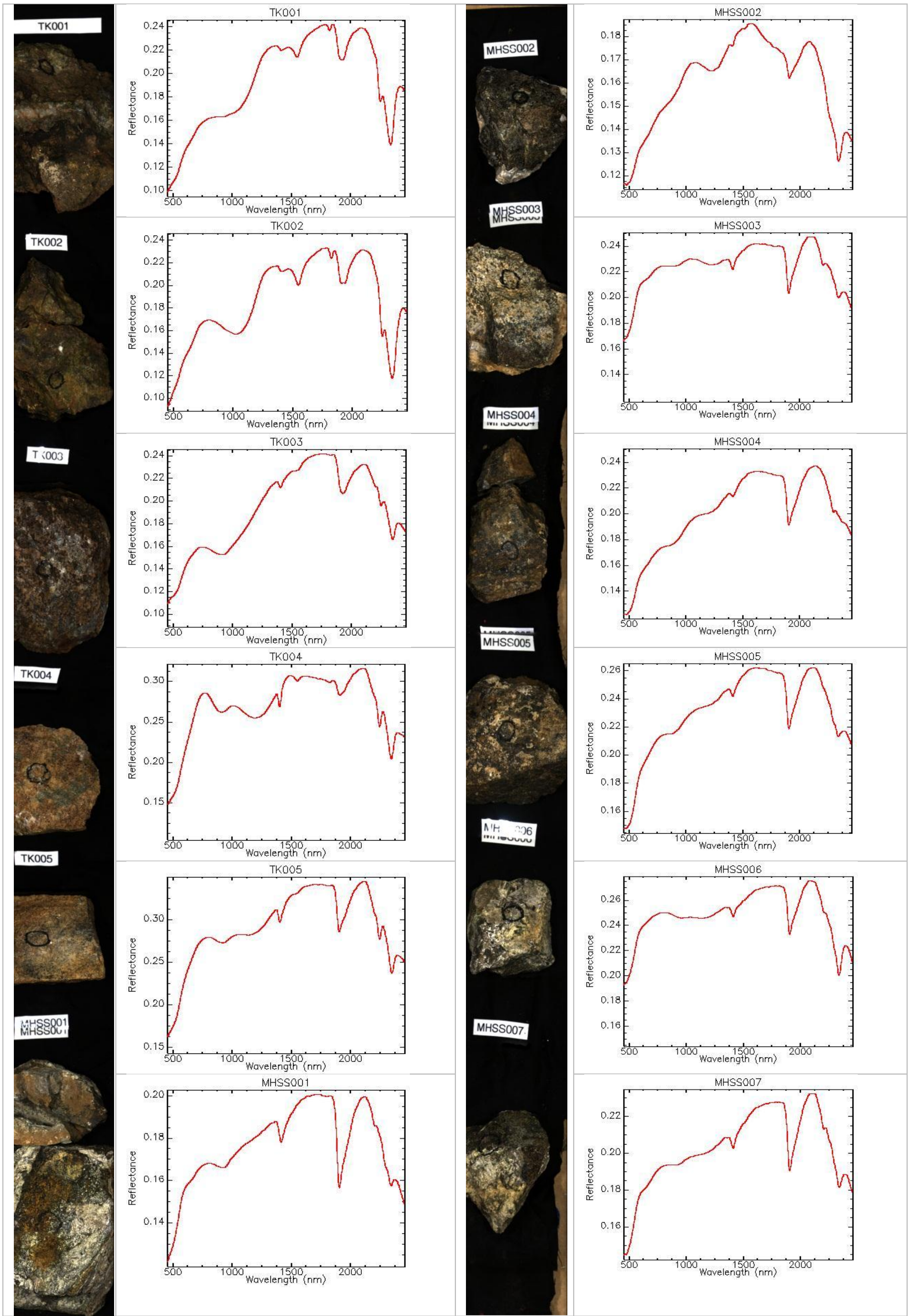


Figure 2; The 12 rock samples scanned and their respective average spectra.

The TK series of samples are all dominated by epidote and chlorite with only traces of silica, illite/smectite, kaolinite, tourmaline, biotite and saponite whereas the MHSS series of samples contains more illite/smectite with subordinate chlorite, carbonate, epidote, saponite and nontronite (table 2). Although the CoreScan data show a more detailed assemblage than did the Hy-Map data, the main minerals identified in the airborne hyperspectral data are represented in each sample series. However, the variability in the assemblages from one sample of a series to another is quite large, especially in the MHSS series, and hence the reliability of mapping any one of those minerals in the airborne data is reduced.

The spectral mean or average spectrum was derived for each of the individual rock samples and is shown alongside its respective sample in figure 2. The important short-wave infrared parts of the spectra for the TK series are all very similar, being dominated by epidote and chlorite whereas carbonate tends to dominate the MHSS series.

Mapping the CoreScan Spectra Within the Hy-Map Data

The usual method for mapping minerals using hyperspectral data is to carry out a linear spectral un-mixing procedure or to use one of a number of spectral matching routines in order to generate and index for the similarity of a pixel spectrum to that of a mineral reference spectrum whether that reference be derived from a spectral library or from within the data themselves. In this case, mapping an assemblage of minerals for each of the samples did not require un-mixing but rather an index of similarity and so three separate methods were applied.

Spectral Feature Fitting (SFF) uses a least-squares fit approach to measure the closeness of fit between an image or pixel spectrum with a reference spectrum (Clark et al., 1990) and mineral abundance is directly proportional to the depth of the spectral feature targeted for the match. This method is reputedly more sensitive to illumination, albedo and aspect effects than other methods and, in this instance, was found to be useful for all of the TK series of spectra but unreliable for the MHSS series.

