SPECTRAL DISCRIMINATION OF SOIL AND REGOLITH ATTRIBUTES WITHIN HERRMANNS CATCHMENT, MOUNT LOFTY RANGES, SA

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INTRODUCTION

The power, and ultimately the success, of remote sensing systems lies within the way radiation over the visible, near- and short wave-infrared portions of the electromagnetic spectrum (400-2500 nm) interacts with earth surface materials and the ability of sensors to record this interaction (Campbell 1996). These interactions result in spectral absorption and emission features (spectral signatures) and are the diagnostic features allowing the spatial determination of the distribution of many hydroxyl and carbonate minerals (Hunt 1979).

The diagnostic spectral features, which are accessible to remote sensing through atmospheric windows, are caused by vibrational overtones, electronic transfers, charge transfers and conduction processes characteristic of each type of mineral (Hunt 1979), thereby allowing the potential determination of the mineral components of soil. Clay minerals, for example, have distinguishing spectral absorption features in the short wave infrared (ca. 1,950-2,300 nm) and successful mapping, to some degree, of smectite, kaolinite, montmorillonite and illite has been documented in many reports, even in vegetated terrains (Chabrilat *et al.* 2002, Ryan & Lewis 2002). Iron oxides and hydroxides also have diagnostic spectral features in the near-infrared (Hunt 1979). The texture, moisture content and organic matter also contributes to the spectral response of soil (Stoner & Baumgardner 1981).

Although laboratory spectrometers have been able to measure the spectral signatures of minerals and soil with a high spatial and spectral resolution since the 1970s, imaging remote sensing systems with the same spectral resolution properties have been operating only in the last decade. These systems, known as hyperspectral sensors, allow the principles of "laboratory grade" spectral analysis to be applied to spatial mapping (Papp 2002). The high spectral resolution (10-20 nm spectral bandwidth) of hyperspectral sensors potentially allows for the discrimination of the many hydroxyl and carbonate minerals, which is unavailable with multispectral systems such as the Landsat series of satellites.

The airborne HyMap™ system is one such hyperspectral imaging system, providing 128 narrow spectral bands across the 400-2,500 nm range. After radiometric calibration to account for solar illumination and atmospheric effects, this imagery can be compared with known reference spectra in order to detect materials, even if mixed, on the basis of their spectral features. Image processing techniques allow production of maps of mineral occurrence, abundance and distribution from the imagery. Band Ratios, Spectral Angle Mapping, Spectral Feature Fits, Minimum Noise Fraction and Matched Tuned Matched Filtering (see Kruse *et al.* 1993) are some techniques that have gained popular usage in processing spectral data.

AIM AND STUDY AREA

The underlying aim of the project was to determine and map, using HyMap™ hyperspectral imagery and commonly accepted spectral processing techniques, the spatial distribution and abundance of clay and iron oxide minerals contained within Herrmanns Catchment. This catchment covers a 2 km^2 area 10 km east of the township of Mount Torrens in the Mount Lofty Ranges, approximately 45 km east of Adelaide in South Australia. The selection of Herrmanns Catchment was made based on the reasonably small size of the catchment, and for the variety of soil and regolith attributes and processes that occur in the catchment. Herrmanns Catchment has also been extensively studied throughout the last three decades and has attracted an interest for mineral prospecting for the close proximity to the Mount Torrens Pb-Zn mineralisation (CRAE 1975, Fitzpatrick *et al.* 1996, Skwarnecki *et al.* 2002). This mineralisation occurs in calc-silicate rocks at the base of the Talisker Calc-siltstone (Skwarnecki *et al.* 2002). The Talisker Calc-siltstone has a near north-south strike and a near vertical dip and occurs through the catchment with reduced intensities of Pb-Zn mineralisation. The Backstairs Passage Formation and Tapanappa Formation also strike through the catchment to the East and West of the Talisker Calc-siltstone, respectively (Drexel & Preiss 1995). These rocks regionally form the Cambrian aged Kanmantoo Trough of the Adelaide Geosyncline, and are

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sporadically covered with deposits of undifferentiated Tertiary and Quaternary sediments (Drexel & Preiss 1995).

