Mapping mine waste using hyperspectral imaging spectrometry data

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ABSTRACT

The Parys Mountain mine on Anglesey, North Wales is a site of great importance both historically and mineralogically. Mining at the site dates back to the Bronze age and this has left a legacy of mine waste at the site. The main objectives of this study are to use hyperspectral imaging spectrometry to: characterise mine waste at, and map contamination transport around, the Parys Mountain mine site and; to map associated vegetation stress using SWIR Imaging Spectrometry. This work builds on the expertise gained during the MINEO project in which mine waste was mapped at various sites across Europe using advanced Earth observation techniques. In MINEO BGS used HyMap data to map an area of abandoned tin mining in Cornwall and so the skills learnt in contamination mapping have been applied to the HyMap data for Parys Mountain. Both HyMap and CASI (Compact Airborne Spectrographic Imager) SWIR (Short Wave Infrared) data have been acquired over Parys Mountain. Mine site characterization has been undertaken using SAM (Spectral Angle Mapper) classification techniques and the contamination at Parys Mountain has been mapped. This is being backed up with geochemical analysis for verification of the spectra observed both in the field and the image data. Historical geochemical and spectral data from the Parys mountain deposit is being used for comparison proposes. Mine waste at the mine site has been characterised and mapped and the resulting maps of contamination will be shown at the conference. These methods will now be applied to the HyMap data of Rheidol Valley, acquired by Vito during 2004.

Keywords: Hyperspectral, Mine waste characterization, Parys Mountain.

1 INTRODUCTION

Parys Mountain is located in the extreme north east of the island of Anglesey, North Wales. Mining activity at Parys Mountain has left a legacy of mine waste and scattered spoil covering an area of around 3 km^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 Iron hydrous oxides and a diverse range of sulphate minerals. Weathering at the site is harsh with sulphuric acid 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.

1.1 Geology

Parys Mountain is composed of Ordovician shales and Silurian shales and rhyolites. A sill of 'felsite', around a hundred meters thick can be found near the intersection of the two lithologies [1]. The whole structure of the mountain is a deep synclinal formation that is bounded and traversed by thrusts that are secondary to the great Carmel Head thrust-plane. All the rocks are silicified and pyritised to varying degrees.

Mineralisation at Parys Mountain, or Mynydd Parys in Welsh, extends approximately 3 km NNE-SSW in a 1 km wide band. This resulted from exhalative volcanic-sedimentary mineralisation accompanying minor rhyolitic volcanism that occurred in the late Ordovician [1]. A secondary phase remobilization occurred during the Caledonian metamorphism, in the Devonian. The lodes themselves are zones of maximum chalco-pyritisation, which would have been mineralised during the great Post-Silurian Caledonian earth-movements.

Amongst the diversity of minerals found at the site are abundant sulphate minerals. Two of the most abundant are jarosite (K $Fe(SO_4)$ (OH)) and anglesite (Pb SO_4) for which Parys Mountain is the world type locality. The primary mineralisation at Parys Mountain is comprised of pyrite and silica followed by a main phase which is dominated by chalcopyrite with secondary galena and sphalerite with minor amounts of other sulphides [2].

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1.2 Mining History

Mining first began at the site in the Bronze Age and it is thought that initially native copper occurring on the ground surface would have attracted early miners to the site. Later Bronze Age miners dug shallow pits, known as bell pits, in attempt to extract more copper than was available at surface. Some of these pits have been discovered up to 50ft below the surface, and without any means of support this was quite an achievement. Bone tools may have been used in early excavations but as the surrounding rock was so hard to remove these would have warn down very rapidly. Pebbles from nearby beaches have been found at the site and these are thought to have been used as rudimentary hammers to pound the rock to extract copper ore.

Where the rock was too hard to be broken by hand a technique known as "fire setting" was employed. The rocks known to contain the ore were piled up against a rock face and a fire lit at the base. The rocks were heated to a sufficient temperature so that when cold water was poured over the hot rocks it would make them brittle and so aid the crushing process. The crushed rock could then be used in the smelting process. A charcoal fire was set in the base of a clay kiln and bellows used to increase the temperature further. Crushed ore was then placed in the kiln, melted and mixed with tin to produce cast bronze objects.