An alternative approach, the Spectral Angle Mapper (SAM) method developed from the work of Kruse and others (1993), measures the angular difference between the image spectrum and the reference spectrum but produces an inverted image in which the lowest values represent the closest match. In this authorŝ experience, the method has given inconsistent results for many minerals and was certainly also the case in this study giving close fits for spectra that were nothing like the reference in many cases and omitting or giving low fit results for spectra within the close vicinity of the Molyhil deposit that were very similar to the reference.

The matched filter (MF) routine is a process that focuses on and maximises values where there is a match and suppresses the response for the composite unknown background (Harsanyi & Chang, 1994, Boardman et al, 1995). Initial inspection of the results for this procedure showed all samples to have high intensities or spectral similarities in and around the Molyhil area. Furthermore, when the different levels of matching were compared to the reference spectra, consistent threshold levels above which the image spectrum showed characteristics of and an increasing similarity to the reference spectrum were observed and the distribution of the thresholded indices mapped coherently with very little noise even though for spectral samples MHSS004 and 005, the thresholded distribution was very limited (figures 3 to 14).

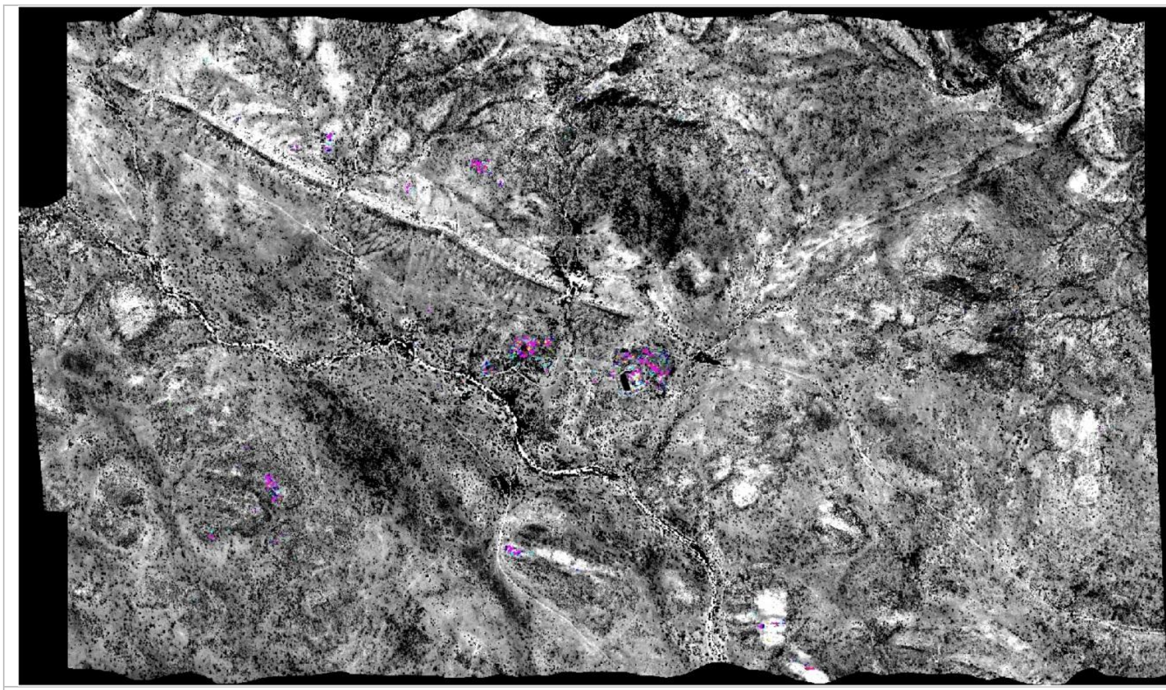


Figure 3; Intensity map for the spectral match of TK001 draped on an albedo image; warmer colours signify higher intensity or closeness of match.

