MONITORING MINING REHABILITATION DEVELOPMENT ACCORDING TO METHODS DERIVED FROM IMAGING SPECTROSCOPY, CASE STUDY IN THE SOTIEL-MIGOLLAS MINE COMPLEX, SOUTHERN SPAIN

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ABSTRACT:

The Sotiel Migollas mine complex is part of the Iberian Pyrite Belt region in Southern Spain. This area has been used for mining since Roman times. More recently, the Sotiel mine was exploited for silver and copper extraction in 1984. It was abandoned in 2002 and some rehabilitation activities have taken place since 2006. Several flight campaigns organized by DLR have flown the mine site and HyMap images were taken during the period it was active, abandoned and rehabilitated. This ongoing project is a direct application of imaging spectroscopy derived models and their evaluation as long-term monitoring techniques of mine waste impacts. Thus this project aims to describe the main changes of the mine according to the following methods: pH level prediction, mineral characterization of secondary minerals caused by acid mine drainage (AMD) and boundaries delimitation of surface coverage. Based on this information it is planned to evaluate the main contributions and limitations of the derived models and to assess if they are suitable to evaluate the rehabilitation goals of regional stakeholders.

1. INTRODUCTION

Methods derived form imaging spectroscopy has been developed as non invasive, efficient and accurate techniques to monitor mining environments Methods such as mineral characterization (Swayze et al., 2000; Ong and Cudahy, 2000, Riaza, 2006), pH prediction (Ong et al., 2003; Zabcic, 2008) and boundaries delimitations (Richter et al., 2008) have been developed and recommended for monitoring mining rehabilitation measures. Recognizing tailing areas and understanding the development of present secondary minerals offers a guideline to apply remediation efforts and assess rehabilitation progress. Table 1 briefly describes contributions of the three methods selected to use on this project.

pH level prediction	Based on oxidation reactions, describe remediation efforts to neutralize areas, derived maps of predicted pH are often more precise than based on mineral maps

mineral characterization	Recognition of secondary minerals (indicators of heavy metals, sulphates, pH), future development of minerals, Describes and may predict effect based on climate conditions
boundaries delimitation	Mapping land cover and landuse, monitor expansion/reduction of tailings boundaries estimation of areas, and comparison within subsequent years

Table 1: Description of main contributions of methods derived from imaging spectroscopy, recommended for monitoring mining environments.

The Sotiel Migollas mine complex is located in the province of Huelva, Southern Spain. It is a lead, zinc and copper mine, geologically part of the Iberian Pyrite Belt. This region has been exploited for mineral extraction over 2000 of years since the Roman times but in recent history the mine was active from 1984 until 2002 When it was left abandoned, rehabilitation measures started in 2006.

Comprehensive flight and field campaigns have been taken place on this mine site. The Sotiel Migollas mine presents a unique situation of having almost a decade covered with HyMap images. The images were taken in 1999, 2004 and 2008, corresponding respectively to the period when the mine was active, abandoned and initially rehabilitated (fig. 1).

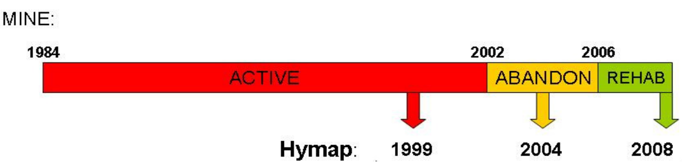


Figure 1. Timeline of Sotiel Migollas mine and years of flight campaigns and data takes.

This ongoing project aims to apply the different methods in the Sotiel Migollas mine in order to describe its main changes during the last decade: From active mining to the time, when the mine was left abandoned until some rehabilitation efforts took place. Contributions and limitations of each method will be described, and it will be assessed if they are suitable to evaluate rehabilitation goals set up by local and regional regulators.

2. METHODOLOGY

2.1 Data acquisition and data processing

2.1.1 Airborne imagery

The images were taken on May 6th 1999, May 19th 2004, and August 1st 2008 (fig. 2). The datasets were obtained using the HyMap airborne sensor during flight campaigns organized by the German Aerospace Center (DLR). HyMap is a whiskbroom imaging spectrometer with 126 bans covering the wavelength range of 0.45 to 2.5 um with contiguous spectral coverage except in the atmospheric water vapour bands (Cocks et al. 1998).
Each dataset undergo the same pre-processing steps to result in images with at surface calibrated reflectance. These pre-processing steps were: radiometric calibration corrected by HyVista, geometric correction using ORTHO (Mueller, R. et al. 2005) and ATCOR (Richter and Schlapfer, 2002) was used for the atmospheric correction.