The main focus of previous research has been on inland saline land and saline sulfidic soils, which have involved pedological, mineralogical, hydrological and physio-chemical investigations (Fitzpatrick *et al.* 1996, Skwarnecki *et al.*, 2002). The work undertaken on the catchment has lead to an understanding of the processes shaping the catchment, and provides an excellent example of how science has helped landholders and local Landcare groups to manage landscapes. The investigations have also developed improved approaches and practices to mineral exploration, whilst highlighting the link between the CRC LEME programs of mineral exploration, natural resource management, and education and training.

METHODS

The HyMap™ imagery was acquired over a portion of the Mount Lofty Ranges in February 2001. Although nine high resolution (ca. 2.5 m pixel resolution) flight lines were acquired, only a small subset of these over Herrmanns Catchment was chosen to evaluate the most suitable spectral processing techniques for highlighting and identifying landscape, soil and regolith features and attributes. This pilot study aimed to develop an efficient processing model that could be applied to the remaining HyMap™ imagery covering a wider area. The summer timing of the image survey in the Mediterranean climate of the Mount Lofty Ranges meant that there was extensive dry pasture cover, but little green vegetation in the catchment.

The spatial subset of the HyMap™ imagery that covers Herrmanns Catchment was analysed using ENVI image processing software and spectral feature fitting (SFF) techniques. This SFF method compares image spectra to reference spectra over specific spectral ranges where minerals have diagnostic absorption features. In this case the reference spectra were derived from the United States Geological Survey (USGS) spectral library, laboratory measured reflectance of soils and materials collected in Herrmanns Catchment and image-derived spectra. From previous investigations into Herrmanns Catchment by Fitzpatrick *et al.* (1996) and Skwarnecki *et al.* (2002), the minerals of gypsum, jarosite, iron oxides and the numerous clay minerals were identified as occurring in the catchment. These were used as reference spectra for SFF. These reference spectra were obtained form the USGS spectral library.

The 1,143-1,243 nm, 1,705-1,805 nm, 2,095-2,305 nm, 2,225-2,285 nm and 2,400-2,528 nm spectral regions were identified as distinguishing absorption features for gypsum, and subsequently SFF was performed on the spectral bands of the HyMap™ imagery that covered these regions. The 2,915 nm, 2,981 nm and 3,067 nm spectral absorption regions of jarosite were also used as a spectral subset to SFF processing with the USGS jarosite reference spectra. The region through 750-900 nm was used for iron oxide SFF. While the 1,950-2,300 nm region was used for clay mineral SFF, including kaolinite (ca. 2,200 nm doublet), muscovite (2,350 nm) and illite (2,340 nm).

Spectra of selected surface materials from Herrmanns Catchment were measured with an ASD FieldSpec Pro spectrometer under controlled illumination and laboratory conditions. The aim of collecting these signatures was to investigate the spectral characteristics of outcropping rocks, weathered surfaces, soils and plant materials and to provide spectral references for the HyMap™ image-based mapping. Field samples, collected in June 2004, included six rocks, twenty-two soils, and one sample of cow dung. Locations of samples in the field were recorded with a single field GPS unit. The dominant outcropping rock type collected was a ferruginous saprolite from several different areas around the catchment. Three spectral signatures were also obtained from an outcropping schist of the Backstairs Passage Formation. This included the freshly broken surface, the weathered surface and the lichen that covers the rock.

Little rainfall had occurred prior to the collection of the field samples. However, once the reflectance of the samples was measured at the field moisture content the samples were then oven dried at ca. 40°C for 58 hours and the spectra recorded again. The low drying temperature was aimed to maintain mineralogy. In the laboratory each soil sample was placed in a 15 cm diameter glass petri dish, filled to a thickness of ca. 15 mm, and reflectance measured with the ASD FieldSpec using the high intensity probe with an internal light source. Reflectance of rock specimens was measured with the same probe. In total sixty spectral signatures were obtained. Texture and Munsell colour was also collected from the soil samples.

To further confirm the relationship between mineralogy and the spectral reflectance gained from the ASD FieldSpec Pro analysis XRD analysis was performed on selected soil and regolith samples collected in Herrmanns Catchment.

