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THE ROLE OF REMOTE SENSING IN GEO-ENVIRONMENTAL MANAGMENT

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ABSTRACT

Mitigating the impact of mining activity is a significant challenge for environmental management. New approaches are required based on environmental information from in-situ, airborne and satellite observations. Airborne hyperspectral remote sensing and geophysical techniques are two such approaches being pursued at the BGS to characterise mine waste and its host rocks and then to monitor its dispersal in the environment. This paper will report on two projects that have followed on from the successful completion of the MINEO project. MINEO applied hyperspectral remote sensing to a range of active and abandoned mining environments across Europe.

Parys Mountain, on Anglesey, was the first site under investigation using HyMap data following MINEO. Here, the main task has been mapping the different tailings and characterising them mineralogically. Secondary investigations have involved the study of vegetation stress around the mine.

Low-level airborne geophysical data already exist for the Bolsover area from the HiRES-1 survey in 1998. HyMap data acquired during the NERC SAR and Hyperspectral Campaign (SHAC) over the Shirebrook mine within the HiRES-1 area have been used to evaluate the use of airborne geophysical and hyperspectral data together to map open cast mines in the region. Mine site classifications were developed based on both field and image spectral interpretations.

In all these projects, various techniques have been applied in order to classify mine sites in terms of mineralogy and contamination. The approach adopted is to use MNF and PPI approaches to extract end-member spectra and then classify the data using the SAM algorithm.

INTRODUCTION

Mining in Europe has left a legacy of mine waste in various forms. Following the World Summit on Sustainable development (Johannesburg, 2002), European directives on soils and water, and related British legislation demand improvements in mitigating the effects of mining activities. Remote sensing, and specifically hyperspectral remote sensing, techniques are being developed to provide non-invasive methods of characterising mine waste. When combined with geochemical data, terrain models and hydrogeological data, remote sensing becomes a very powerful tool for determining the hazard rating for a site, with particular emphasis on transport of waste away from a site.

Since 2001 many advances have been made in the operational use of hyperspectral remote sensing, especially within the European community. This is in part due to the success of the MINEO project, an EC 5th Framework research and development project which focussed on the development of hyperspectral data processing techniques for the characterisation of mine waste in the temperate European environment. Until then many hyperspectral studies had involved exploration for economic minerals in an arid environment with little or no vegetation cover. Techniques were developed within the MINEO project to map various different types of mine waste and also develop site-specific spectral libraries for mine waste characterisation and the analysis of vegetation stress.

The UK MINEO study site is an area of abandoned tin mining in Cornwall. Mineralisation in the region occurred in several phases with the emplacement of granite [1]. Mining began in the Bronze age, peaked in the late 19th century, and then declined post War, before ceasing in the 1990's. This has left a landscape scattered with abandoned mining adits, disturbed ground and mine shafts [2]. There are several environmental issues associated with mining pollution in the region.

Since the MINEO project officially closed in 2003 several related studies have followed, using the hyperspectral data processing techniques developed during the MINEO project at other mine sites within the UK.

To further develop metaliferous mine classification techniques BGS initially focussed on the abandoned copper mine at Parys Mountain. The mine is located near the north east coast of Anglesey, North Wales. Mining activity at Parys Mountain has left a legacy of mine waste and scattered spoil covering an area of around 3km^2. So unique is the variety of lithologies and minerals and resulting flora and fauna at Parys Mountain that several Sites of Special Scientific Interest (SSSI) have been established on the mountain. Weathering of the tailings results in the formation of colourful red and yellow hydrous iron oxides and a diverse range of sulphate minerals [3]. Weathering at the site is harsh, with sulphuric acid being generated by the oxidation of pyrite and other sulphide minerals. It is this diversity of minerals and weathering products that make this site so challenging to characterize and map.

One of the deliverables of the HiRES (High-resolution Resource and Environmental Surveys) project was to demonstrate the potential synergy of airborne geophysics and airborne (thermal and hyperspectral) remote sensing. Low-level, high-resolution airborne geophysics already exists for the North Nottinghamshire coalfields. The next stage in the project has been to evaluate the possibility of using airborne geophysical and hyperspectral data together to map open cast mines in the region. HyMap data was also available over this region and so was chosen to characterise and map non-metaliferous mine waste. Due to the low reflectance of the mine waste material this was a more challenging mining environment to characterise the mine waste spectrally. The dark colour of the coal waste leads to lower signal to noise. Techniques were developed for characterising organic material and associated waste materials, such as brick waste from demolished mine buildings.