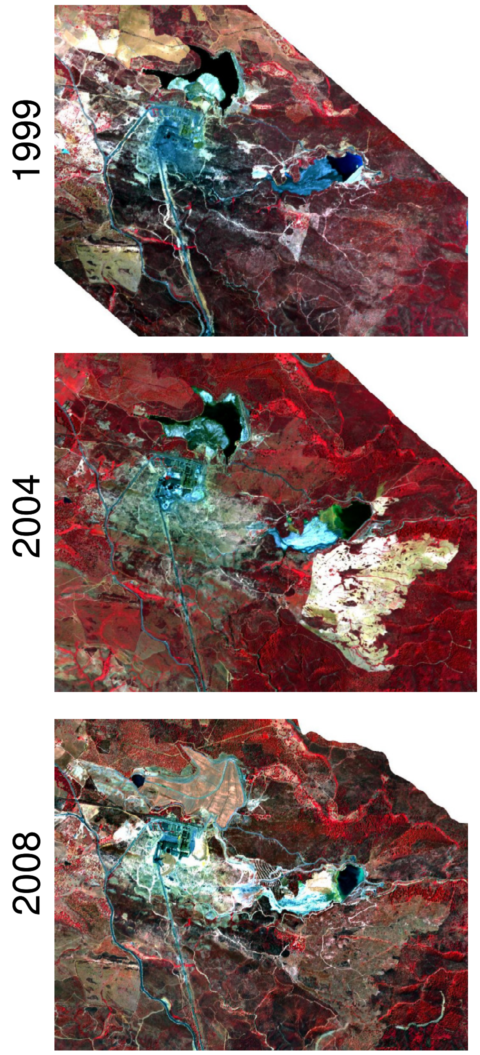


Figure 2: At surface reflectance HyMap images of Sotiel Migollas mine site for the years of 1999, 2004 and 2008.

2.1.2 Field campaign

Fieldwork took place during the same days as the over flight in 2008. Homogeneous areas of very high reflectance such as a football field, parking lot, school platform and basketball court were selected as calibration targets. Spectral measurements were taken from each site as well as from selected areas where soil samples were collected for further X-Ray Diffraction (XRD) mineral analysis and laboratory spectral measurements. Spectra measurements were taken using an Analytical Spectral Devices Field Spec Pro (ASD).The ASD is a portable spectrometer composed of three detectors covering the wavelength range from ~350 nm to 2500 nm. Calibration targets were sampled using the bare fiber, without using any foreoptics of the ASD. For the spectra measurements of soil samples the 8° FOV lens was used. Field and laboratory spectra were corrected for erroneous measurements, e.g. 2nd detector jump correction, and calibrated with a spectralon reference panel.

2.2 Application of models

The three selected models for this project are going to be applied to each of the three image set corresponding to the years 1999, 2004 and 2008.

2.2.1 Ph Model

Developed by Zabcic (2008) using partial a least squares (PLS) regression approach, this model is a site specific model for Sotiel Migollas based on extensive analysis of soil samples and laboratory spectra, up scaled to the radiometric resolution of the HyMap image from 2004.

2.2.2 Boundary delimitation

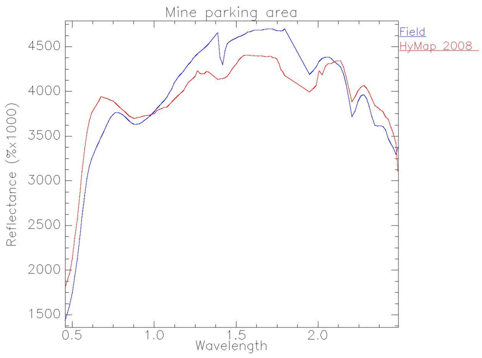
A pre-segmentation of the images is performed to exclude bad and noise pixels. Endmember extraction is done by a sequential maximal angle convex cone (SMAAC). The extracted endmember are then classified into three groups: soils and minerals, dry vegetation and green vegetation. Using a constrained linear unmixing method, µMESMA (Bachman et al. 2004), abundance maps are derived for each category (fig 5a). A definition of threshold of abundances is then delimited to create boundaries within each class.

2.2.3 Mineral characterization

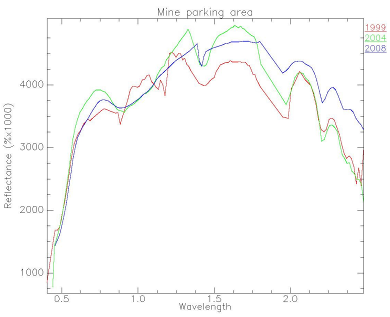
For this method further mineral identification of end members classified as soils and minerals is needed. This will be done by visual interpretation and comparisons between spectra library references (Grove et al, 1992; Preissler, 1999; Specmin-FE, 2003; Clark et al., 2007) XRD analysis results and expert knowledge. Using µMESMA this enmembers will then be spatially characterized in the HyMap images.

3. PRELIMINARY RESULTS

The image from 2008 was validated with the field spectra from the calibration targets. The spectra difference between image and field measurements is within 5%, which indicates that the overall spectra is suitable for further analysis (fig.3a). Common calibration targets were compared from the three datasets to validate it's at surface reflectance (fig 3b). Differences of spectra in the results should be caused by differences in materials and conditions and not by atmospheric distortions.



a)



b)

Figure 3: Calibration target for spectra validation of datasets. a) Field and image spectra of the mine site' parking area calibration target, b) same calibration target and its image spectra for the three datasets (1999, 2004 and 2008).