Following these primitive first excavations in the Bronze age, significant quantities of Copper ore were not discovered until around 1770, when a miner named Rowland Puw realized that Parys Mountain held a great deal of wealth in Copper. Since then extensive mining activity at Parys Mountain has left the mountain covered with piles of debris, which are so acidic in their nature that no vegetation can grow. The site has now become a heritage centre where tourists visit and marvel at the piles of mine waste that give Parys Mountain the appearance of the surface of Mars, if it wasn't for the remains of the windmill on the summit.

Figure 1. View across Parys Mountain Mine. Different coloured tailings piles make up most of the site, and the remains of the windmill used to pump water from the working mine can be seen at the summit.

2 AIMS AND OBJECTIVES

The main aim of this study is to map and characterise mine waste at the Parys Mountain mine site using advanced airborne remote sensing techniques.

The objectives of the image processing for Parys Mountain were to:

- Develop a spectral library to be used in conjunction with image data,
- Map mine waste and related minerals throughout the site,
- Study vegetation health/stress in proximity to sources of contamination.

3 METHODOLOGY

Techniques used to map mine waste at the Parys Mountain site were first employed during the MINEO project that ran from 2000 to 2003 [3]. MINEO was an EC 5th Framework research and development project. Its aim was to develop hyperspectral data methods in a European context, dealing with mine pollution in a populous, temperate environment rather than mineral exploration in arid countries. The methods developed were used in the UK to map mine waste in the Camborne – Redruth region of Cornwall, Southwest England. Mining in Cornwall was more diffuse than the Parys Mountain site, but the same techniques are still relevant as the metaliferous mining in both cases produced very similar waste products.

3.1 HyMap Data

The HyMap data used for this study was flown as part of the SAR and Hyperspectral Campaign (SHAC) in 2000 and preliminary results were presented in 2001. Following the initial year of research and initial reporting, the data became available for use within other research projects. 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 10 m, depending on flying height. The Parys Mountain dataset comprises four flight lines covering an area of around 60 km^2, covering Parys Mountain itself and also the land to the northwest and to the sea.

3.2 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.

3.3 Field Spectra Collection

Several field visits were made to the Parys Mountain site 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.

3.4 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 [4]. 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.

3.5 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 [4]. 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.

4 RESULTS

The following figures illustrate the results of the classification process.

4.1 Classification Results

The classification seen in Figure 2 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: jarosite and goethite for the dark red tailings; jarosite and hematite for the orange tailings; jarosite for the yellow tailings; muscovite and albite for white tailings and albite and goethite for the pink tailings.