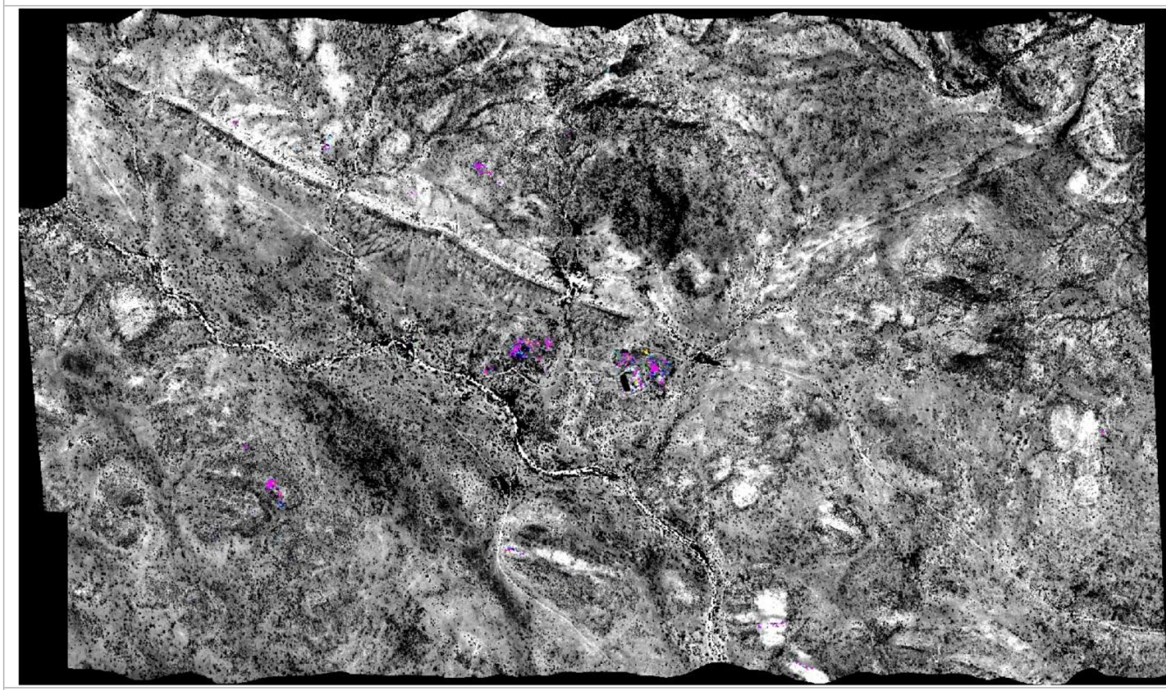


Figure 4; Intensity map for the spectral match of TK002 draped on an albedo image; warmer colours signify higher intensity or closeness of match.

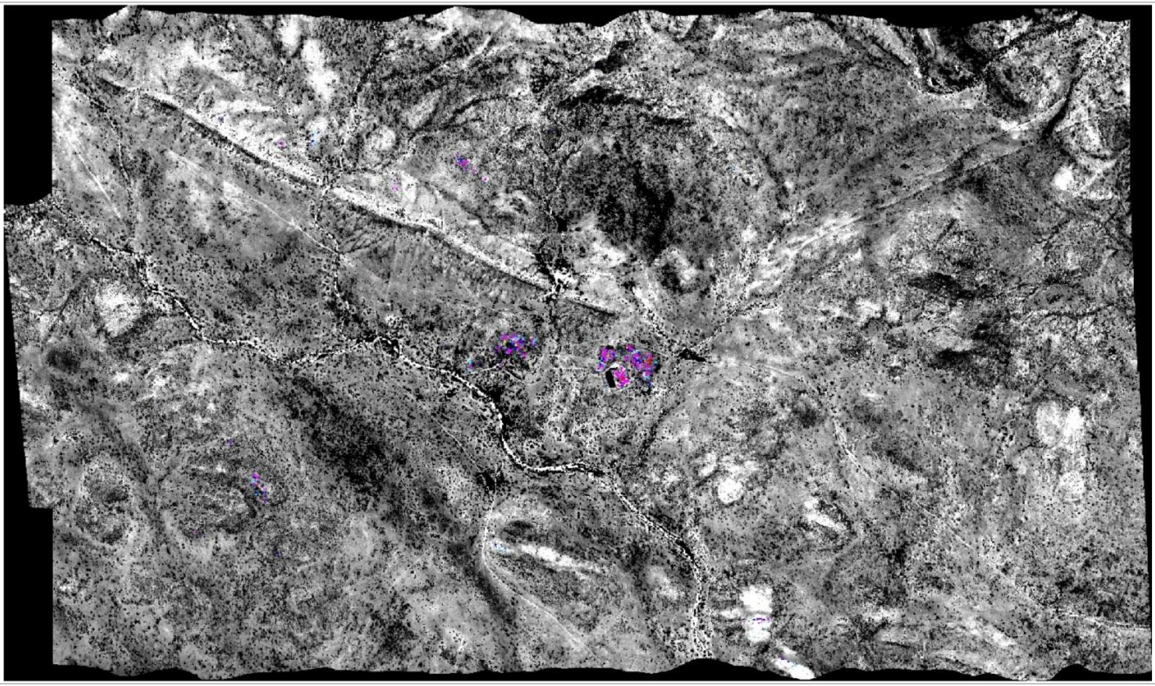


Figure 5; Intensity map for the spectral match of TK003 draped on an albedo image; warmer colours signify higher intensity or closeness of match.