RESULTS AND DISCUSSION

The spectral signature of ferruginous saprolite collected with the ASD FieldSpec instrument revealed similarities to goethite and kaolinite absorption features shown in USGS spectral library samples. XRD analysis confirmed this mineralogical composition. However, in one pale red ferruginous saprolite sample the near-infrared spectrum showed a shift to the longer wavelength hematite (ca. 910 nm) absorption from the shorter goethite (ca. 850 nm) absorption. No XRD was performed on this sample, although it is reasonable to suggest the weathering of goethite to hematite is occurring in some areas where ferruginous saprolite occurs.

The characteristic kaolinite double absorption feature at ca. 2,200 nm was dominant in all soil samples within Herrmanns Catchment, reflecting the old weathering surface of Mount Lofty landscape (Drexel & Preiss 1995). This spectral feature was best observed in the dried soil samples, significantly increasing in depth as the moisture content decreased.

XRD found muscovite in most of the samples, and it was identified in the spectral analysis by changes in the characteristic double absorption features at ca. 1,400 nm and ca. 2,200 nm for kaolinite. When mixed with kaolinite the single symmetric ca. 2,200 nm absorption feature of muscovite reduces the intensity of the double absorption and asymmetric left shift of this double absorption feature.

The ca. 1,400 nm and ca. 1,900 nm moisture absorption features previously identified by Hunt (1977) was also seen in all the field moisture and dried soil spectra (Figure 1). The characteristic influence of moisture affecting the spectral response across all wavelengths was also observed between *in situ* field moisture and dried spectral soil sample (Figure 1).

Interesting relationships were also seen in the spectra for the distribution of quartz across the toposequence that was the focus of investigations by Fitzpatrick *et al.* (1996). Six surface soil samples were collected along this toposequence that takes in the catchment's saline scald. Three of these samples were analysed with XRD, and the results showed a reduction of quartz up the toposequence. The reduction in the quartz content of the soil was interpreted through a reduction of intensity count in the XRD results from 21,000 to 18,000 counts, which corresponds to an approximate reduction of 10-15% in the soil's quartz content. This quartz content reduction from the foot slope of the toposequence up to the crest can also be seen in a plot of the reflectance spectra collected along the toposequence (Figure 1). The spectral signatures show the same absorption features, although there is a reduced intensity of these absorption features when the spectra of the soil from the crest is compared to the spectra of soil from foot slope of the toposequence. This is a spectral characteristic of quartz, where quartz has no significant spectral features, but reduces the absorption intensity. This increase in the content of quartz in soils down the toposequence relates to the regolith-landform processes, with regard to the physical weathering and down slope sediment transport.

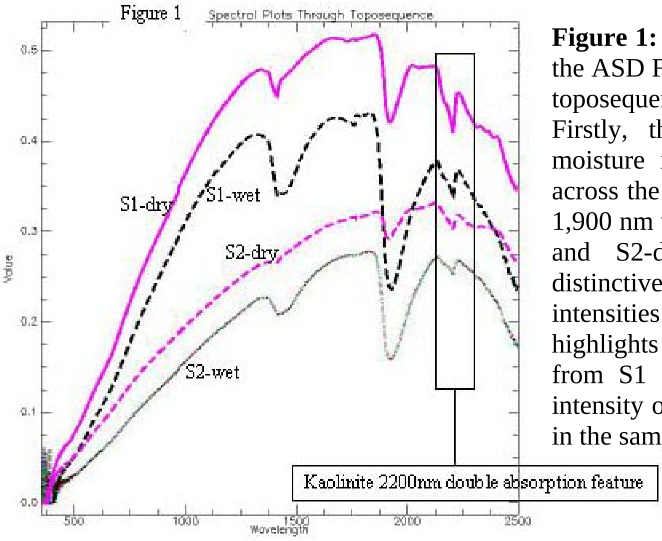

Figure 1: Plot of wet and dry soil spectra recorded using the ASD FieldSpec Pro spectrometer. The soil is from the toposequence of interest in Fitzpatrick *et al.* (1996). Firstly, the change in spectral signature owing to moisture is shown by a reduced reflectance intensity across the full wavelength range and at the 1400 nm and 1,900 nm water absorptions (S1-dry compared to S1-wet, and S2-dry compared to S2-wet). Secondly, the distinctive kaolinite absorption is shown, and the intensities of the kaolinite absorption feature also highlights reducing kaolinite percentage in the sample from S1 to S2 down the slope. Finally, the reduced intensity of reflectance owing to the proportion of quartz in the sample is highlighted when S1 is compared to S2.