The main objectives of all this work are to develop repeatable techniques for characterising and mapping mine waste using advanced earth observation techniques and, in conjunction, develop site specific spectral libraries for distinct waste types for use in other studies at other mine sites. At all test sites described above vegetation stress has also been evident. Techniques such as NDVI have been used to identify areas of less vigorous vegetation associated with mine waste. Vegetation stress is a useful indicator of what lies beneath, especially at sites such as Shirebrook where extensive remediation has occurred.

METHODS

Techniques used to map mine waste at the Parys Mountain and Shirebrook sites were first employed during the MINEO project that ran from 2000 to 2003 [4]. The methods developed were used on the UK MINEO HyMap dataset to map mine waste in the Camborne – Redruth region of Cornwall, Southwest England. Mineralisation in Cornwall is more diffuse than both the Parys Mountain and Shirebrook sites, but the same techniques are still relevant as the mining in all cases produced waste products that are spectrally distinct.

HyMap Data

The HyMap data used for the Parys Mountain and HiRES studies were flown as part of the SAR and Hyperspectral Campaign (SHAC) in 2000. HyMap data has 126 bands and covers the wavelength range from 0.45 - 2.5 μm. HyMap provides contiguous spectral coverage, except across the atmospheric water vapour bands, and has bandwidths between 15 and 20 nm. Pixel size is typically between 3 and 10m, depending on flying height. The Parys Mountain dataset comprises four flight lines covering an area of around 60km2, covering Parys Mountain itself and also the land to the northwest and to the sea. The Shirebrook data set comprises 8 strips of HyMap data and covers an area of around 90km^2.

Pre-Processing

Atmospheric correction and calibration of the data had already occurred before the data were received. The ATCOR programme had been used for pre-processing and to transform the data from raw radiance values to reflectance data that would give useful mineralogical information. Verification of this atmospheric correction and calibration was achieved using field spectra of vegetation and other materials not related to the mine site. An empirical line calibration was also undertaken on the raw radiance data for comparison purposes.

HyMap Geocoding Lookup tables (GLT) were used to geocorrect the calibrated HyMap data to the local map grid. This process was undertaken following all other processing steps in order to preserve the integrity of the spectral data. The files were provided by HyVista and can be used directly within the ENVI software using the option 'Georeference from GLT', under the 'Map' function. From the initial geocorrection the projection information can then be edited to match the map projection used in all other mapping datasets. As geocorrection was used for display purposes only, three band natural colour composites of the geocorrected files were created. The SAM classification results following image processing were then also geocorrected using the same technique as above, laid over the geocorrected colour composites, and used for comparison and visualisation purposes.

Field Spectra Collection

Several field visits were made to each of the study sites for the collection of field samples and for the measurement of in situ field spectra. The samples collected were used for both spectral interpretation in the laboratory and X-Ray Diffraction (XRD) analysis. An ASD (Analytical Spectral Device) field spectrometer was used to measure spectra both in the field and in the laboratory. The main reason for measuring samples in the lab was to enable both wet and dry spectra to be recorded from the same sample. Samples were first measured in the field, in their in situ state, which could present the problem of surface moisture. To overcome this problem samples measured in the laboratory were dried overnight at low oven temperatures to drive off any surface moisture. All spectra were then collated and a site-specific spectral library was produced.

End Member Collection

The first process in analysing the HyMap data was to perform a minimum noise fraction (MNF) transform to determine the inherent dimensionality of the image data, to separate noise from signal in the data, and to reduce the computational requirements for subsequent processing [5]. The MNF transform uses two Principal Component transformations. The first transformation decorrelates and rescales the noise in the data. The second step is a standard Principal Components transformation of the noisiest data. The result of the MNF transform can be used in further processing steps to determine end members for classification purposes.