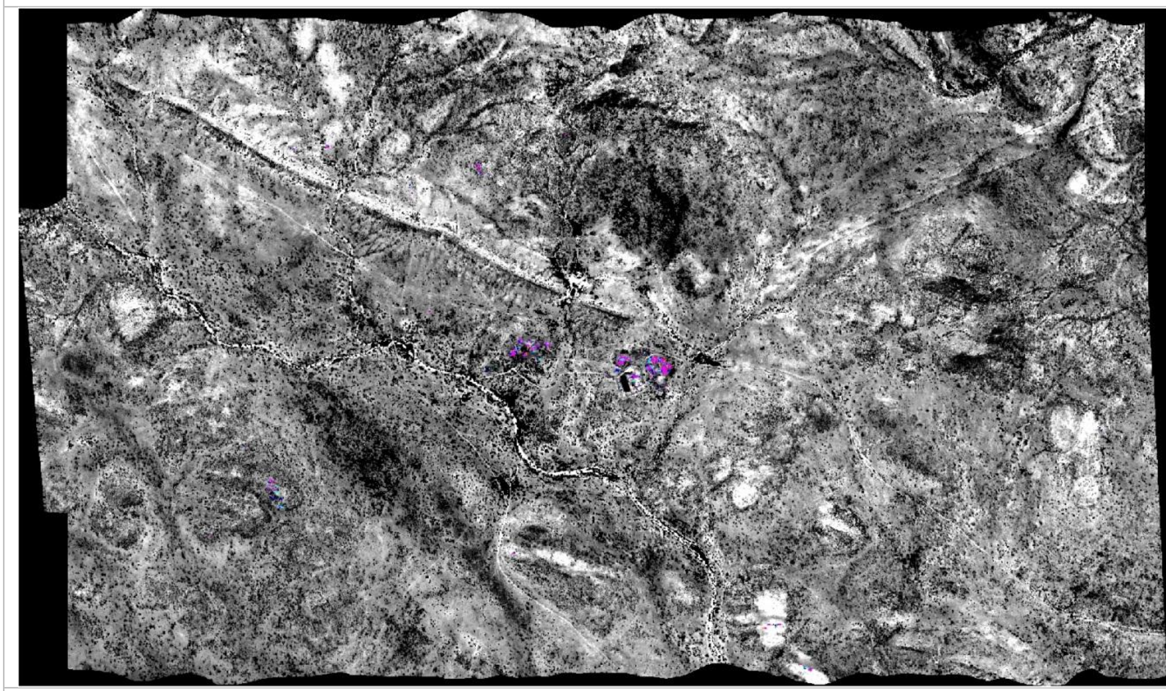


Figure 6; Intensity map for the spectral match of TK004 draped on an albedo image; warmer colours signify higher intensity or closeness of match.

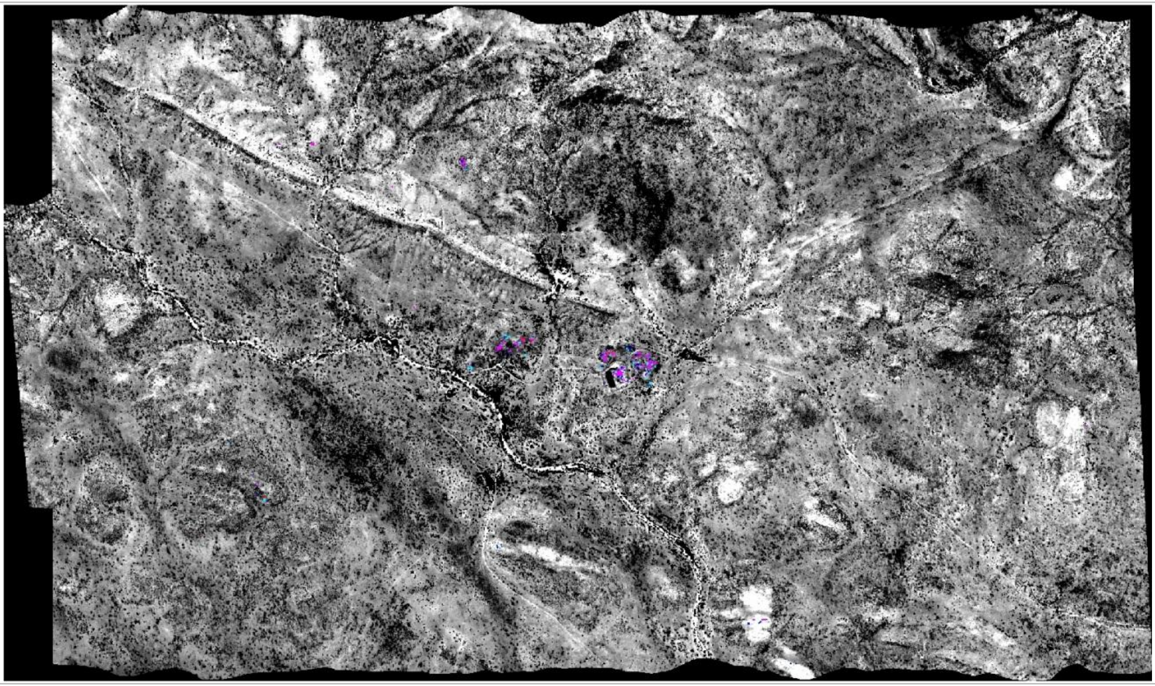


Figure 7; Intensity map for the spectral match of TK005 draped on an albedo image; warmer colours signify higher intensity or closeness of match.