Unfortunately, the comparison of the quartz soil properties observed through spectral characteristics could not be made using the imagery spectra across more toposequences in the catchment, due to the dominant dry vegetation influence on the pixels. It would be interesting, however, to compare such a soil property across the north facing slopes (containing the toposequence investigated Fitzpatrick *et al.* (1996)) to the more steeply sloping south facing slopes, possibly relating such soil-regolith characteristics to units identified in a small scale regolith-landform map.

The cow dung spectrum was recorded in an attempt to identify distinctive spectral features that could be used to determining its abundance in the grazed catchment. The spectrum showed spectral features of water, cellulose and lignin, which are very similar to those shown by vegetation, and consequently the dung spectra could not be used in image mapping.

The minerals associated with the saline sulfidic environments have spectrally observable features and were of prime interest in the study, however, the size of the wetlands containing the sulfide minerals and vegetative growth of the catchment presented a limitation to image-based mapping, even with the ca. 2.5 m pixel resolution of the HyMap™ imagery. Consequently, spectral feature fit processing of the HyMap™ imagery over Herrmanns Catchment using the absorption features characteristic to the gypsum and jarosite identified by Fitzpatrick *et al.* (1996) as occurring in the wetlands proved unsuccessful.

Spectral feature fitting (SFF), however, did prove successful with spectral subsets around the absorption features for kaolinite (2,207 nm) and iron oxides (ca. 750-900 nm). All input spectra produced good spectral fits and abundance results for the kaolinite absorption feature, whilst the laboratory and USGS library spectra provided better references for mapping than the image-derived spectra. The abundance maps from this processing highlighted the occurrence of kaolinite lining dry dams, dam walls, roads, drainage networks, soil exposures and erosion scalds (Figure 2), while SFF with iron oxides highlighted erosion scalds, some soil exposures, dams, dam wall and even a coincidence with exposures of ferruginuos saprolite mapped by Skwarnecki *et al.* (2002) (Figure 3). It was not possible to map muscovite in the catchment using spectral feature fitting, even though a muscovite presence was identified in XRD.

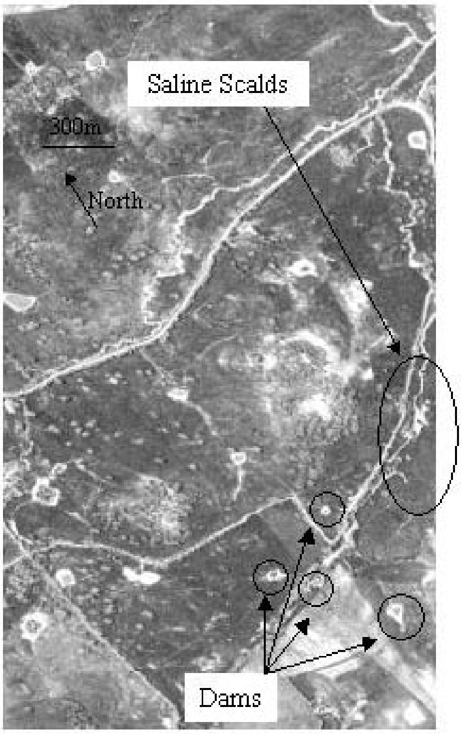

Figure 2: Spectral Feature Fit with USGS kaolinite spectra with a spectral subset of 2,195-2,235 nm, which highlights the kaolinite doublet. The white areas are the best fit areas to the spectra of kaolinite. Attention is drawn to the circled features, which correspond to features in Figure 3. This image does not cover the whole of Herrmanns Catchment. The image is not georeferenced.