Selected bands from the MNF transform can be used to determine end members by viewing them as two-dimensional scatter plots. Pixels are grouped in discrete clusters in a two-dimensional representation of n-dimensional space. The clusters can be selected and saved as regions of interest and used as end members in Spectral Angle Mapper (SAM) classification. End members were also selected by manually selecting training regions of different tailings and averaging the spectra for that class. The averaged spectra were then used in the classification as above. Several iterations were undertaken to get end member spectra that would produce a classification result consistent with the geological context.

Classification

SAM classification is one of the preferred classification techniques used in previous studies into mine waste and mine classification and is the technique that produced the most accurate classification at the MINEO test site in Cornwall. The Spectral Angle Mapper (SAM) is a physically based spectral classification that uses an n-dimensional angle to match pixels to reference spectra. The algorithm determines the spectral similarity between two spectra by treating them as vectors in a space with dimensionality equal to the number of bands and calculating the angle between the spectra [5]. End members, selected using the methodology above, are used as reference spectra to which other image spectra are matched and therefore classified. SAM compares the angle between the end member spectrum vector and each pixel vector in n-dimensional space. Smaller angles represent closer matches to the reference spectrum. Pixels further away than the specified maximum angle threshold in radians are not classified.

RESULTS

Parys Mountain

The classification seen in Figure 1 was developed using the Spectral Angle Mapper technique. Colours used are designed to make the classes more obvious when laid over a natural colour composite. Field mapping carried out has verified the accuracy of each of the classes of tailings mapped at the Parys Mountain mine. XRD analysis has been carried out based on field samples and the major constituent of all tailings is quartz with minor amounts of: goethite and jarosite for the dark red tailings; hematite and jarosite for the orange tailings; jarosite for the yellow tailings; muscovite and albite for white tailings and goethite and albite for the pink tailings.

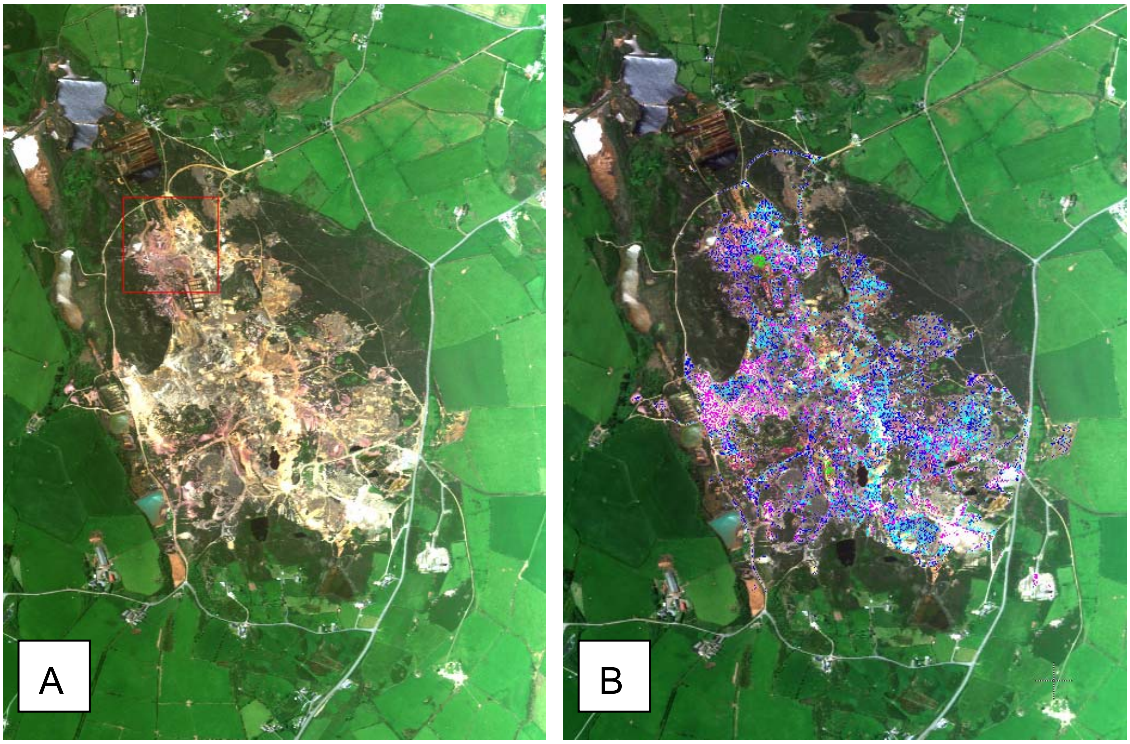

Figure 1: Results of the classification process. (A) natural colour composite made up of HyMap bands 16, 8 and 2, and displays how well the different colours of tailings can be seen in the imagery. (B) the result of the classification process. Images are shown before the geocorrection process to preserve spectral features of tailings.