For soil mineral identification XRD analysis, laboratory and field spectra show similar results, e.g. according to XRD results, sample no 2 is a major composition of clay minerals and jarosite, both substances are identified in the spectra (fig 4).

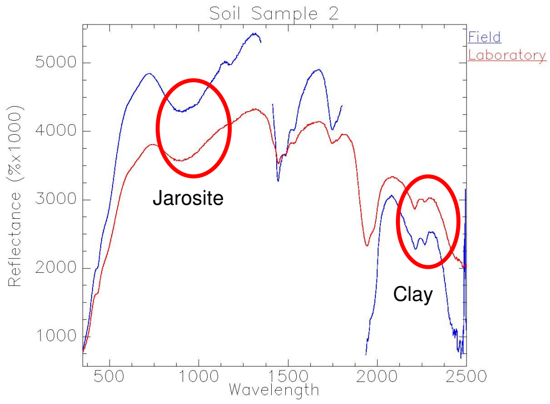
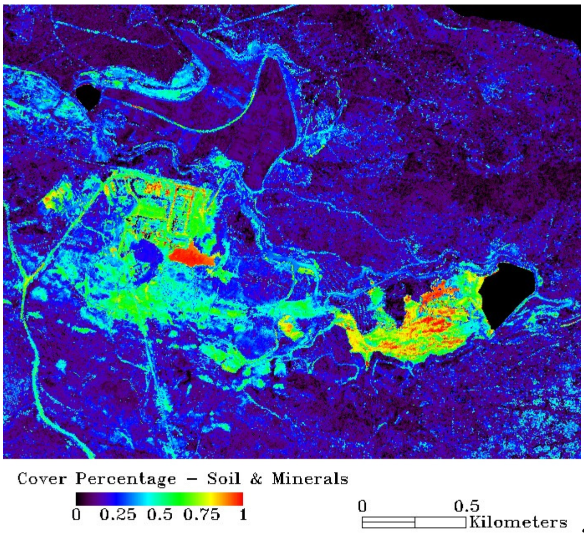


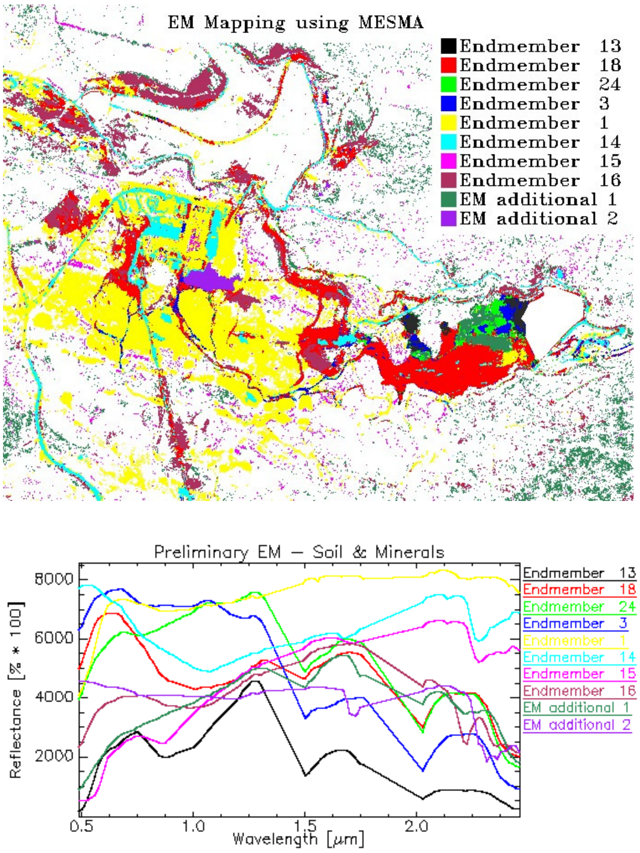
Figure 4. Similar results retrieved from XRD analysis, field and laboratory spectra. Soil sample no. 2 with major components of clay and jarosite, are visible in both spectra.

Figure 5 shows preliminary results of soil and mineral abundances and endmember derivation for 2008 data set when using µMESMA constrained linear unmixing method.



a

a)



b)

Figure 5 Preliminary results using μMESMA for the 2008 image. a) Soil and minerals coverage, b) endmember extraction and location.

4. EXPECTED OUTCOMES

Thematic maps of minerals, pH level and boundary delimitation for 1999, 2004 and 2008 are the expected outcomes of this project. These maps will be validated by cross checking results from each method to evaluate if the results are accurate and relatively comparable. XRD analysis, prior studies from the area and expert knowledge will also serve as validation.
Thematic datasets are the basis for change detection analysis to describe changes from the time the mine site became abandoned and when rehabilitation measures have been started.
As next steps, an evaluation of the contributions and limitations of each method will be carried out. Finally an assessment if the studied methods are suitable for the evaluation of regional stakeholder's rehabilitation goals will be conducted.

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