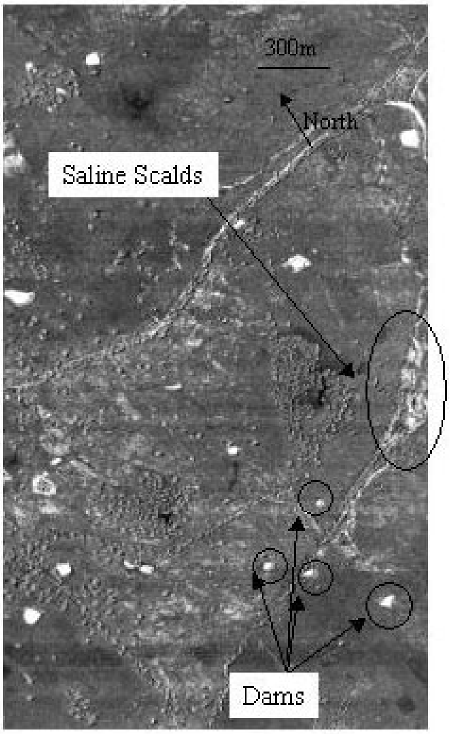

Figure 3: Spectral Feature Fit of the 850-1,140 nm iron oxide absorption feature, using USGS hematite spectra. The white areas are areas of best fit to this input spectra. Attention is drawn to the circled feature, which corresponds to Figure 2. This image does not cover the whole of Herrmanns Catchment. The image is not georeferenced.

The coincidence of SFF highlighting similar areas of kaolinite (Figure 2) and iron oxides (Figure 3) has potential advantages for land care issues in Herrmanns Catchment and surrounding areas covered in the total

HyMap™ acquisition, principally because the saline scalds are an exposure of the clayey B-horizon of the region's duplex soils. The mineralogy (identified through XRD) of the exposed clayey B-horizon comprises kaolinite, hematite, quartz, albite, orthoclase, muscovite and halite. The occurrence of the hematite iron oxide is also supported by Munsell Colour tests performed on the soil in the scalded area, which had a 10YR 6/6 value. Other spectral signatures that also had varying degrees of iron oxide absorptions also had Munsell values of 10 YR with high value/chroma.

The numerous SFF occurrences of kaolinite also proved important to the detection of areas where the soil contains highly crystalline kaolinite and high proportions of kaolinite in the total soil matrix. The asymmetry of the kaolinite absorption features is the diagnostic parameter for determining these kaolinite percentages (Hauff *et al.* 1990). The potential for the detection of high-grade kaolinite deposits is important to possibly finding suitable deposits for mining. There are known occurrences of kaolinite deposits, which are currently or have been mined, in the Mount Lofty Ranges (Drexel & Preiss 1995).

Processing using the Minimum Noise Fraction (MNF) produced interesting abundance images that further differentiated the mineralogy of exposed soils and distinguished areas of exposed clayey B-Horizon from the network of dirt roads, dams, dry creeks beds and general areas of limited vegetation cover.

CONCLUSION

The use of hyperspectral remote sensing in the solar domain (400-2,500 nm) to the spatial determination of clay and iron oxide minerals has significance to reconnaissance studies for both mineral exploration and environmental management, particularly in mapping the spatial occurrence of minerals and landform features associated with inland acid sulfate soils. For example, it is possible to identify waterlogged saline scalds, which are the early indicator of the formation of saline swamp-like and structureless soils that are very prone to water erosion (Fitzpatrick *et al.* 1996) through identifying simultaneous exposures of iron oxides and kaolinite.

In this study the identification of clay and iron oxide minerals was best made through spectral subsets of the important discriminative absorption bands between the 600-800 nm and 1,950-2,300 nm spectral regions, for iron oxides and clay minerals respectively. This supports findings from Ryan & Lewis (2002). For Herrmanns Catchment the dominant clay mineral is kaolinite. The ability to discriminate such landscape mineralogy provides a straightforward approach to highlight exposures of clayey B-Horizons in eroded duplex soils. Thus, the remaining HyMap™ imagery from the acquisition can be easily and quickly processed to highlight similar conditions in other areas of the Mount Lofty Ranges.

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