Verification of the classification was based on comparisons with field spectra, rather than mineral spectra from a commercially available spectral library. XRD analyses were carried out to determine the composition of the tailings at the site. Initially the minerals identified in XRD analysis were viewed spectrally, based on spectra re-sampled to HyMap wavelengths, from the USGS spectral library. The USGS spectra were then compared with image spectra of the tailings. Very few perfect matches were found using spectra of pure minerals from the USGS spectral library, although similar spectral features were found in some cases.

This was initially thought to be a problem with the calibration of the data, but when field spectra were re-sampled and compared with image spectra very good matches were observed (Figures 2 and 3). Some areas of the image spectra are still thought to contain small artefacts from the pre-processing and atmospheric correction process. For example a feature occurs consistently at around 734nm. This feature is observed as a pronounced peak in all tailings spectra (Figure 2 and 3) but is only seen as a slight shoulder in vegetation spectra. Another feature is observed in all tailings spectra at around 1137nm, but this feature can not be seen in vegetation spectra so it is not certain whether it is an artefact or not. These features are not seen in field spectra.

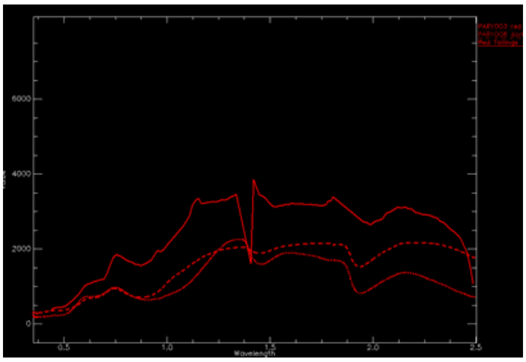

Figure 2: Red tailings (goethite and jarosite) image and field spectra.

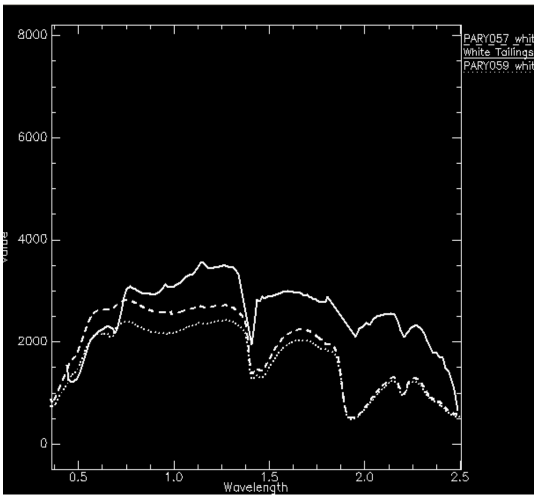

Figure 3: White tailings (muscovite and albite) image and field spectra.

Shirebrook

Figure 4 shows how colliery waste can be spectrally characterised. The purple line towards the bottom of figure 4 shows the field spectrum of coal waste from the Thoresby colliery, which is located west of the study site. The white line associated with the purple line represents the characteristic image spectrum of the coal spoil at Shirebrook mine. Other materials have also been characterised using both field and image spectra. The red line in Figure 4 is the field spectrum of the red brick material also found at the abandoned Shirebrook site. As can be seen the image spectrum of the red brick material is also a good match for the field spectrum. Any other material of this nature can therefore be characterised and mapped using supervised classification techniques such as Spectral Angle Mapping (SAM).