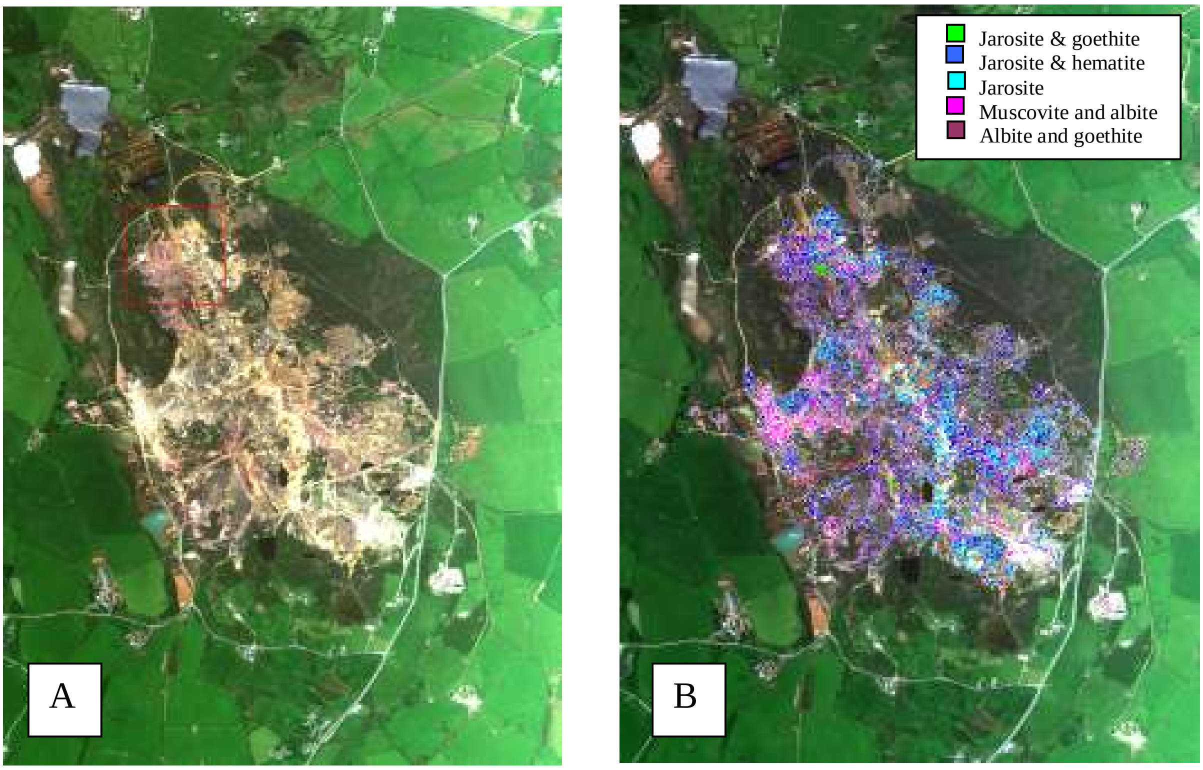

Figure 2. Results of the classification process. (A) natural colour composite made up of HyMap bands 16, 8 and 2, and displays how well the different colours of tailings can be seen in the imagery. (B) the result of the classification process. Images are shown before the geocorrection process to preserve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

4.2 Verification and comparison with XRD

Verification of the classification is 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 and initially minerals identified in XRD analysis were viewed spectrally, based on spectra re-sampled to HyMap wavelengths, from the USGS spectral library. These spectra were then compared with image spectra of the tailings. No good matches were found using spectra of pure minerals from the USGS spectral library, although image spectra showed some similarities in some cases.

This was initially thought to be a problem with the data, but when field spectra were re-sampled and compared with image spectra very good matches were observed (Figures 3, 4 and 5). Some areas of the image spectra are still thought to contain artefacts from the pre-processing and atmospheric correction process. For example a feature occurs consistently at around 734 nm. This feature is observed as a pronounced peak in all tailings spectra (Figure 3 and 4) but is only seen as a slight shoulder in vegetation spectra (Figure 5). Another feature is observed in all tailings spectra at around 1137 nm, 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.

In all figures below, the image spectra are shown as solid lines with example field spectra shown as dotted and dashed lines. The image spectra shown are based on an averaged spectrum of a particular tailings pile. For example the spectrum of white tailings in figure 4 shows a prominent sloping off at around 1410nm and a very characteristic absorption feature at 2206 nm. This is quite consistent with the presence of muscovite, however, other features in the spectrum do not match due to mixing of minerals into the pure muscovite spectrum. Comparisons between field and image spectra show strong correlation, despite the small artefacts mentioned above.

Figure 3. Results of the classification process. Red Tailings (jarosite and goethite) image and field spectra.

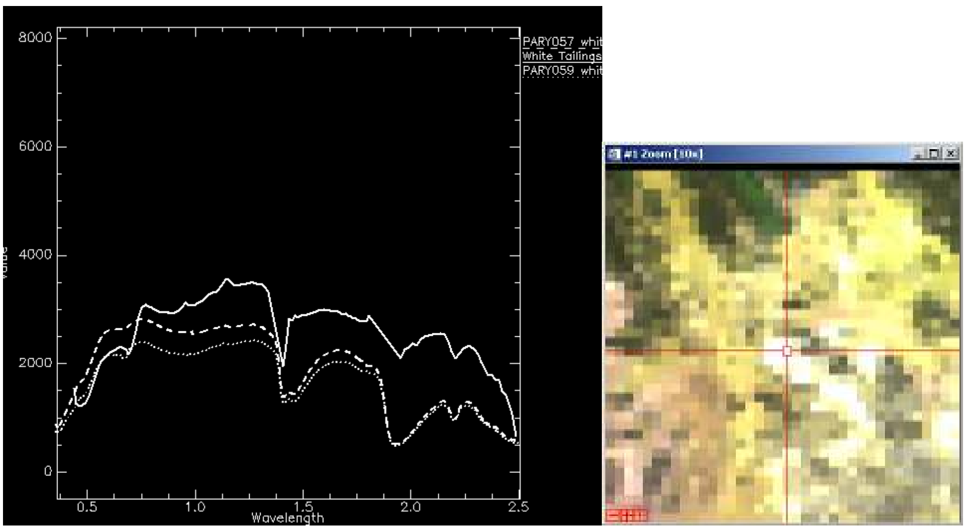

Figure 4. Results of the classification process. White Tailings (muscovite and albite) image and field spectra.