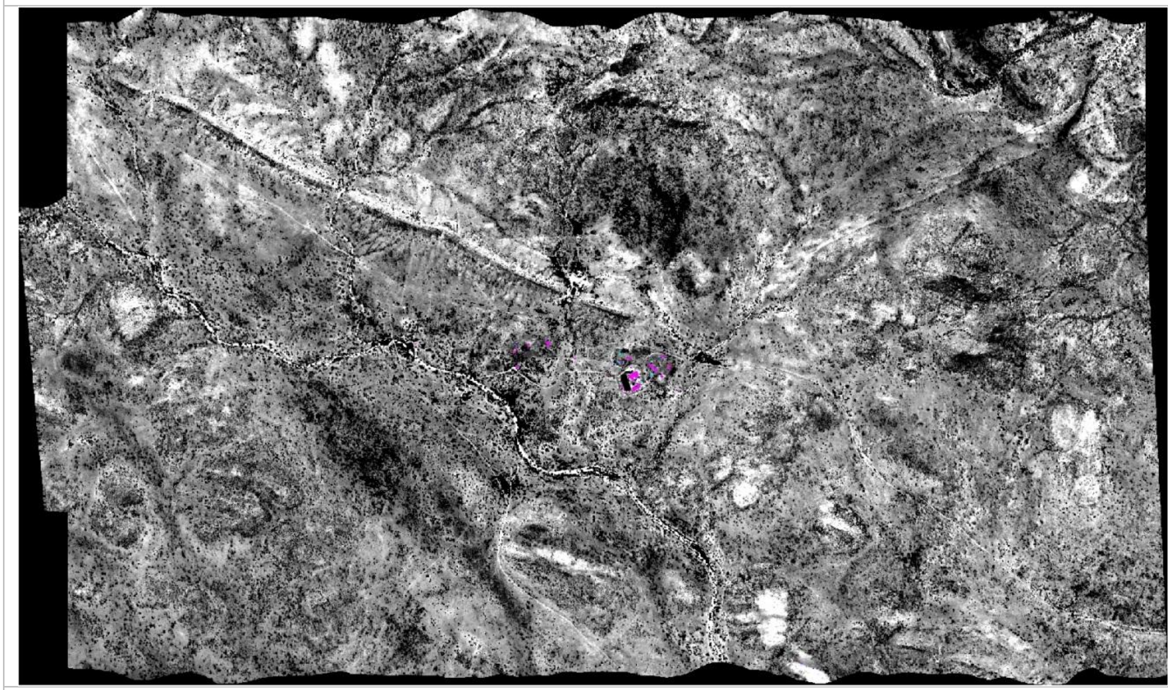


Figure 8; Intensity map for the spectral match of MHSS001 draped on an albedo image; warmer colours signify higher intensity or closeness of match.

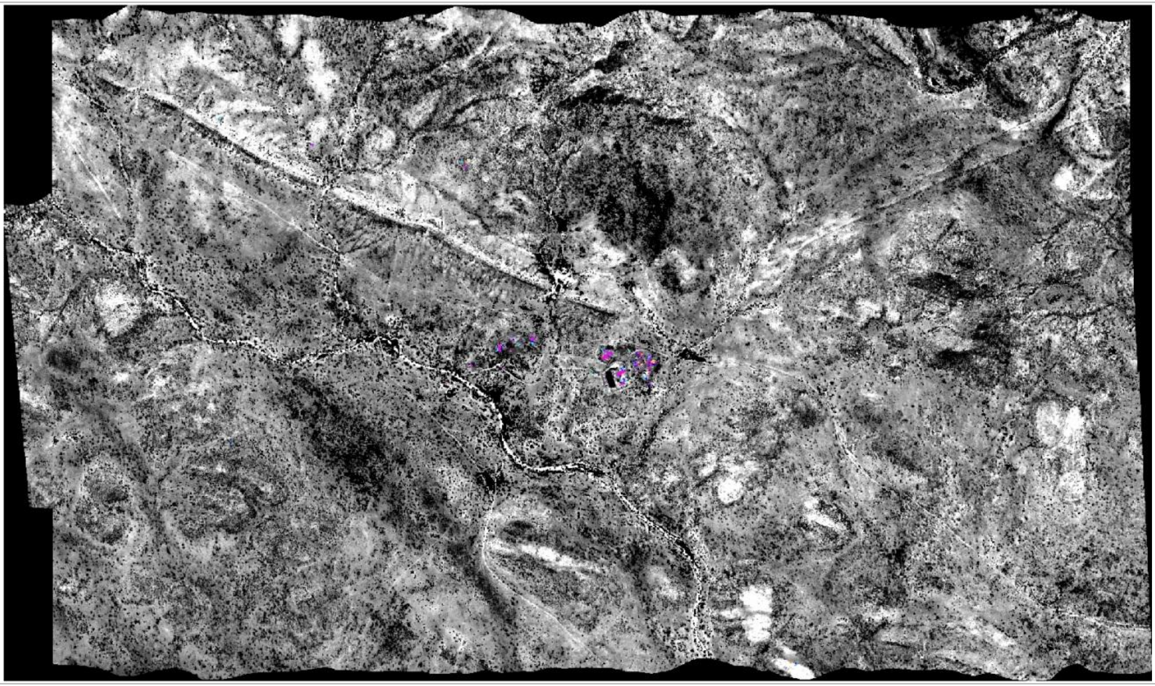


Figure 9; Intensity map for the spectral match of MHSS002 draped on an albedo image; warmer colours signify higher intensity or closeness of match.