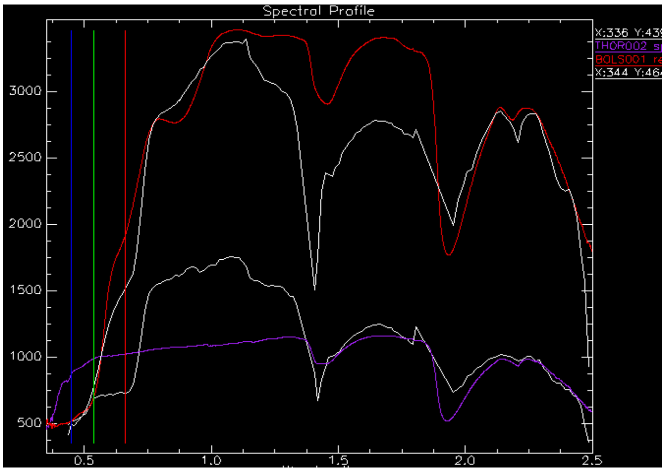

Figure 4: Spectral comparison between image and field spectra.

Using the SAM classification technique various classes associated with mine waste were mapped. The results can be seen in Figure 5. Several of the classes were selected as they characterise different types of vegetation near the mine. Vegetation stress is quite an important factor in this study as many of the mines in the region are currently undergoing remediation. This quite often involves covering the spoil that has built up with a layer of soil into which grasses and trees can be planted. This process aims to disguise the spoil that is left behind following mining and also helps to stabilise the waste heaps as the plants root systems develop and prevent dispersion by wind.

Although many of the remediation projects work well, some plants may not become established due to poor nutrients or being exposed to high concentrations of a certain mineral that may stunt a plants growth. It is this type of stress that can be detected using remote sensing. Stressed vegetation will have less chlorophyll in its leaves and will therefore display a different spectral signature to healthy vegetation. This is measured by observing the steepness of the ‘red edge’, which is the difference between the visible and near infrared (NIR). Healthy vegetation will display a strong step in this region with less healthy vegetation displaying a less steep slope.

Figure 5: SAM classification of the Shirebrook Colliery site.

Spectral analysis of the different types of vegetation on and near the mine site shows differences in the red edge (Figure 6). The healthiest vegetation is shown as dark blue spectra and this shows the steepest red edge when compared with other less healthy vegetation (cyan and yellow spectra). This can then be used to map the extent of the less healthy vegetation.

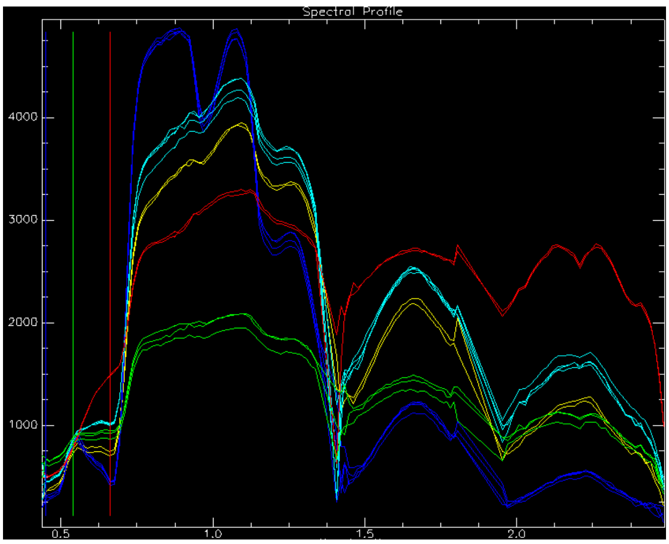

Figure 6: Image spectra of all classes used in SAM classification figure 5.

CONCLUSIONS

The techniques used for all studies within this paper are very repeatable. Where HyMap data exists spectral libraries can be developed and compared and eventually added to those already available through MINEO and other projects. In all studies of this type geochemical analysis is invaluable for verification of classification results. Where complex mineral mixtures exist it can be impossible to determine the mineral constituents from spectral analysis alone, even with laboratory spectral measurements.

Future projects to study mine waste using hyperspectral airborne sensors will look at a different suite of minerals in a more challenging environment. HyMap data was flown in June 2004 over the Rheidol Valley lead mining district in west Wales, as part of VITO's summer campaign. The study site is mountainous with mine sites dotted about the landscape. The resulting project to study the data will be a collaboration between the Royal Museum for Central Africa of Tervuren and BGS. Fieldwork has already been undertaken to collect calibration targets and spectral information about mine waste in the study site.

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