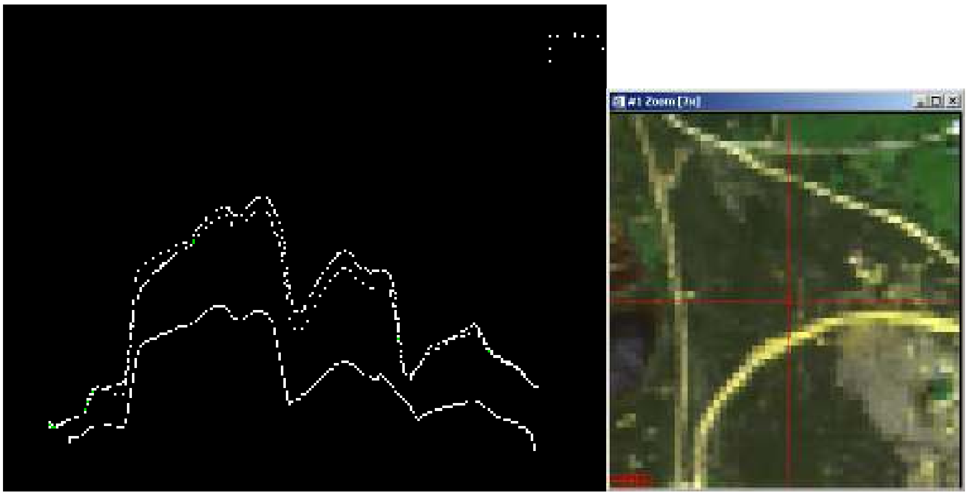

Figure 5. Results of the classification process. Heather image and field spectra.

5 CONCLUSIONS

Mine waste at the Parys Mountain site has been characterised using HyMap data and various supervised classification techniques. Verification of the classification shows that all of the piles of mine waste at the site can be characterised spectrally based on end member spectra and field measurements.

It is not surprising that pure mineral spectra from a commercially available spectral library don't always match image spectra sampled from a mixed pixel that is measuring a complex material that is made up of many different minerals. Field spectra can be used much more effectively to develop a site-specific spectral library of minerals and mineral mixtures. Characterisation and verification of classifications can then be based on these reference spectra. Further verification can then be carried out to characterise field samples by undertaking geochemical analysis to determine the exact composition of a sample in terms of the mixture of minerals it contains. A suite of "materials" of interest can then be built up to produce a site-specific spectral library.

6 FUTURE STUDIES

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 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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REFERENCES

[1] GREEN, E., 1919: The Geology of Anglesey. Memoir of the Geological Survey of Great Britain.

[2] POINTON, C. R., AND IXER, R.A., 1980: Parys Mountain Mineral Deposit, Anglesey, Wales. Transactions of the Institute of Mining and Metallurgy, B89, pp. 143-155.

[3] CHEVREL, S., KUOSMANEN, V., GROESEL, K., MARSH, S., TUKIAINEN, T., SCHAEFFER, U., QUENTAL, L., VOSEN, P., LOUDJANI, p., KURONEN, E. and AASTRUP, P., 2003. Remote sensing monitoring of environmental impacts. Mining Environmental Management, 11(6), p 19-23.

[4] KRUSE, F. A., LEFKOFF, A. B., BOARDMAN, J. B., HEIDEBRECHT, K. B., SHAPIRO, A. T., BARLOON, P. J., and GOETZ, A. F. H., 1993: The Spectral Image Processing System (SIPS) - Interactive Visualization and Analysis of Imaging spectrometer Data". Remote Sensing of Environment, v. 44, p. 145 - 163.