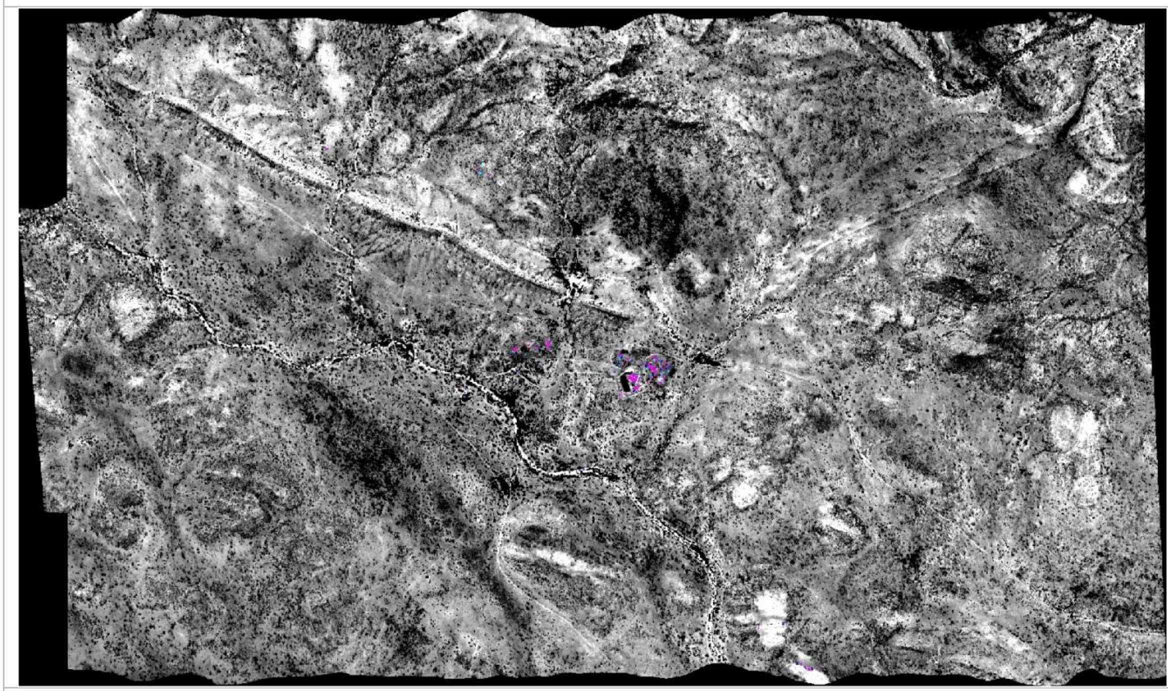


Figure 10; Intensity map for the spectral match of MHSS003 draped on an albedo image; warmer colours signify higher intensity or closeness of match.

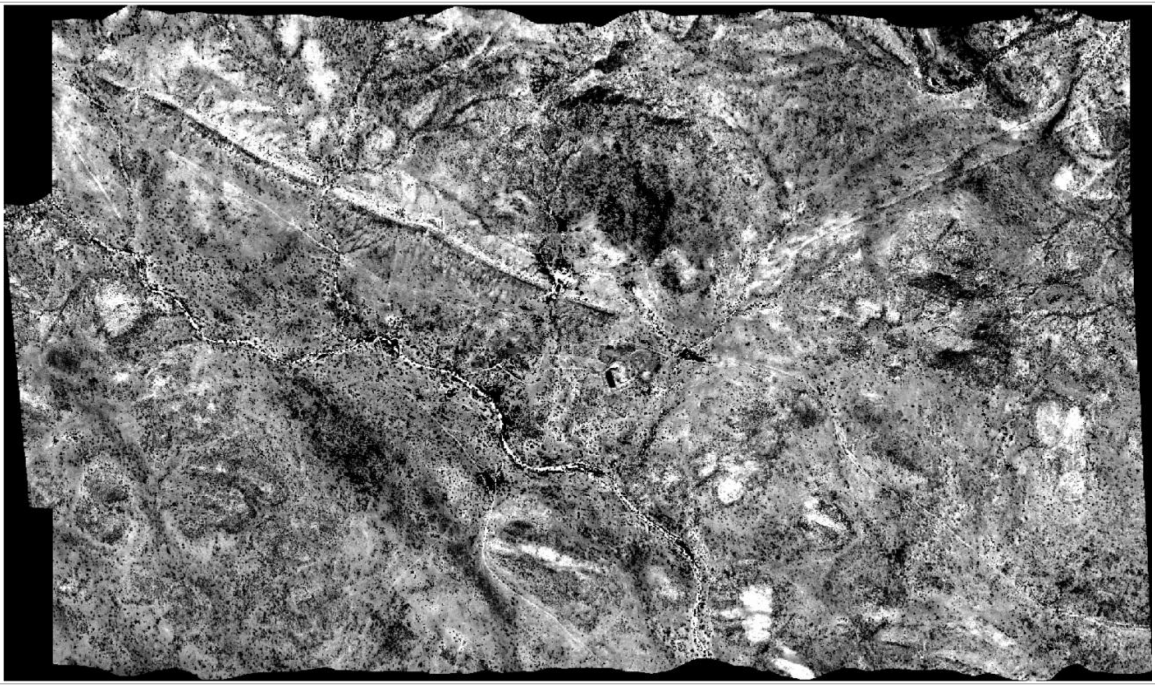


Figure 11; Intensity map for the spectral match of MHSS004 draped on an albedo image; warmer colours signify higher intensity or closeness of match.

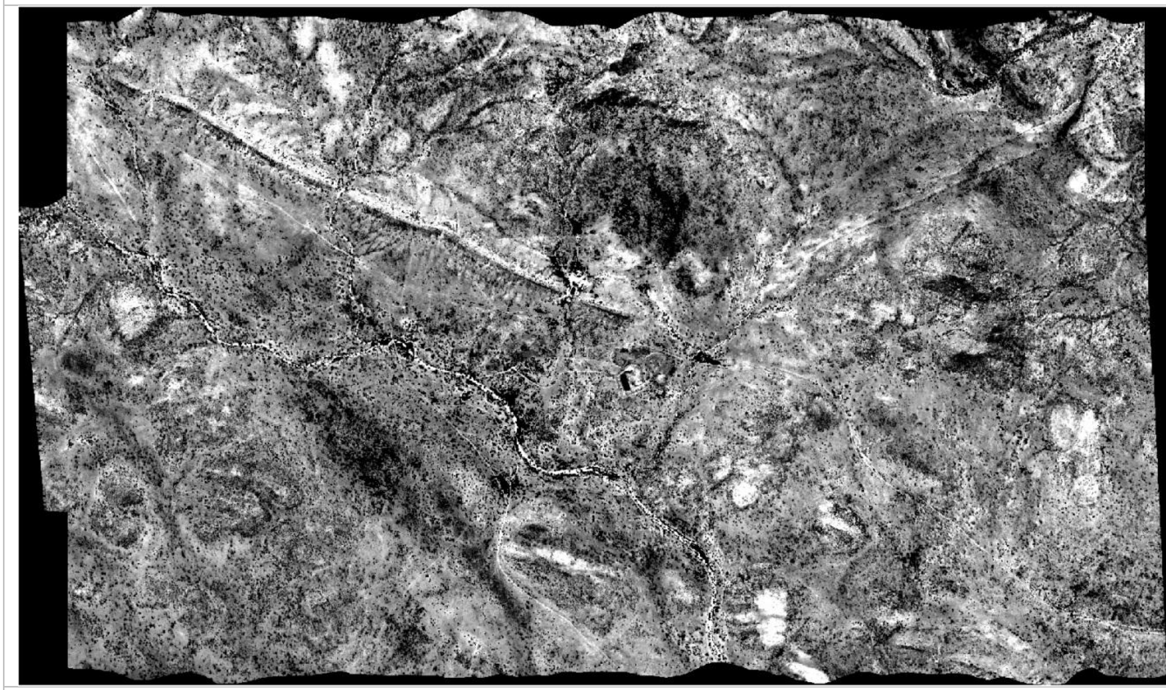


Figure 12; Intensity map for the spectral match of MHSS005 draped on an albedo image; warmer colours signify higher intensity or closeness of match.

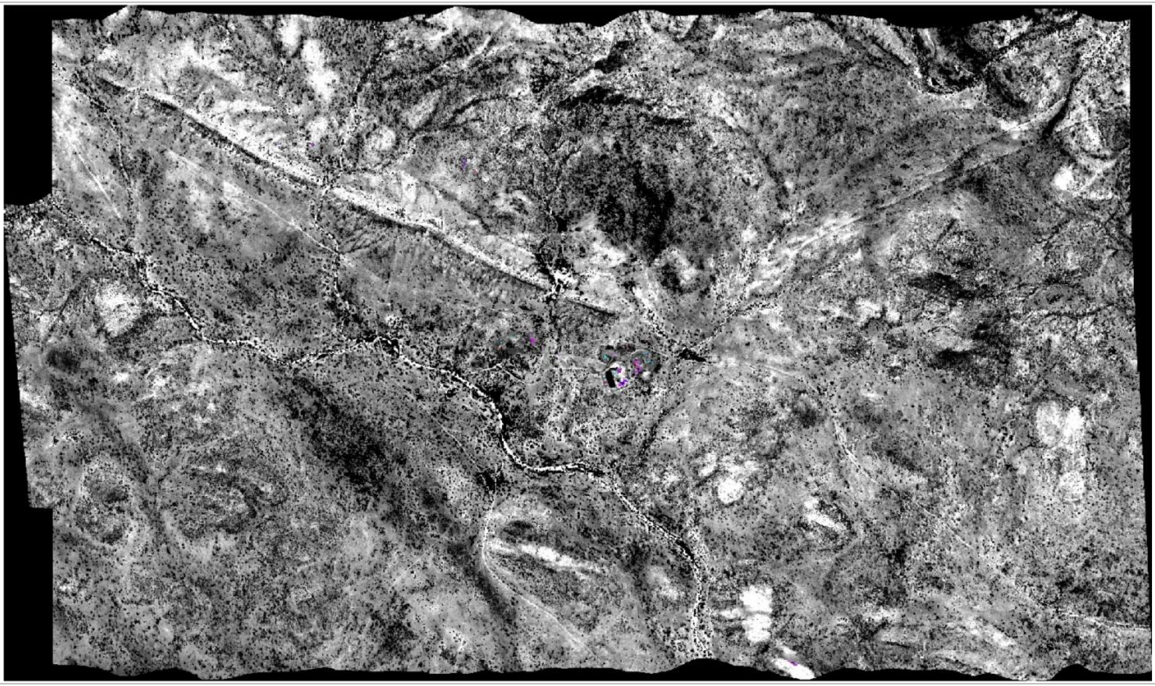


Figure 13; Intensity map for the spectral match of MHSS006 draped on an albedo image; warmer colours signify higher intensity or closeness of match.

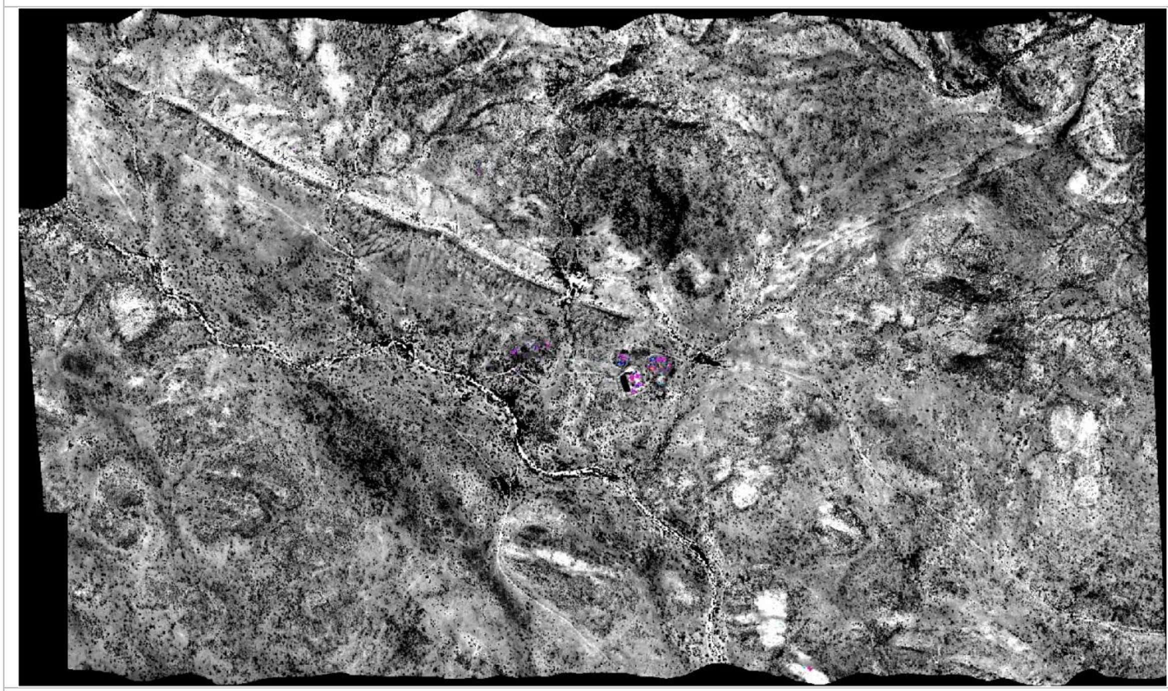


Figure 14; Intensity map for the spectral match of MHSS007 draped on an albedo image; warmer colours signify higher intensity or closeness of match.

While the different samples and sample series do not map to exactly the same locations or with the same intensities, they are all very closely spatially associated in the thresholded output data and so constitute genuine exploration targets wherever they occur together. Zones in the study area that contain thresholded matched with either of the TK or MHSS series of samples have been selected as potential exploration targets and are shown in figure 15. These targets should be ranked according to whether they have indications of both series of rock samples and the number of matches to the different sample reference spectra as well as with criteria from the original Hy-Vista mineral mapping output.

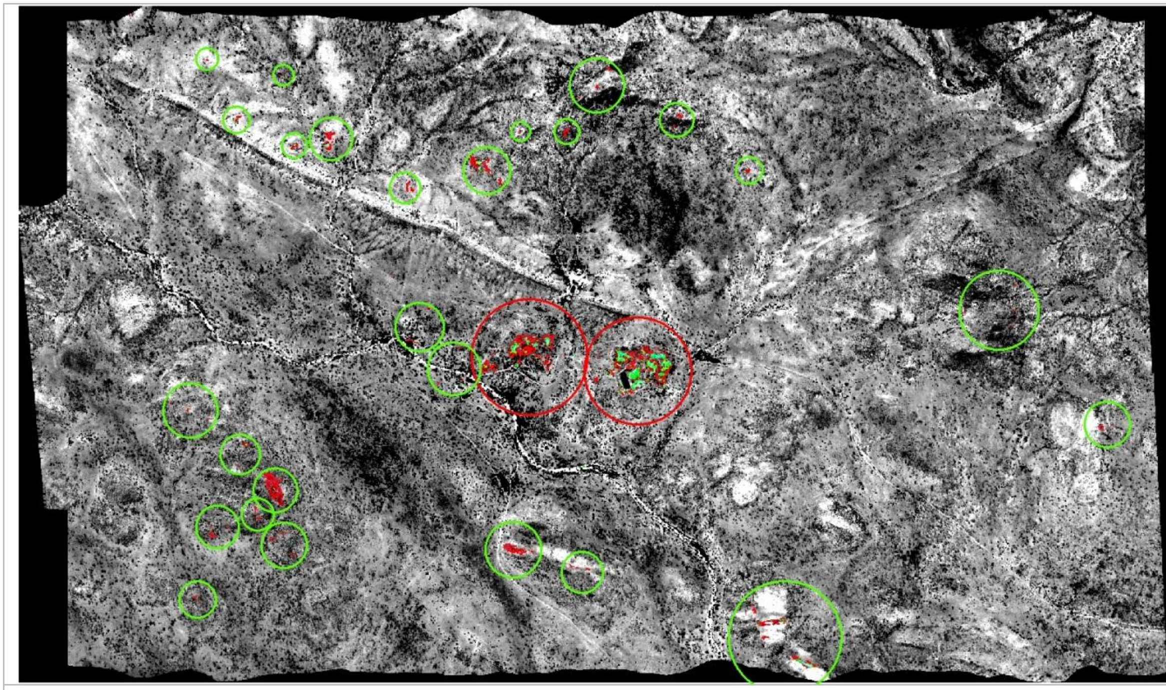


Figure 15; Spectral matches for the TK rock series in red and the MHSS series in green with potential exploration targets identified by green circles and the Molyhil areas marked by red circles.

Conclusions & Recommendations

The mineral mapping carried out from the airborne hyperspectral image data identified epidote, chlorite, carbonate, muscovite and tourmaline as the main alteration indicators and the rock samples analysed spectrally from the CoreScan image data confirmed this.

While the alteration mineral mapping showed increases in intensity for the matches of the key minerals, separating out potential target zones from the individual intensities alone would be a subjective exercise and likely to miss small, relatively subtle targets.

Furthermore, targeting using a method that relied upon the co-location of a number of minerals from the airborne output data would be limited by the level of confidence in un-mixing complex spectral signatures that would vary across a zone where the mineral assemblage was essentially the same.

The CoreScan data enabled the generation of spectral means or average spectra for each of the individual rock samples submitted and, rather than un-mixing individual minerals from complex spectra, a simple spectral matching technique was able to identify tightly constrained areas or zones where above a certain threshold value for the spectral match, each of the rock type spectra were identifiable.

These zones were found to all be closely spatially associated at Molyhil itself and indeed elsewhere in the image suggesting that they truly represent the rock types analysed and thus, wherever they were seen to occur in the survey area, realistic exploration targets.

A total of 26 target zones comprising close spatially associated indications of one or both of the rock sample series assemblages were identified as possible exploration targets. These targets should be reviewed in terms of the number and intensities of spectral matches within them as well as with the original individual mineral map data provided by Hy-Vista in order to assess their relative strengths and provide a means of ranking and prioritising field follow up.

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